ECHO HAWAII 30th ANNUAL

Valvular heart disease: A decade of progress

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New York, NY

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Disclosures

Speaker:
- Abbott Vascular
- Boston Scientific
- Philips Healthcare
- Siemens Healthineers

Consultant
- Gore&Associates

Core Lab for a number of trial for which I receive no direct compensation

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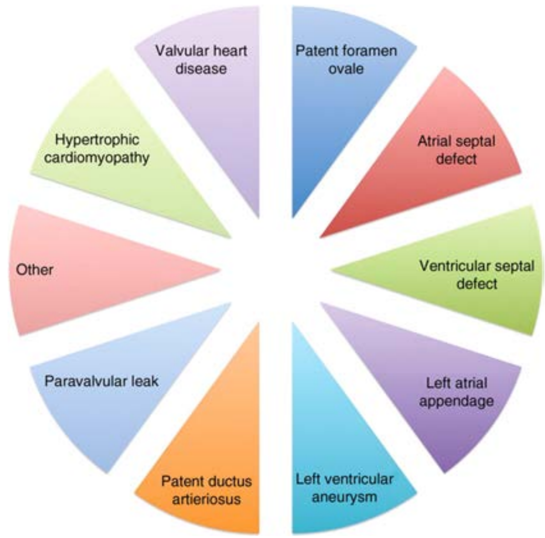
"Structural Heart Disease"

'Structural heart disease' is a term first introduced by Martin Leon at the 1999 Transcatheter Cardiovascular Therapeutics meeting to provide an over-reaching term encompassing non-coronary cardiac disease processes and developing interventional techniques



Steinberg D H et al. Eur Heart J Suppl 2010;12:E2-E9

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Published Literature

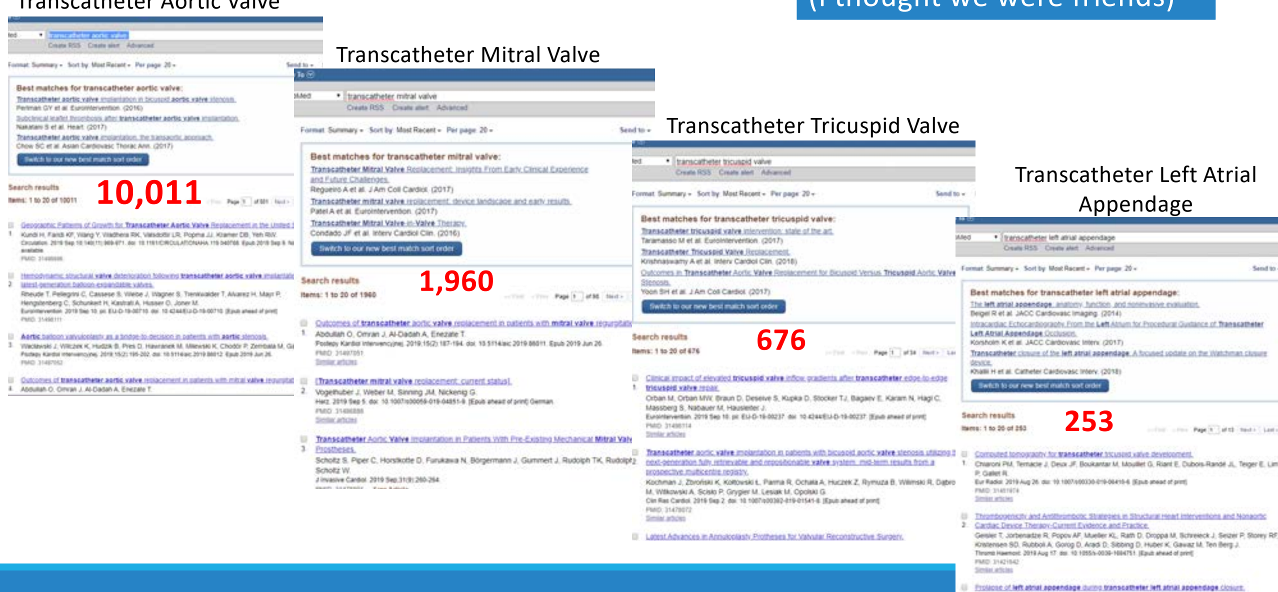
Thanks A LOT Jim and Neil!!
(I thought we were friends)

Transcatheter Aortic Valve

Transcatheter Mitral Valve

Transcatheter Tricuspid Valve

Transcatheter Left Atrial Appendage



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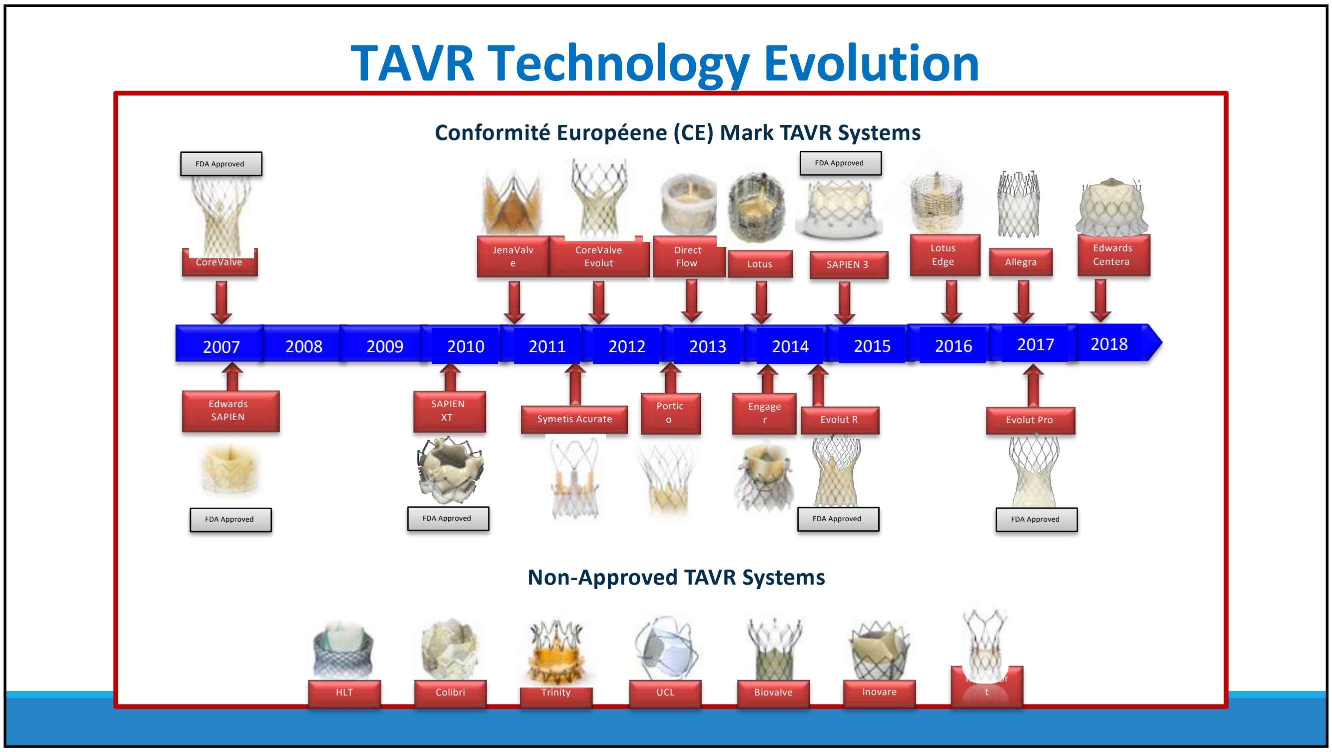
TAVR Technology Evolution
Conformité Européene (CE) Mark TAVR Systems
FDA Approved
CoreValve
JenaValv
e
CoreValve
Evolut
Direct
Flow
Lotus
FDA Approved
SAPIEN 3
Lotus
Edge
Allegra
Edwards
Centera
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Edwards
SAPIEN
SAPIEN
XT
Symetis Acurate
Portic
o
Engage
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Evolut R
Evolut Pro
FDA Approved
FDA Approved
FDA Approved
FDA Approved
Non-Approved TAVR Systems
HLT
Colibri
Trinity
UCL
Biovalve
Inovare
t

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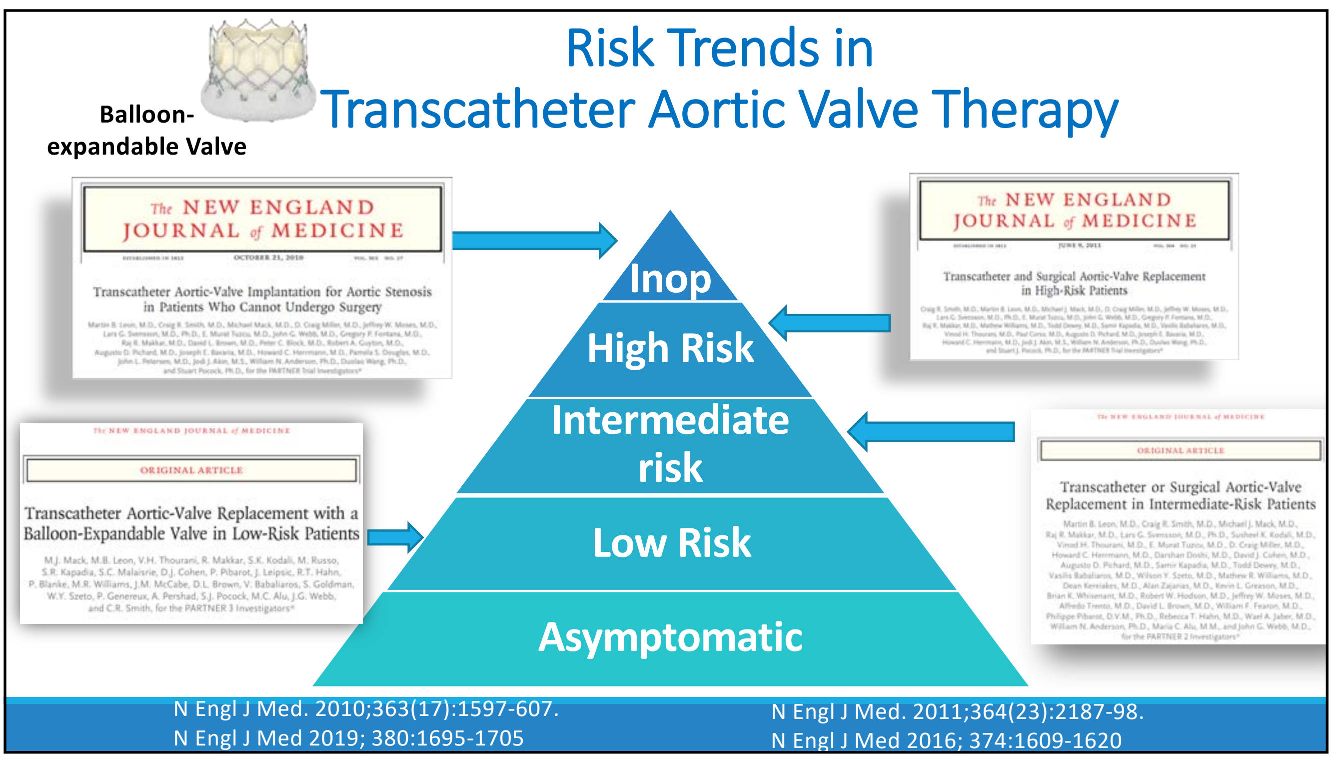
Risk Trends in
Transcatheter Aortic Valve Therapy
Balloon-
expandable Valve
The NEW ENGLAND JOURNAL of MEDICINE
Transcatheter Aortic-Valve Implantation for Aortic Stenosis in Patients Who Cannot Undergo Surgery
The NEW ENGLAND JOURNAL of MEDICINE
Transcatheter and Surgical Aortic-Valve Replacement in High-Risk Patients
ORIGINAL ARTICLE
Transcatheter Aortic-Valve Replacement with a Balloon-Expandable Valve in Low-Risk Patients
ORIGINAL ARTICLE
Transcatheter or Surgical Aortic-Valve Replacement in Intermediate-Risk Patients
Inop
High Risk
Intermediate
risk
Low Risk
Asymptomatic
N Engl J Med. 2010;363(17):1597-607.
N Engl J Med 2019; 380:1695-1705
N Engl J Med. 2011;364(23):2187-98.
N Engl J Med 2016; 374:1609-1620

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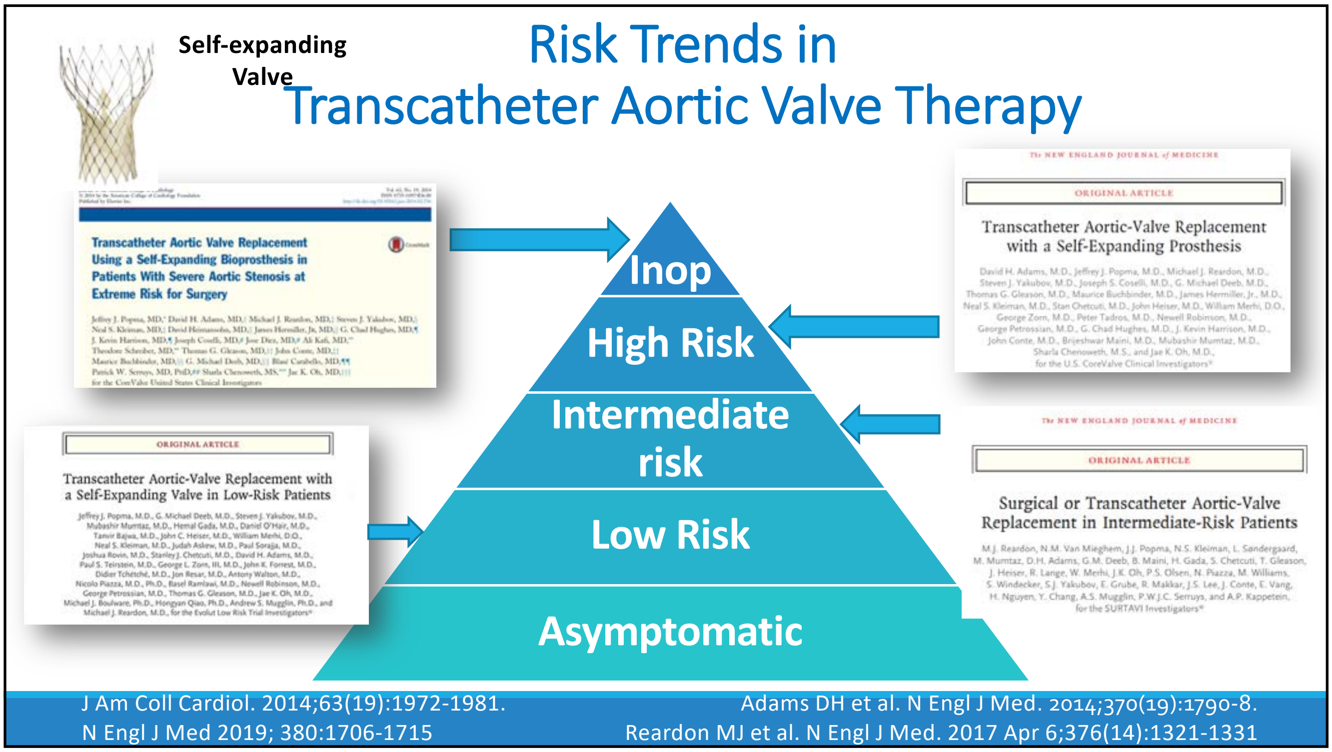
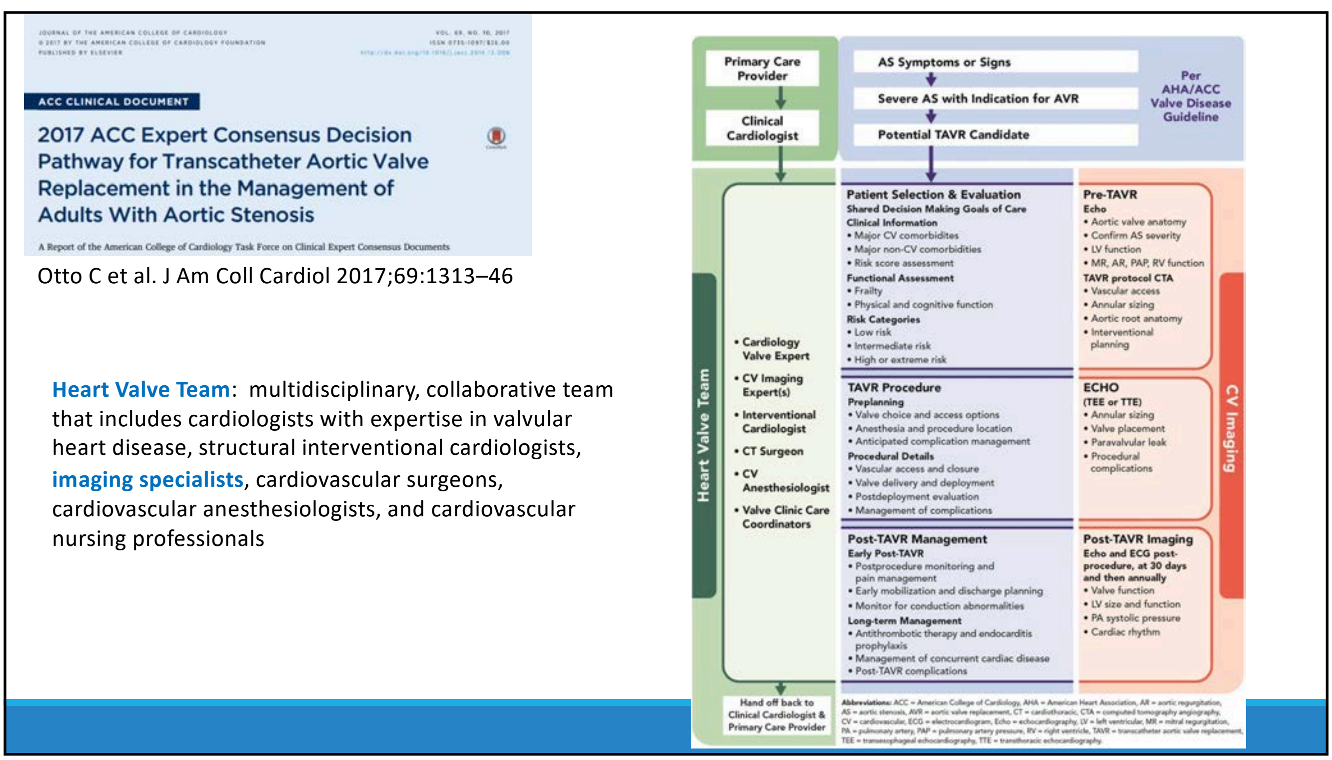

Self-expanding Valve
Risk Trends in Transcatheter Aortic Valve Therapy
Transcatheter Aortic Valve Replacement Using a Self-Expanding Bioprosthesis in Patients With Severe Aortic Stenosis at Extreme Risk for Surgery
Transcatheter Aortic-Valve Replacement with a Self-Expanding Valve in Low-Risk Patients
THE NEW ENGLAND JOURNAL of MEDICINE
ORIGINAL ARTICLE
Transcatheter Aortic-Valve Replacement with a Self-Expanding Prosthesis
Surgical or Transcatheter Aortic-Valve Replacement in Intermediate-Risk Patients
Inop
High Risk
Intermediate risk
Low Risk
Asymptomatic
J Am Coll Cardiol. 2014;63(19):1972-1981.
N Engl J Med 2019; 380:1706-1715
Adams DH et al. N Engl J Med. 2014;370(19):1790-8.
Reardon MJ et al. N Engl J Med. 2017 Apr 6;376(14):1321-1331

7


ACC CLINICAL DOCUMENT
2017 ACC Expert Consensus Decision Pathway for Transcatheter Aortic Valve Replacement in the Management of Adults With Aortic Stenosis
A Report of the American College of Cardiology Task Force on Clinical Expert Consensus Documents
Otto C et al. J Am Coll Cardiol 2017;69:1313–46
Heart Valve Team: multidisciplinary, collaborative team that includes cardiologists with expertise in valvular heart disease, structural interventional cardiologists, imaging specialists, cardiovascular surgeons, cardiovascular anesthesiologists, and cardiovascular nursing professionals
Primary Care Provider
Clinical Cardiologist
AS Symptoms or Signs
Severe AS with Indication for AVR
Potential TAVR Candidate
Per AHA/ACC Valve Disease Guideline
Heart Valve Team
• Cardiology Valve Expert
• CV Imaging Expert(s)
• Interventional Cardiologist
• CT Surgeon
• CV Anesthesiologist
• Valve Clinic Care Coordinators
Patient Selection & Evaluation
Shared Decision Making Goals of Care
Clinical Information
• Major CV comorbidites
• Major non-CV comorbidities
• Risk score assessment
Functional Assessment
• Frailty
• Physical and cognitive function
Risk Categories
• Low risk
• Intermediate risk
• High or extreme risk
Pre-TAVR
Echo
• Aortic valve anatomy
• Confirm AS severity
• LV function
• MR, AR, PAP, RV function
TAVR protocol CTA
• Vascular access
• Annular sizing
• Aortic root anatomy
• Interventional planning
TAVR Procedure
Preplanning
• Valve choice and access options
• Anesthesia and procedure location
• Anticipated complication management
Procedural Details
• Vascular access and closure
• Valve delivery and deployment
• Postdeployment evaluation
• Management of complications
ECHO
(TEE or TTE)
• Annular sizing
• Valve placement
• Paravalvular leak
• Procedural complications
Post-TAVR Management
Early Post-TAVR
• Postprocedure monitoring and pain management
• Early mobilization and discharge planning
• Monitor for conduction abnormalities
Long-term Management
• Antithrombotic therapy and endocarditis prophylaxis
• Management of concurrent cardiac disease
• Post-TAVR complications
Post-TAVR Imaging
Echo and ECG post-procedure, at 30 days and then annually
• Valve function
• LV size and function
• PA systolic pressure
• Cardiac rhythm
CV Imaging
Hand off back to Clinical Cardiologist & Primary Care Provider

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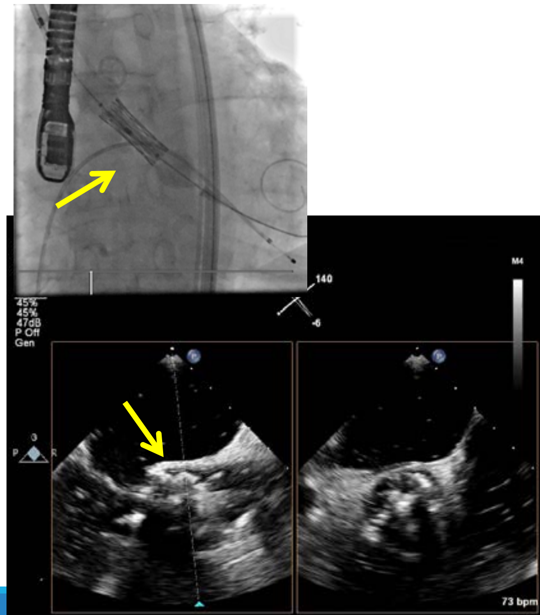
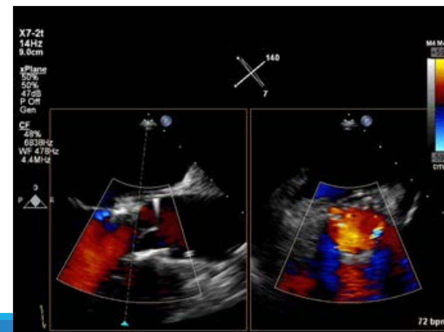
Imaging Guided Refinement of Procedures

Avoiding Aortic Rupture: Slowing Deployment





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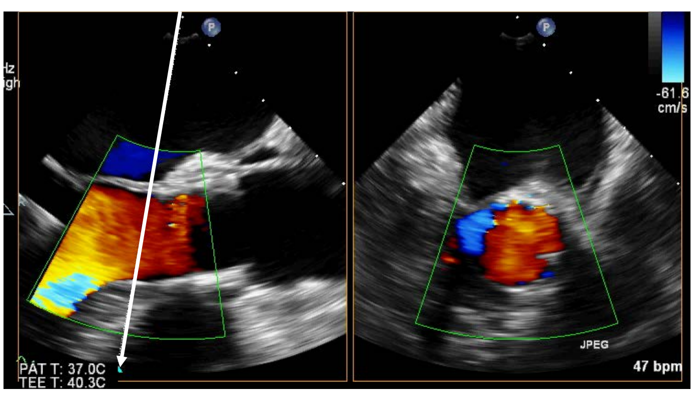
Grading severity of PVR

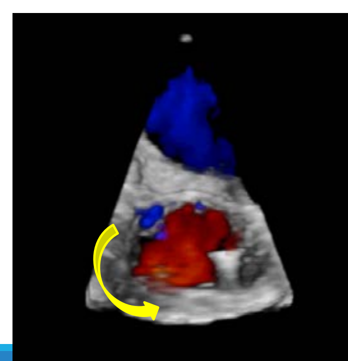


Assess just at the vena contracta at the ventricular edge of stent frame

Use circumferential extent of the individual jets

Retained calcific leaflets result in atypical Jet Paths

Wrap-around flow!



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GUIDELINES AND STANDARDS

Guidelines for the Evaluation of Valvular Regurgitation After Percutaneous Valve Repair or Replacement

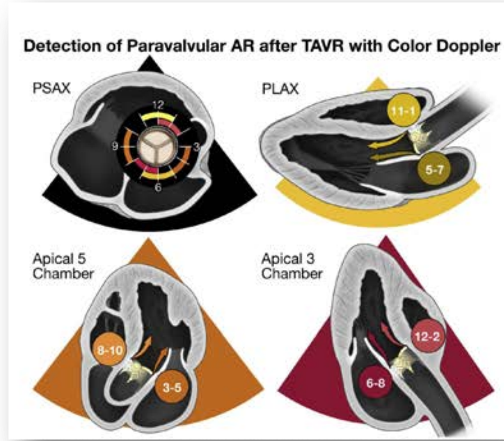
A Report from the American Society of Echocardiography Developed in Collaboration with the Society for Cardiovascular Angiography and Interventions, Japanese Society of Echocardiography, and Society for Cardiovascular Magnetic Resonance

Check for updates

William A. Zoghbi, MD, FASE, (Chair), Federico M. Asch, MD, FASE, Charles Bruce, MBChB, FASE, Linda D. Gillam, MD, MPH, FASE, Paul A. Grayburn, MD, FASE, Rebecca T. Hahn, MD, FASE, Ignacio Inglessis, MD, Ashequl M. Islam, MD, MPH, FSCAI, Stamatios Lerakis, MD, FASE, Stephen H. Little, MD, FASE, Robert J. Siegel, MD, FASE, Nikolaos Skubas, MD, DSc, FASE, Timothy C. Slesnick, MD, FASE, William J. Stewart, MD, FASE, Paaladinesh Thavendiranathan, MD, MSc, FASE, Neil J. Weissman, MD, FASE, Satoshi Yasukochi, MD, JCC, SJSUM, and Karen G. Zimmerman, BS, ACS, RDCS, RVT, FASE, *Houston and Dallas, Texas; Washington, District of Columbia; Rochester, Minnesota; Morristown, New Jersey; New York, New York; Boston and Springfield, Massachusetts; Los Angeles, California; Cleveland, Ohio; Atlanta, Georgia; Toronto, Ontario, Canada; Nagano, Japan; and Morgantown, West Virginia*

To assess residual AR with CD after TAVR, the following caveats should be considered:

1. The whole length of the transcatheter valve should be scanned
2. The entire short axis of the valve should be imaged in a single
3. Central prosthetic AR jets will occur at the level of leaflet coaptation whereas PVR will be seen at the proximal (ventricular) edge of the valve.
4. Small jets of regurgitation are typically isolated to the open stent cells
5. The ratio of jet width to LVOT width or jet cross-sectional area to cross-sectional area of the valve or LVOT should not be used to assess the severity of AR since regurgitant jets are frequently eccentric, constrained by and entrained within the LVOT, leading to rapid jet broadening



Using a clock face to represent the short-axis view (placing the tricuspid valve at 9 o'clock) may be helpful for recording the jet location and number, and useful for follow-up comparisons

Zoghbi WA et al. J Am Soc Echo 2019;32(4):431 - 475

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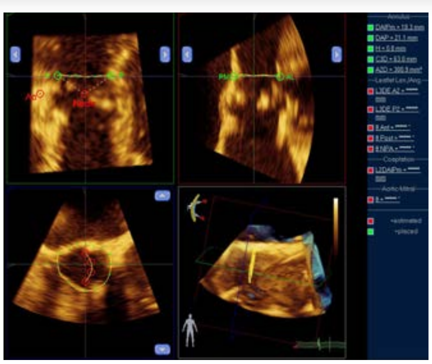
CLINICAL INVESTIGATIONS
VALVULAR HEART DISEASE

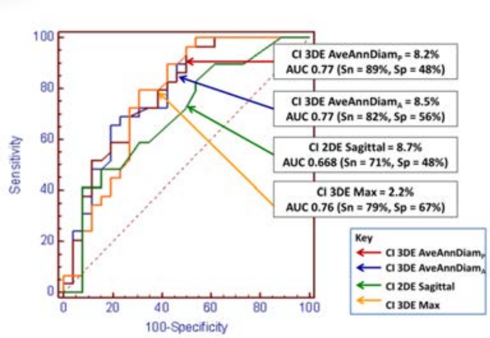
Predicting Paravalvular Regurgitation Following Transcatheter Valve Replacement: Utility of a Novel Method for Three-Dimensional Echocardiographic Measurements of the Aortic Annulus

Rebecca T. Hahn, MD, Omar Khalique, MD, Mathew R. Williams, MD, Elana Koss, MD, Jean-Michel Paradis, MD, Benoit Daneault, MD, Ajay J. Kirtane, MD, SM, Isaac George, MD, Martin B. Leon, MD, and Susheel Kodali, MD, *New York, New York*

Indirect Planimetry

1. Uses long-axis anatomy to identify the annulus
2. Eliminates tracing errors
3. Allows for more "educated" approximation of annulus in regions of acoustic artifact





Hahn RT et al. J Am Soc Echocardiogr 2013;26:1044-1052.

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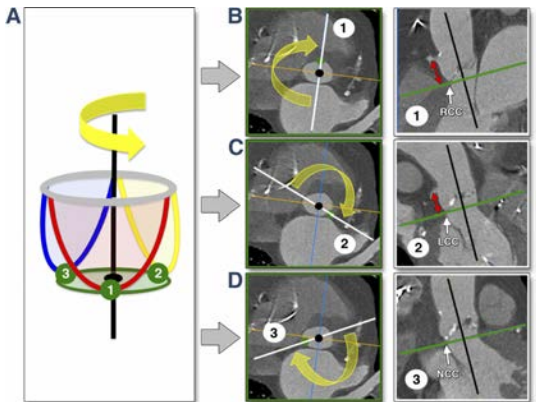
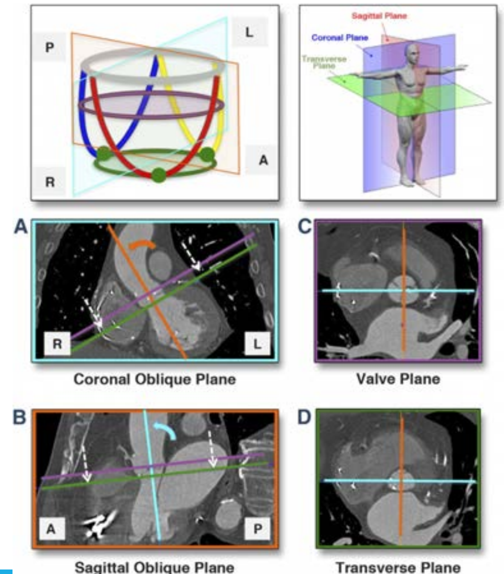
Lesson Learned: Multi-modality Imaging

Detailed and reliable description of the complex 3-dimensional aortic root anatomy in patients undergoing TAVR





Kasel AM et al. J Am Coll Cardiol Img 2013;6:249 – 62

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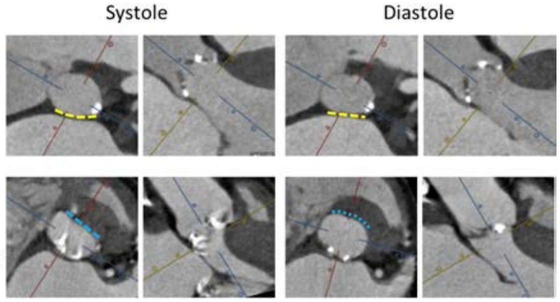
CT for Procedure Planning

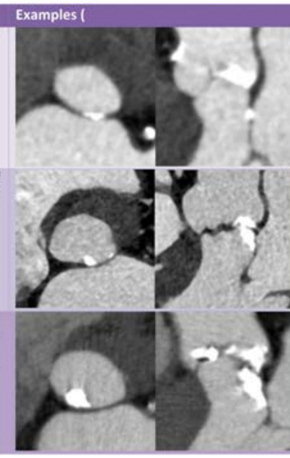
Systole Diastole

Common anatomy Systole > Diastole

Septal hypertrophy Systole < Diastole



Grade		Examples (
Mild	Single, adherent, non-protruding focus of calcification	
Moderate	Two or more nodules of calcification or a single nodule with limited protrusion into the annular/subannular lumen	
Severe	Single or multiple nodules of calcification, protruding into the annular lumen, and/or extending into the LVOT.	



Qualitative grading of annular/sub-annular and left ventricular outflow tract calcification.

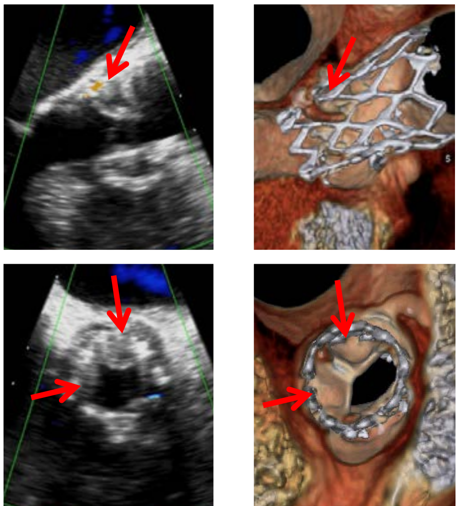
- Patient and procedure related factors increasing risk of annular rupture include
  - female sex, use of balloon-expandable valves, significant prosthesis oversizing, and prior radiation therapy
  - CTA assessed presence of moderate/severe subannular calcification (particularly below the non-coronary cusp) and depth of calcification within the LVOT

Blanke P et al. JACC: Cardiovasc Img 2019:12(1);1-24

14

Role of TEE and CT for Follow-up

There was 100% concordance in the assessment of leaflet motion between TEE and 4D VR-CT in 10 out 22 patients with reduced leaflet motion undergoing TEE



- 9/2019 NEW DATA: The PARTNER 3 substudy : the incidence was similar at 1 year (27.5% with TAVR vs 20.2% with surgery; $P = 0.19$)
- Of the 25 patients with HALT at 30 days, there was resolution of leaflet thickening at 1 year in 14 subjects, none of whom received oral anticoagulation
- Routine 4D CT is not indicated

N Engl J Med 2015;373:2015–2024.

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AMERICAN COLLEGE OF CARDIOLOGY FOUNDATION

VOL. 70, NO. 19, 2017
ISSN 0735-1097/$36.00

EXPERT CONSENSUS DECISION PATHWAY

2017 ACC Expert Consensus Decision Pathway on the Management of Mitral Regurgitation

A Report of the American College of Cardiology Task Force on Expert Consensus Decision Pathways

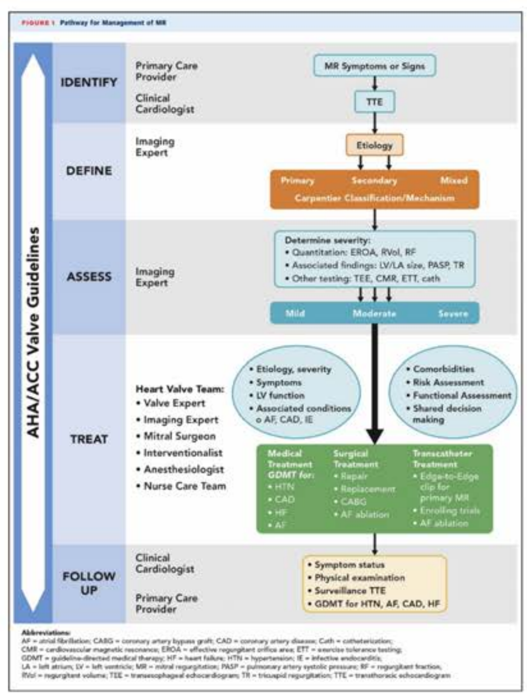
Identification of MR

Define the etiology of MR (including whether MR is primary or secondary)
- **Carpentier classification of leaflet motion**

Assess the severity of MR

Treatment decisions that begin with the Heart Valve Team

Follow-up with clinical cardiology and the primary care provider



O'Gara PT et al. J Am Coll Card 2017 Nov 7;70(19):2421-2449.

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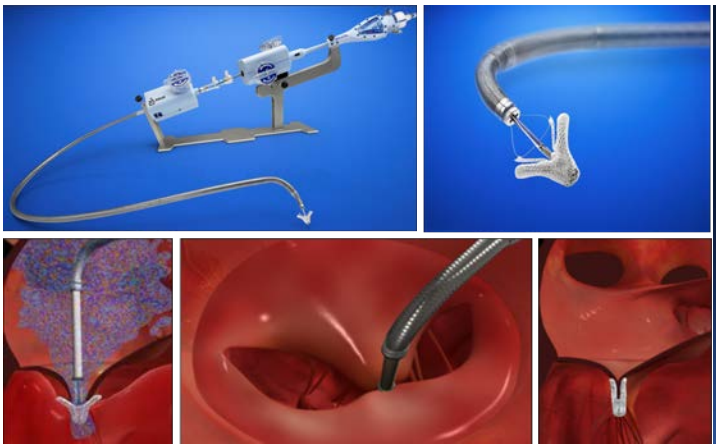
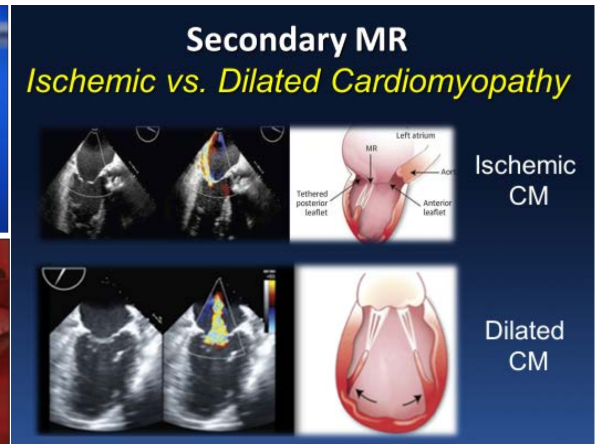
MitraClip for DMR and FMR





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Echocardiographic Features Determining Suitability for the MitraClip

	Ideal Echo Features	Challenging Echo Features	Relative Echo Contra-indications
Location of Pathology	• **Segment 2**	• **Segments 1 or 3**	• **Body of leaflet (i.e. perforation or cleft/deep fold)**
Calcification	• **None**	• **Mild, outside grasping zone** • **Extensive annular calcification**	• **Severe calcification at site of grasping zone**
Mitral Valve Area/Gradient	• **≥4 cm²** • **<4 mmHg**	• **>3.5 cm² <4 cm² with small BSA or very mobile leaflets** • **≥4 mmHg**	• **<3.5 cm² AND ≥4 mmHg**
Grasping Zone Length	• **>10 mm**	• **7-10 mm**	• **<7 mm**
Functional MR	• **Normal thickness and mobility** • **Coaptation depth <11 mm**	• **Carpentier IIIB (restricted)** • **Coaptation depth >11 mm**	• **Carpentier IIIA (rheumatic thickening and restriction)**
Degenerative MR	• **Flail width <15 mm** • **Flail gap <10 mm**	• **Flail width <15 mm with large valve area and option for >1 MitraClip** • **Flail gap >10 mm with possibility of adjunctive measures**	• **Barlow's disease with significant regurgitation segments 1-3**
Other Pathology		• **Annuloplasty ring with adequate mitral valve area and leaflet length** • **HOCM with Systolic anterior motion**	• **Extreme disease (Markedly dilated annulus or EROA ≥ 70.8 mm²)**

Hahn RT ***Circ Res*****. 2016;119:341-356.**

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Advantage to 3D: The Columbia Experience

	Age	MV Path	# Clips	Minutes	Min/Clip
2D Guidance	77.6 ± 11.1	2 Functional 6 Degen	0 = 2 pts 1 = 2 pts 2 = 4 pts	175.7 ± 58.0*	109.8 ± 11.6*
3D Guidance	75.3 ± 9.7	8 Functional 5 Degen	0 = 1 pt 1 = 11 pts 2 = 1 pts	80.4 ± 30.5*	68.4 ± 15.4*

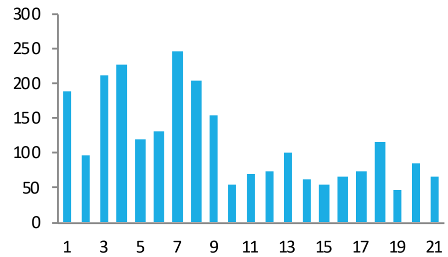
*p <0.001

Other variables:

Learning curve:

- 2D guidance alone used prior to 10/2007
- 2D with 3D guidance used after 10/2007

Pathology



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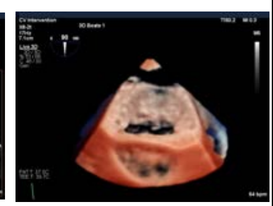
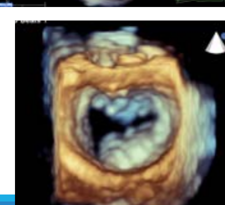
MitraClip Procedure

Easy MitraClip	• **Good Imaging** • **Good Anatomy** • **Pre-Procedural Planning**
Challenging MitraClip	• **Poor Anatomy with Good Imaging** • **Pre-procedural Planning** • **Adaptability**
Difficult MitraClip	• **Poor Imaging** • **Poor Anatomy** • **Failure to Plan Ahead**

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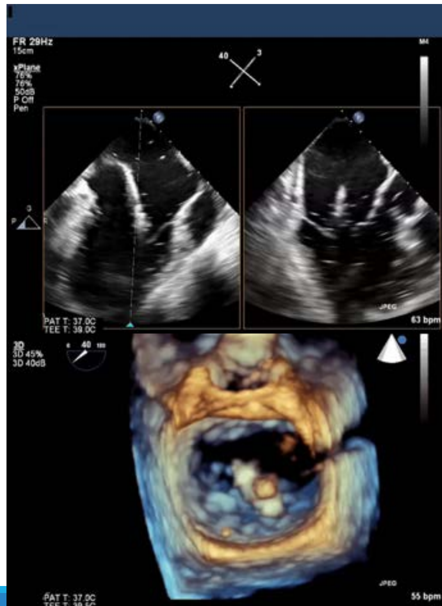
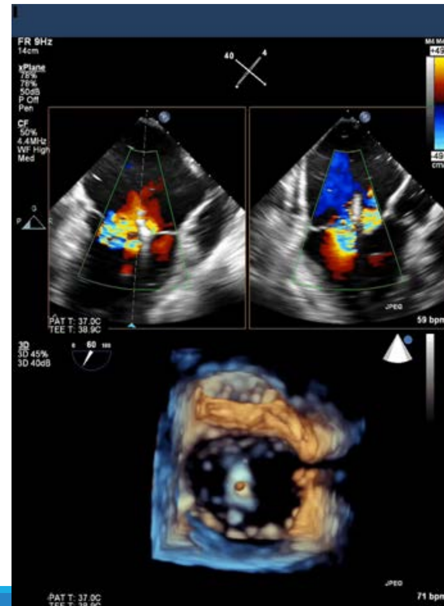
Guiding Device Deployment





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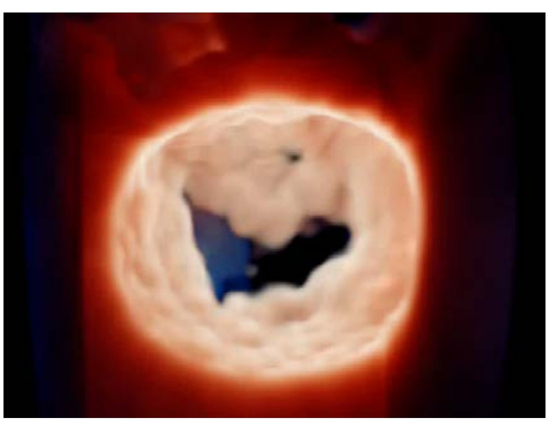
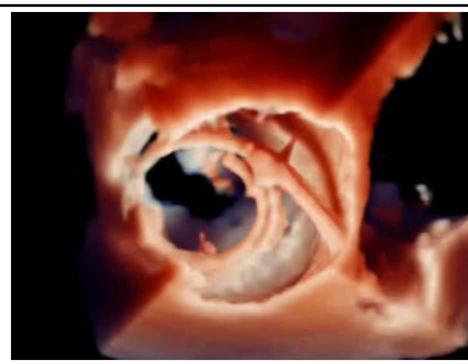
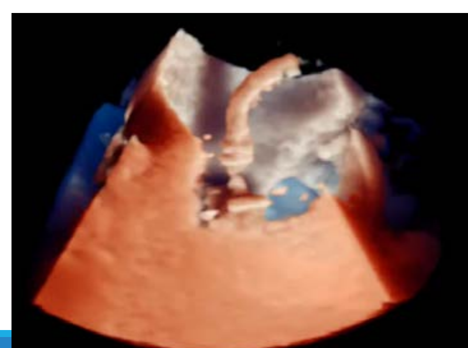
MitraClip Procedure

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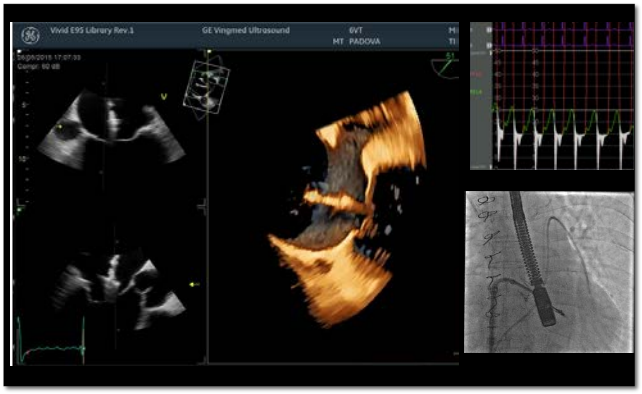
Enhancing the communication in the Cath Lab



Live Fluoro Image and Hemodynamics visible to Echocardiographer

CT-Fluoro Fusion visible to Echocardiographer

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Transcatheter MV Repair: Device Landscape

Edge-to-edge
- MitraClip*
- MitraFlex

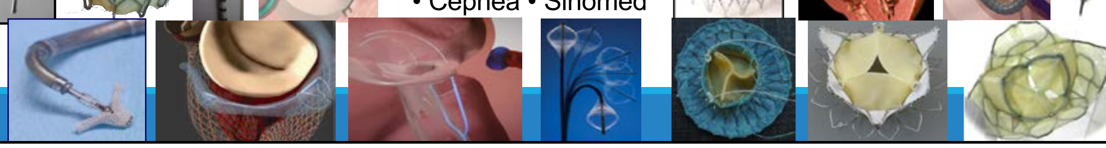
Direct annuloplasty and basal ventriculoplasty
- Mitralign Bident*
- GDS Accucinch*
- Valtech Cardioband*
- MVRx*
- Valcare*
- Mitraspan*
- Quantum Cor (RF)
- Micardia enCor

Coronary sinus annuloplasty
- Cardiac Dimensions Carillon*
- Cerclage annuloplasty

MV replacement
- Edwards CardiAQ*
- Edwards Fortis*
- Neovasc Tiara*
- Abbott Tendyne*
- Medtronic Twelve*
- NCSI Navigate
- Mvalve* • Direct Flow
- Micro Interventional
- Valtech Cardiovalve
- ValveXchange
- HighLife
- MitrAssist
- Cephea • Sinomed

Other approaches
- MitraSpacer*
- St. Jude leaflet plication*
- Cardiac Implant perc ring
- NeoChord*
- Babic chords*
- Valtech Vchordal
- Middle Peak Medical
- Mardil BACE*
- Mitralis
- Millipede

*In patients



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Role of Echocardiography in Transcatheter Mitral Valve Replacement in Native Mitral Valves and Mitral Rings

G. Burkhard Mackensen, MD, PhD, FASE, James C. Lee, MD, Dee Dee Wang, MD, FASE, Paul J. Pearson, MD, PhD, Philipp Blanke, MD, Danny Dvir, MD, and James N. Kirkpatrick, MD, FASE, *Seattle, Washington; Detroit, Michigan; Milwaukee, Wisconsin; and Vancouver, British Columbia, Canada*

Adaptation and evolution of transcatheter aortic valve replacement (TAVR) technologies has led to approval of TAVR for consideration in patients at intermediate risk for surgical aortic valve intervention. As TAVR becomes more mainstream, attention is shifting toward percutaneous mitral valve (MV) repair and transcatheter MV replacement (TMVR) techniques. Transcatheter heart valves (both purpose-built and off-label-use TAVR valves) are being implanted during TMVR procedures to treat clinically significant MV disease (native disease, degenerated bioprosthetic valves, and dysfunctional surgical MV annuloplasty repairs) when the risk of open heart MV surgery is prohibitive. The success of these high-risk procedures is directly related to accurate peri-procedural imaging with echocardiography and other modalities. Although a multidisciplinary heart valve team approach is necessary for optimal patient selection, a multimodality team-based imaging approach and comprehensive understanding of the MV are required for safe procedural planning. Collaboration between noninvasive cardiac imagers and the intraprocedural interventional imaging team and translation of the peri-procedural imaging to the implanting team are crucial to the success of TMVR technology. Currently, the TMVR procedures discussed here are conducted either as part of clinical research or off label. The US Food and Drug Administration–approved mitral valve-in-valve procedures for the treatment of degenerated mitral bioprosthetic valves are not discussed here. (J Am Soc Echocardiogr 2018;31:475-90.)

Keywords: Mitral valve, Transcatheter mitral valve replacement, Structural heart disease, Percutaneous, Echocardiography (all modalities, applications)

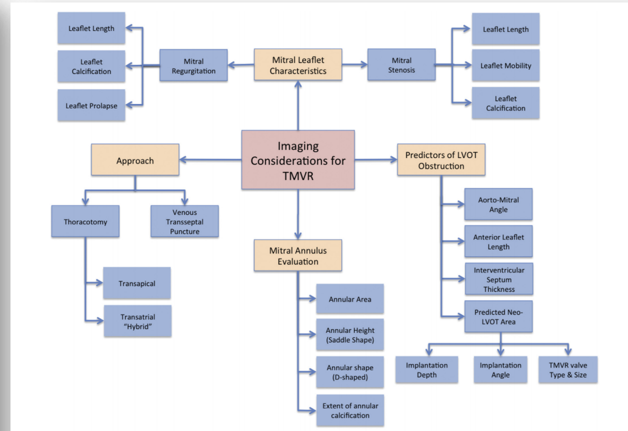

Figure 1 Major imaging consideration before TMVR in a native valve or valve in ring. Imaging planning of TMVR requires a robust assessment of MV leaflet characteristics, the mitral annulus, the potential for dynamic LVOT obstruction, and the optimal vascular access for the transcatheter approach.

Mackensen GB et al. J Am Soc Echocardiogr 2018;31:475-90

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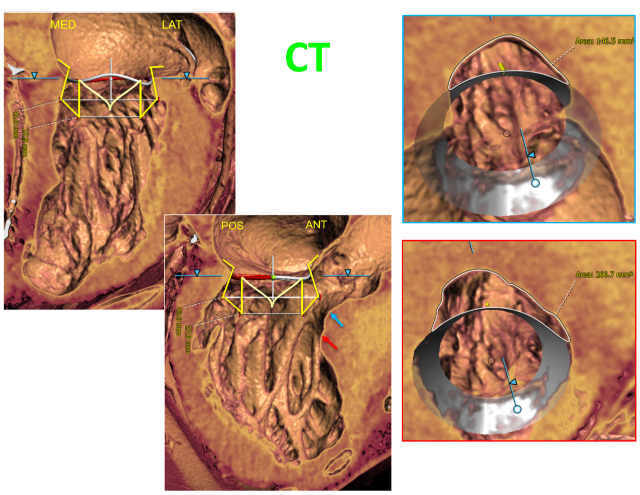
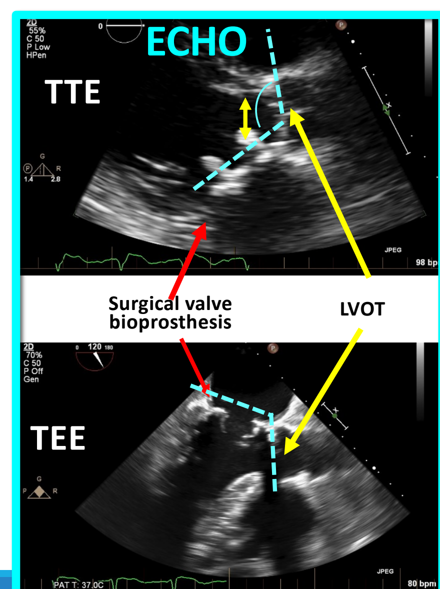
Pre-procedural Imaging: Prediction of LVOT Obstruction





Prediction of LVOT obstruction

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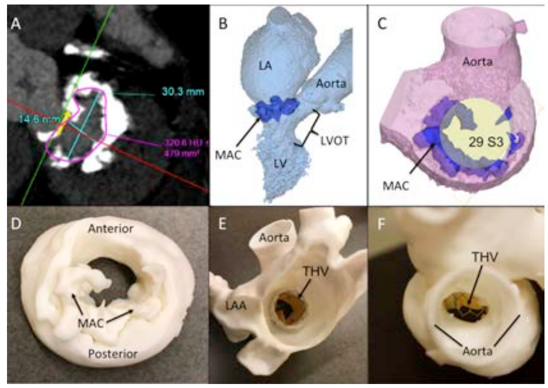
Table 1 Role of echocardiographic imaging before transcatheter MV procedures

Parameters and structures assessed by preprocedural echocardiographic imaging in TMVR
1. Valve pathology
2. Severity of valve dysfunction (MR and/or MS)
3. Morphologic and anatomic characterization of mitral leaflets
4. Shape and sizing of MV annulus
5. MAC
6. Subvalvular apparatus (including chords)
7. Hemodynamic and flow assessment
8. Geometry of left atrium and left ventricle, including the interventricular septum
9. Interatrial septum (shunt, defect, presence of surgical patch, aneurysm, hypertrophy)
10. Left atrial appendage and left atrium (rule out thrombus)
11. LVOT (structure, size, and function)
12. Aortomitral angle
13. Coexisting structural and functional cardiac disease
14. LV systolic and diastolic function
15. Right ventricular systolic function
16. Tricuspid regurgitation
17. Aortic valve stenosis
18. Aortic valve regurgitation
19. Pulmonary artery pressure
20. Pericardial disease
21. Aortic pathology



Mackensen GB et al. J Am Soc Echocardiogr 2018;31:475-90

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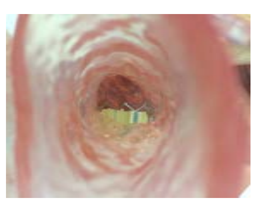
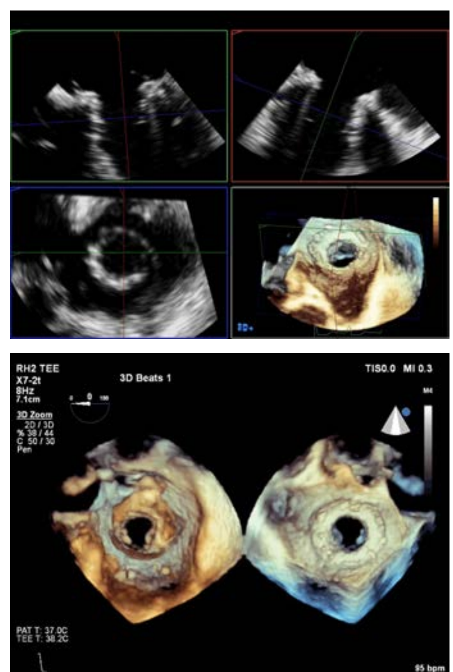
Cardiac CT Scan

MV Ring

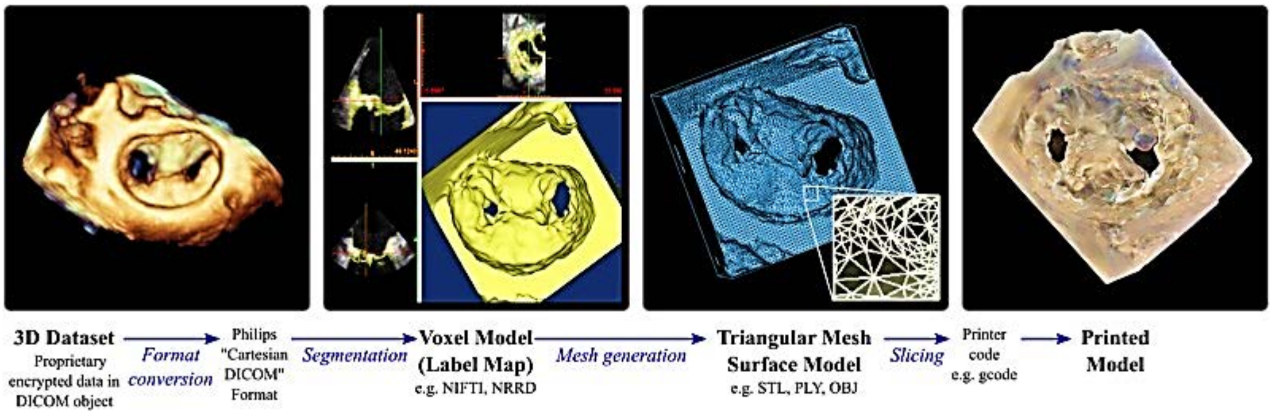




Physical Testing of Device position and fit

28

Echocardiography-derived 3D printing of intracardiac structures: an evolving technology.



Mashari et al Echo Res Pract 2016 Dec;3(4):R57-64

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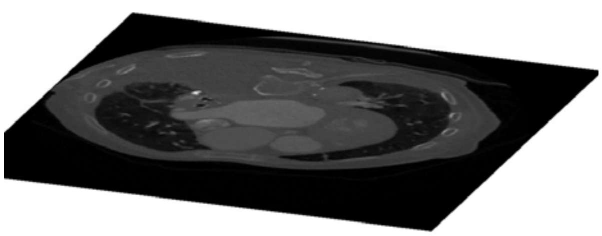
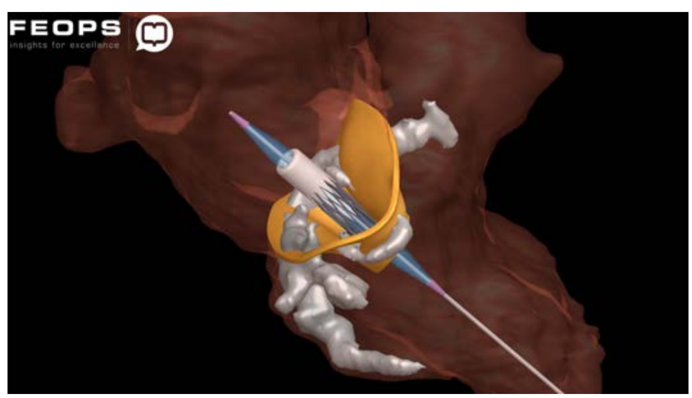
Virtual Valve Implantation

TAVR Modeling



Valve-in-MAC Modeling



Requires an understanding of anatomy, tissue characteristics and device behavior

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EDITORIALS AND VIEWPOINTS

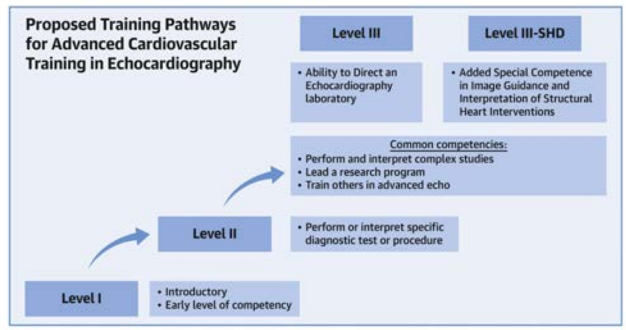
Core Competencies in Echocardiography for Imaging Structural Heart Disease Interventions

An Expert Consensus Statement

Rebecca T. Hahn, MD,[a] Feroze Mahmood, MD,[b] Susheel Kodali, MD,[a] Roberto Lang, MD,[c] Mark Monaghan, PhD,[d] Linda D. Gillam, MD,[e] Madhav Swaminathan, MD,[f] Robert O. Bonow, MD,[g] Ralph Stephan von Bardeleben, MD,[h] Jeroen J. Bax, MD, PhD,[i] Paul Grayburn, MD,[j] William A. Zoghbi, MD,[k] Partho P. Sengupta, MD,[l] Y. Chandrashekhar, MD,[m] Stephen H. Little, MD[k]

Interventional Imagers are key to the technical success of the procedure thus this document attmepts to define the subspecialty and core competencies required (Medical Knowledge, Patient Care and Procedural Skills.

CENTRAL ILLUSTRATION: Proposed Training Pathways for Advanced Cardiovascular Training in Echocardiography



Hahn, R.T. et al. J Am Coll Cardiol Img. 2019;12(12):2560-70.

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Core Competencies: MINIMUM Procedural Volume

TABLE 3 Minimum Procedural Volume Typically Necessary for the Development and Demonstration of Level III-Structural Heart Disease

Procedure/Technical Skill	Numbers*	
Echocardiographic guidance of interventional procedures, which includes:	75	
Structural valvular intervention†		30
Transseptal catheterization guidance		10
Percutaneous closure of septal defects/perivalvular leaks		15
Alcohol septal ablation		10
Placement of devices to exclude the left atrial appendage		10
Ventricular assist device placement and assessment	20	
Intraoperative transesophageal echocardiography,† which includes:	75	
surgical valve repair or replacement		50
Intracardiac echocardiography	10	

From Wiegers et al. (7). *Numbers are based on consensus and intended as general guidance based on the educational needs and progress of typical Level III echocardiography trainees. Competency to perform each procedure must be based on evaluation by the supervising echocardiography laboratory director and may exceed or be below the threshold number shown in this table. †The Level III trainee should successfully complete both right-sided and left-sided procedures if the goal is to obtain competency in the full range of structural heart disease interventions.

NOTE:

1. There are no robust data that outline the number of procedures that an echocardiographer needs to train before becoming competent in SHD imaging.
2. In the absence of learning curve data, arriving at a consensus on the suggested minimum numbers of procedures to achieve SHD competence requires a challenging **compromise between what is achievable in centers performing low volumes of structural interventions and what is considered the minimum requirement to achieve a safe level of proficiency and competence in uncomplicated cases.**

Hahn RT et al. JACC Cardiovasc Img 2019;12(12):2560-2570

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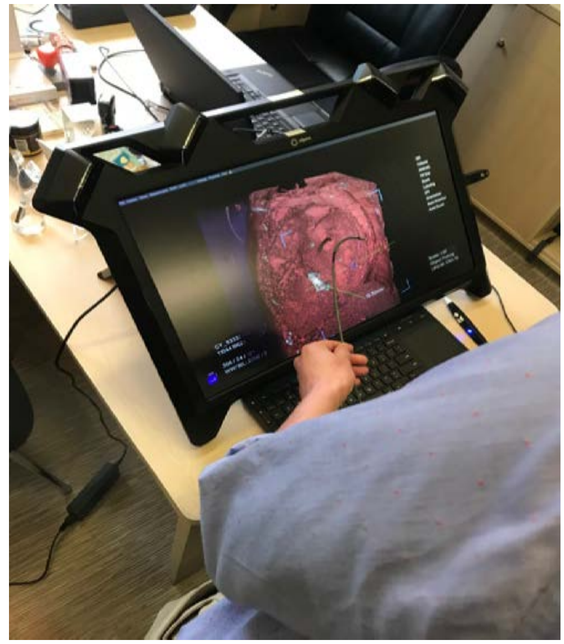
Novel Procedural Rehearsal

- Enables a hybrid approach
- Operator visualizes 3D/4D view of anatomy at 1:1 scale with product
- Product can be manipulated in open space (in virtual anatomy)
- Multiple viewers/observers possible
- Facilitates case preparation and product selection



Courtesy of Saurabh Sahon

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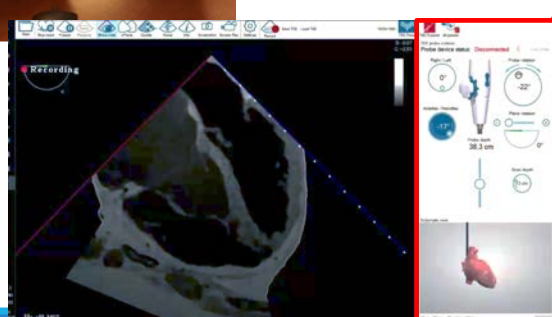
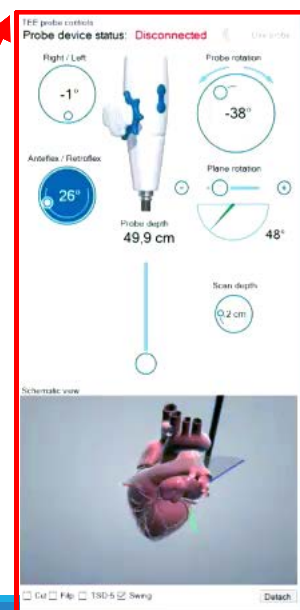
TEE Simulation

- **CT-based imaging**
- **Realistic probe position and manipulation**
- **Simulated device guidance**





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Pathophysiology of
Valvular Heart Disease

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Multi-modality Imaging

1. Quantitation of Valvular Heart Disease Severity
2. Understanding of Disease Pathophysiology
3. Risk Stratification/Prediction of Outcomes

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EACVI/ASE CLINICAL RECOMMENDATIONS

Recommendations on the Echocardiographic Assessment of Aortic Valve Stenosis: A Focused Update from the European Association of Cardiovascular Imaging and the American Society of Echocardiography

Helmut Baumgartner, MD, FESC, (Chair), Judy Hung, MD, FASE, (Co-Chair), Javier Be
John B. Chambers, MB BChir, FESC, Thor Edvardsen, MD, PhD, FESC, Steven Goldst
Patrizio Lancellotti, MD, PhD, FESC, Melissa LeFevre, RDCS, Fletcher Miller Jr., M
and Catherine M. Otto, MD, FESC, *Muenster, Germany; Boston, Massachusetts; Madrid, Spa
Kingdom; Oslo, Norway; Washington, District of Columbia; Liège, Belgium; Bari, Italy; Durh
Rochester, Minnesota; and Seattle, Washington*

(1) appropriate in all patients with AS (yellow);
(2) reasonable when additional information is needed in selected patients (green)

1. Use an integrative approach when grading the severity of AS, combining all Doppler and 2D data as well as clinical presentation
2. Loading conditions influence velocity and pressure gradients
3. Irregular rhythms or tachycardia can make assessment of AS severity challenging.

Ideally, heart rate, rhythm, and blood pressure should be stated in the echocardiographic report and hemodynamic assessment should be performed at heart rates and blood pressures within the normal range.

Table 2 Measures of AS severity obtained by Doppler-echocardiography

	Units	Formula/method	Cut-off for severe	Concept	Advantages	Limitations
AS jet velocity[12-15]	m/s	Direct measurement	4.0	Velocity increases as stenosis severity increases	Direct measurement of velocity. Strongest predictor of clinical outcome	• Correct measurement requires parallel alignment of ultrasound beam • Flow dependent.
Mean gradient[12-14]	mmHg	$\Delta P = \sum 4v^2/N$	40	Pressure gradient calculated from velocity using the Bernoulli equation	• Mean gradient is obtained by tracing the velocity curve • Units comparable to invasive measurements	• Accurate pressure gradients depend on accurate velocity data • Flow dependent
Continuity equation valve area[16-18]	cm^2	$AVA = (CSA_{LVOT} \times VTI_{LVOT})/VTI_{AV}$	1.0	Volume flow proximal to and in the stenotic orifice is equal	• Measures effective orifice area • Feasible in nearly all patients • Relatively flow independent	Requires LVOT diameter and flow velocity data, along with aortic velocity. Measurement error more likely
Simplified continuity equation[18,19]	cm^2	$AVA = (CSA_{LVOT} \times V_{LVOT})/V_{AV}$	1.0	The ratio of LVOT to aortic velocity is similar to the ratio of VTIs with native aortic valve stenosis	Uses more easily measured velocities instead of VTIs	Less accurate if shape of velocity curves is atypical
Velocity ratio[19,20]	None	$VR = \frac{V_{LVOT}}{V_{AV}}$	0.25	Effective AVA expressed as a proportion of the LVOT area	Doppler-only method. No need to measure LVOT size, less variability than continuity equation	Limited longitudinal data. Ignores LVOT size variability beyond patient size dependence
Planimetry of anatomic valve area[21,22]	cm^2	TTE, TEE, 3D-echo	1.0	Anatomic (geometric) CSA of the aortic valve orifice as measured by 2D or 3D echo	Useful if Doppler measurements are unavailable	Contraction coefficient (anatomic/effective valve area) may be variable. Difficult with severe valve calcification

Baumgartner H et al. J Am Soc Echocardiogr 2017;30:372-92

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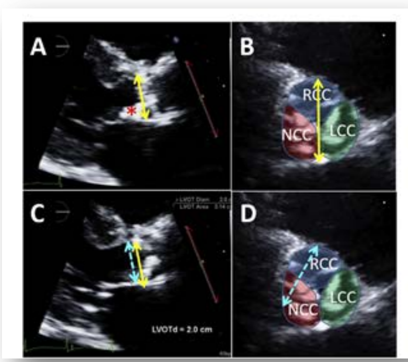

PREDICTED LVOT Diameter (mm)= (5.7 x BSA) + 12.1

Use with caution in obese patients!!

For a BSA of 2.0, LVOT ~ 23.5 mm
For a BSA of 1.5 m2, LVOT ~ 20.7 mm
± 2 mm

Leye, M et al. J Am Soc Echocardiogr 2009;22:445-451

Table 1 Checklist for verification of the accuracy of the measurement of LVOT area for the calculation of AVA for the assessment of aortic stenosis severity

Actions	Interpretation and caveats
Use the midsystolic image that bisects the largest dimension of the aortic annulus: i.e., the plane that bisects the right coronary cusp hinge point anteriorly and the interleaflet triangle between the left and noncoronary cusps posteriorly (see Figure 1B)	If two leaflets are well visualized both anteriorly and posteriorly, this may not be the plane providing the largest diameter, and LVOTd may be underestimated from this view (see Figures 1C and 1D).
Measure LVOTd at the aortic annulus: not 0.5 to 1 cm below	Look for the hinge point of the right coronary cusp anteriorly and measure to the mitral-aortic curtain, perpendicular to the long-axis of the aorta (see Figure 1A).
In the presence of LVOT ectopic calcification: use the plane that bisects the largest diameter but excludes the calcification from the LVOTd measurement (see Figure 1A)	
Calculate predicted LVOTd using the formula: LVOTd = (5.7 × BSA) + 12.1	If the LVOTd measured at the annulus is 2 mm smaller or larger than the predicted LVOTd, suspect error in the measurement of LVOTd. Note that the formula may overestimate LVOTd in obese individuals.
Calculate the DVI: $DVI = VTI_{LVOT}/VTI_{AoV}$	If AVA is <1.0 cm^2 and indexed AVA is <0.6 cm^2/m^2 but DVI is >0.25, suspect underestimation of LVOTd.
Corroborate the calculation of LVOT area obtained by 2D TTE with other modalities:	
3D TTE or TEE	Accuracy of 3D TTE determined by the echogenicity of the patient.
MDCT	Planimetered LVOT by MDCT area may be larger than LVOT area calculated using a linear diameter.
Corroborate the measure of LVOT stroke volume by other methods:	
Biplane Simpson	Biplane Simpson may underestimate stroke volume.
3D TTE volumes	Accuracy of 3D TTE determined by the echogenicity of the patient.
Corroborate the measure of AVA by other methods:	
Planimetry of AVA by TTE or TEE	The "anatomic" AVA measured by planimetry is often larger than the "effective" area measured by the continuity equation because of the flow contraction that occurs downstream of the valve orifice.
Hybrid MDCT-Doppler: LVOT area is measured by MDCT and used in the continuity equation to calculate the "hybrid" AVA	The hybrid method systematically measures larger AVAs, and therefore a larger cutoff value (i.e., <1.2 instead of 1.0 cm^2) should be used to define severe aortic stenosis.[6]
In the presence of discordant grading (small AVA with low gradient), calculate indexed AVA: AVA/BSA (cm^2/m^2)	A small AVA in a small patient may correspond to moderate AS. In such patients, the AVA is <1.0 cm^2, suggesting severe AS, but the indexed AVA is >0.6 cm^2/m^2, with a low gradient (<40 mm Hg), suggesting that the stenosis is in fact not severe. The indexed AVA may overestimate the severity of AS in obese patients.

AoV, Aortic valve; *AS*, aortic stenosis; *BSA*, body surface area; *DVI*, Doppler velocity index; *LVOTd*, LVOT diameter; *MDCT*, multidetector computed tomography; *TEE*, transesophageal echocardiography; *3D*, three-dimensional; *TTE*, transthoracic echocardiography.

Hahn and Pibarot J Am Soc Echocardiogr 2017;30(10):1038-1040

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Stages of Valvular AS

Stage	Definition	Valve Anatomy	Valve Hemodynamics
D1	Symptomatic severe high-gradient AS	Severe leaflet calcification or congenital stenosis with severely reduced leaflet opening	• Aortic Vmax ≥4 m/s or mean ΔP ≥40 mm Hg • AVA typically is ≤1.0 cm2 (or AVAi ≤0.6 cm2/m2) but may be larger with mixed AS/AR
D2	Symptomatic severe low-flow/low-gradient AS with reduced LV EF	Severe leaflet calcification with severely reduced leaflet opening	• AVA ≤1.0 cm2 with Aortic Vmax <4 m/s or mean ΔP <40 mm Hg • Dobutamine stress echocardiography shows AVA ≤1.0 cm2 with Vmax ≥4 m/s at any flow rate
D3	Symptomatic severe low-gradient AS with normal LVEF or paradoxical low-flow severe AS	Severe leaflet calcification with severely reduced leaflet opening	• AVA ≤1.0 cm2 with Aortic Vmax <4 m/s or mean ΔP <40 mm Hg • AVAi ≤0.6 cm2/m2 and • Stroke volume index <35 mL/m2 • Measured when patient is normotensive (systolic BP <140 mm Hg)

Nishimura, RA et al JAmCollCardiol 2014 Jun 10;63(22):2438-88

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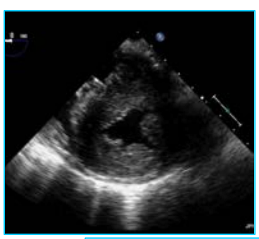
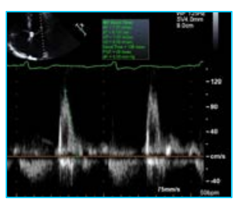
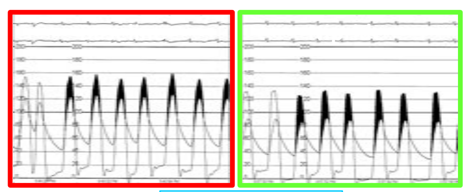




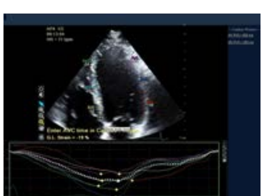


Hypertension

Concentric Hypertrophy, Diastolic Dysfunction

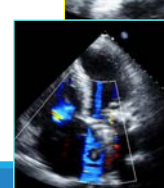
D3: Paradoxical Low Flow (SVI < 35 ml/m2) Normal EF (≥ 50%)

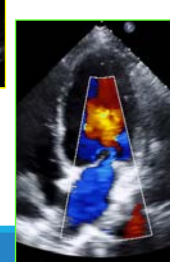
RV dysfunction or concomitant valve disease



Abnormal LV mechanics

Tachycardia (↓ ejection time)





Variable	Period; mean* ± standard error of the mean: Control	First pacing (P_1)	Second pacing (P_2)
Heart rate (beats/min)	80.9 ± 3.7	109.0 ± 4.7†	131.0 ± 4.2†
Stroke index (ml/m⁻²)	37.1 ± 1.5	29.4 ± 1.6§	23.8 ± 1.6§

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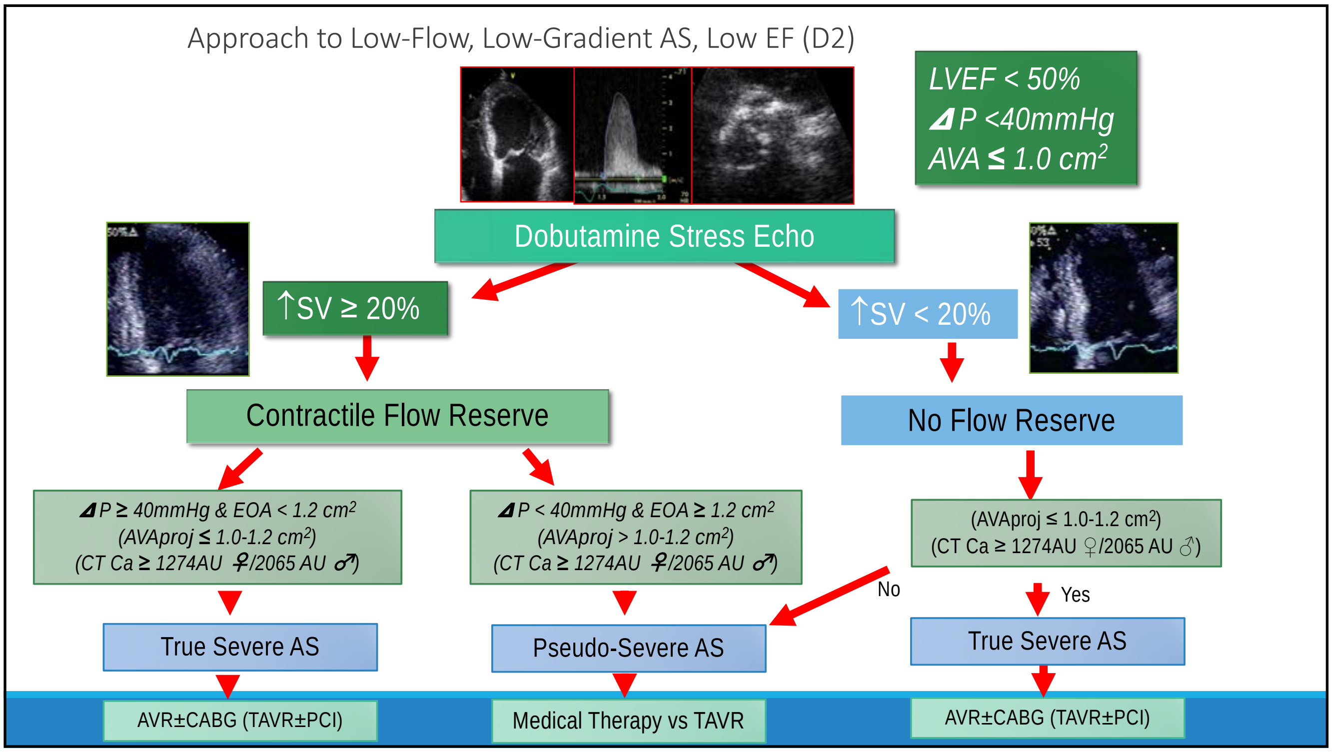

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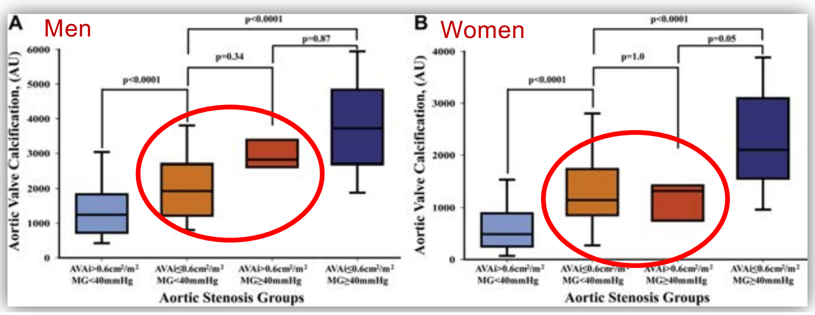
Distribution of Aortic Valve Calcification by Sex in the Various AS Groups



Clavel MA et al. J Am Coll Cardiol. 2013; *62*:2329–2338.

1. **Range of AVC load in patients with "Discordant Gradient" is wide, suggesting that this group is heterogeneous.**
2. **Half of these patients had evidence of severe calcified aortic valve disease on the basis of AVC load measured by MDCT**

	Women	Men
AVC	**1,274 AU**	**2,065 AU**
AVC density	**292 AU/cm2**	**476 AU/cm2**

(Note: AVC density = AVC indexed to annulus cross-sectional LVOT area)

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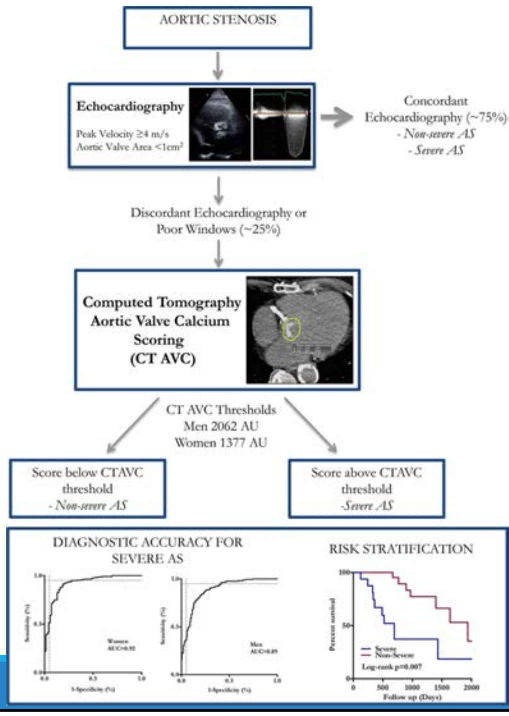

Patients with aortic stenosis (AS) should initially be assessed with echocardiography.

When there is discordance, CT-AVC provides an alternative and complementary assessment of disease severity.

Sex-specific thresholds (men 2062 Agatston unit [AU], women 1377 AU) are highly reproducible

CT-AVC also provides powerful prognostic information and pts with severe calcification have a 3- to 4-fold increase in AVR and death (HR 3.90 [95% confidence interval, 2.19–6.78]; *P*<0.001)

Pawade T et al. Circ Cardiovasc Imaging. 2018;11:e007146.

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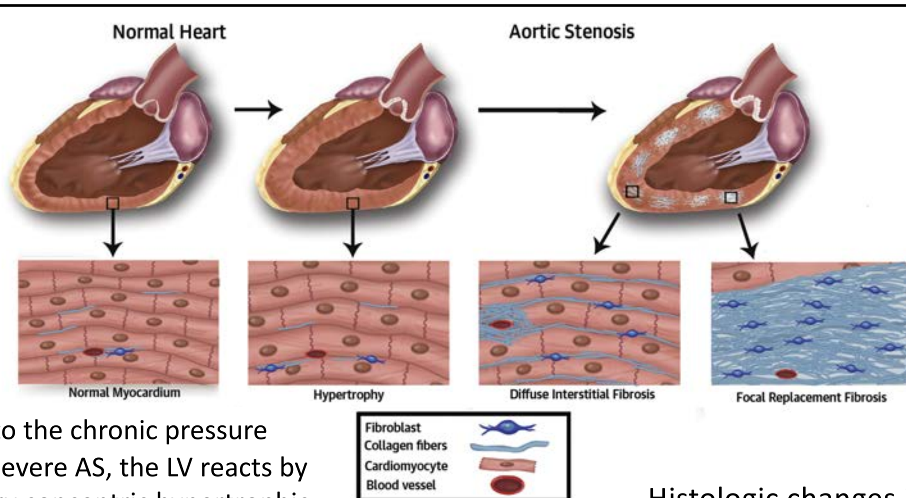

In response to the chronic pressure overload of severe AS, the LV reacts by compensatory concentric hypertrophic remodeling. This phenomenon involves not only increased myocyte volume but also coordinated remodeling and increased extracellular matrix

Histologic changes involve both interstitial diffuse reactive fibrosis as well as focal replacement fibrosis

Barone-Rochette, G. et al. J Am Coll Cardiol 2014;64:144–54

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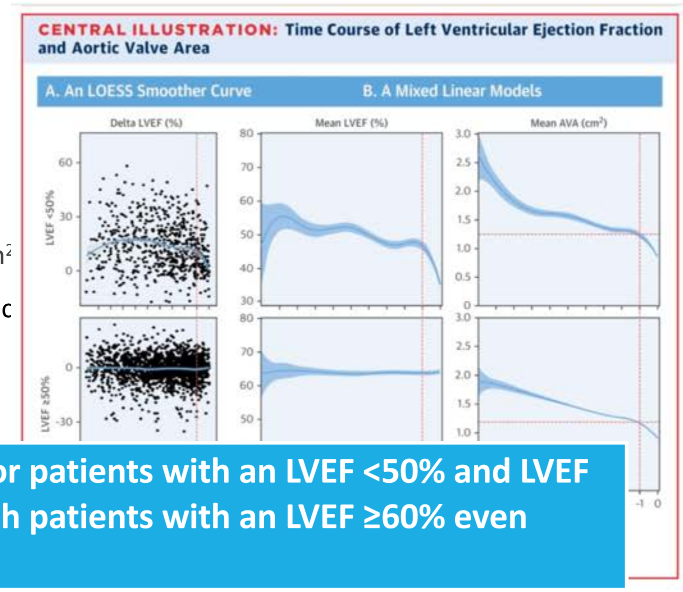
LVEF in Severe AS

In patients with severe AS and reduced LVEF, a decline in LVEF began before AS became severe and accelerated after AVA reached 1.2 cm²

LVEF <60% in the presence of moderate AS predic further deterioration of LVEF and appears to represent abnormal LVEF in AS.



Mortality was significantly worse for patients with an LVEF <50% and LVEF of 50% ≤ LVEF <60%, compared with patients with an LVEF ≥60% even after AVR ($p < 0.001$).

Ito S et al. (J Am Coll Cardiol 2018;71:1313–21.

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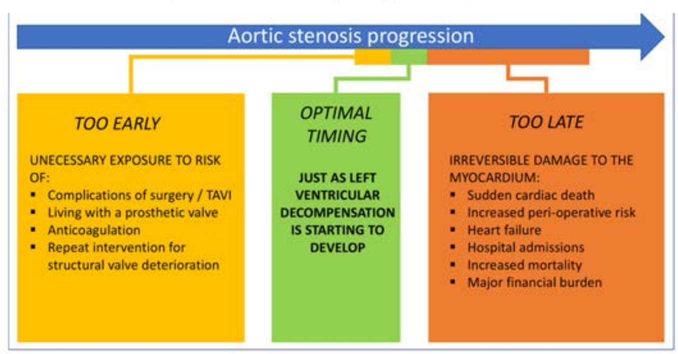
Timing of intervention in aortic stenosis: a review of current and future strategies

Russell James Everett,[1] Marie-Annick Clavel,[2] Philippe Pibarot,[2] Marc Richard Dweck[1]



Optimising the timing of aortic valve intervention in progressive aortic stenosis. TAVI, transcatheter aortic valve insertion.

► Aortic stenosis is a disease of both valve and myocardium, characterised by fibrosis and calcification of valve leaflets, progressive left ventricular hypertrophy and myocardial fibrosis.

► Timing of valve intervention is crucial.

Everett RJ, et al. Heart 2018;0:1–11. doi:10.1136/heartjnl-2017-312304

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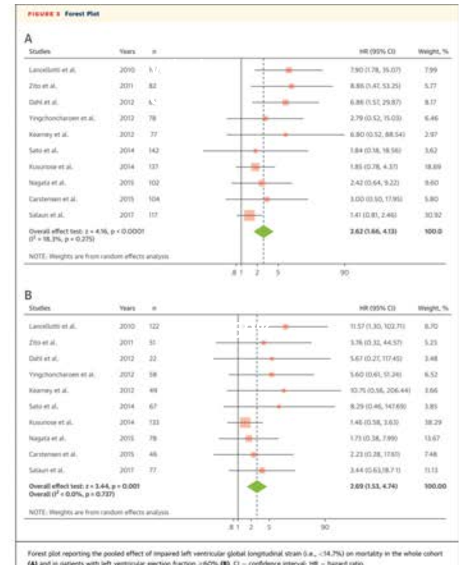
Meta-analysis of GLS in Asymptomatic, Severe AS

- 10 Studies, n = 1067 asymptomatic patients with LVEF >50%
- The best cutoff value identified was LVGLS of 14.7% (sensitivity, 60%; specificity, 70%).
- Risk of death with LVGLS <14.7% is multiplied by >2.5 (hazard ratio: 2.62; 95% CI: 1.66 to 4.13; p < 0.0001)
- The relationship between LVGLS and mortality remained significant in patients with LVEF ≥60% (p = 0.001).

Forest plot reporting the pooled effect of impaired LV GLS(i.e., <-14.7%)



Magne, J et al. J Am Coll Cardiol Img 2019;12:84–92

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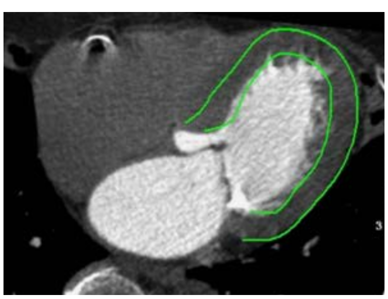
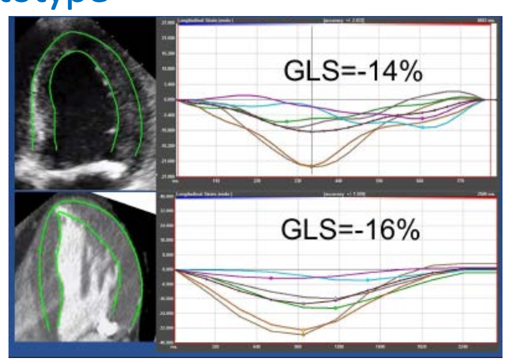
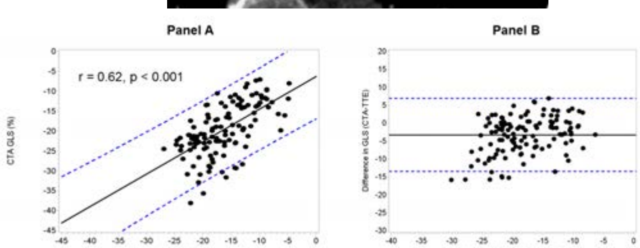
Feature-Tracking Global Longitudinal Strain from Retrogated CTA TomTec 2D Prototype







- N=123 patients undergoing TAVR in NSR and adequate image quality.
- GLS measured as the average of 18 segments (2ch, 3ch, 4ch)
- Values are modality-specific and not interchangeable

Fukui M et al. J Cardiovasc Comput Tomogr 2019 Mar - Apr;13(2):157-162.

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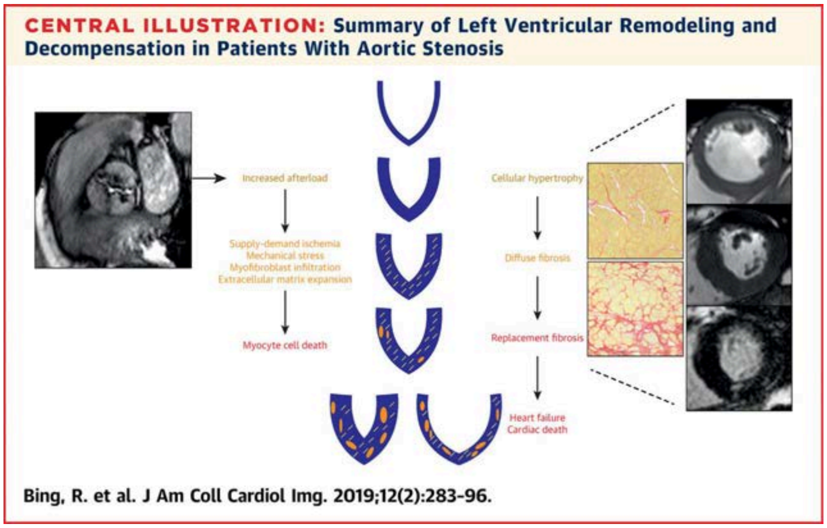
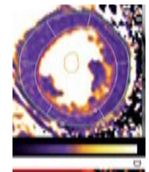
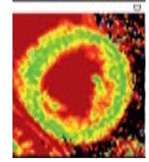
Imaging and Impact of Myocardial Fibrosis in Aortic Stenosis



Diffuse fibrosis

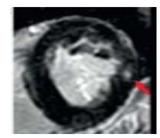


Native T1 map



Extracellular volume fraction map

Replacement fibrosis



LGE

- ➢ ***Diffuse fibrosis*** **occurs earlier, is potentially reversible, and can be quantified with CMR T_1mapping.**
- ➢ ***Replacement fibrosis*** **is irreversible and identified using late gadolinium enhancement on CMR**

Bing R. et al. J Am Coll Cardiol Img 2019;12 (2): 283-96 Doris MK et al. J Am Coll Cardiol Img 2019;12:185–97

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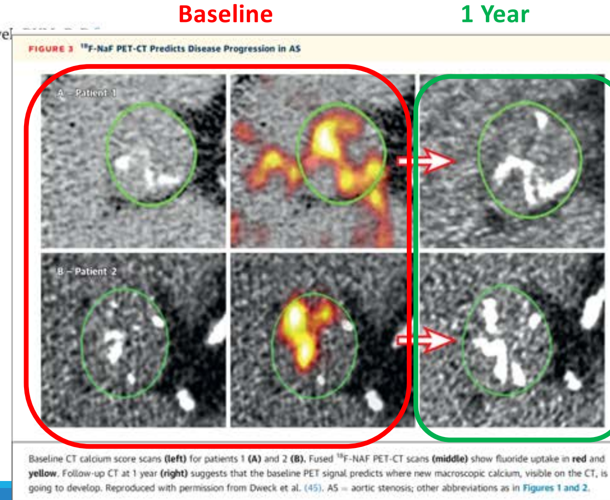
STATE-OF-THE-ART PAPER

The Role of Imaging in Measuring Disease Progression and Assessing Novel Therapies in Aortic Stenosis

Mhairi K. Doris, MD,[a] Russell J. Everett, MD,[a] Matthew Shun-Shin, MD,[b] Marie-Annick Clavel
Marc R. Dweck, MD, PhD[a]

Radioactive Sodium Flouride PET

Baseline 1 Year



- PET uptake is a marker of disease activity and very early calcium formation
- PET may detect early therapeutic effects in AS at a stage in the process when calcium is more likely to be reversible

Doris MK et al. J Am Coll Cardiol Img 2019;12:185–97

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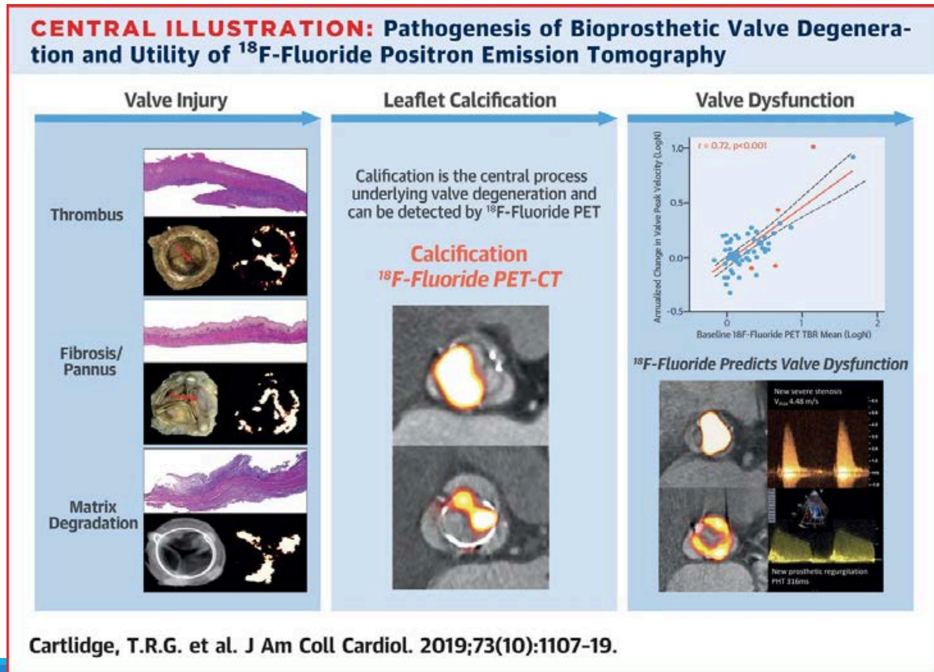

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APPROPRIATE USE CRITERIA

ACC/AATS/AHA/ASE/ASNC/HRS/SCAI/SCCT/SCMR/STS 2017 Appropriate Use Criteria for Multimodality Imaging in Valvular Heart Disease

A Report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Thoracic Surgeons

Writing Group Members: John U. Doherty, MD, FACC, FAHA, Chair,[*] Smadar Kort, MD, FACC, FASE, FAHA,[†] Roxana Mehran, MD, FACC, MSCAI, FAHA,[‡] Paul Schoenhagen, MD, FAHA,[§] Prem Soman, MD, PhD, FACC[‖]

5.1. Initial Evaluation for VHD

TABLE 1 Initial Evaluation of an Asymptomatic Patient

Indication		TTE	TEE (With Possible 3D)	3D TTE	CMR	CCT
1.	■ Unexplained murmur or abnormal heart sounds	A (9)	R (2)	R (3)	R (2)	R (1)
2.	■ Reasonable suspicion of VHD	A (9)	R (2)	M (4)	R (1)	R (1)
3.	■ History of rheumatic heart disease	A (9)	R (3)	M (4)	R (1)	R (1)
4.	■ Known systemic or acquired disease associated with VHD	A (9)	R (3)	R (3)	R (3)	R (2)
5.	■ First-degree family history of a bicuspid aortic valve	A (8)	R (1)	R (1)	R (1)	R (1)
6.	■ Exposure to medications that could result in development of VHD	A (7)	R (1)	R (1)	R (1)	R (1)

3D = 3-dimensional; A = appropriate; CCT = cardiac computed tomography; CMR = cardiovascular magnetic resonance imaging; M = may be appropriate; R = rarely appropriate; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography; VHD = valvular heart disease.

TABLE 2 Initial Evaluation of a Patient with Clinical Signs and/or Symptoms

Indication		TTE	TEE (With Possible 3D)	3D TTE	Ex.-SE	DSE	RVG	FDG-PET	MPI (SPECT/PET)	CMR	CCT
Arrhythmias											
7.	■ Palpitations AND ■ No other symptoms or signs of cardiovascular disease	M (4)	R (1)	R (1)	R (1)	R (1)	R (1)		R (1)	R (1)	R (1)
Presyncope/Syncope											
8.	■ Presyncope AND ■ No other symptoms or signs of cardiovascular disease	M (6)	R (1)	R (1)	R (1)	R (1)	R (1)		R (1)	R (1)	R (1)
9.	■ Syncope AND ■ No other symptoms or signs of cardiovascular disease	A (8)	R (3)	R (1)	M (4)	R (1)	R (1)		R (2)	R (3)	R (1)
Hypotension or Hemodynamic Instability											
10.	■ Hypotension or hemodynamic instability AND ■ Uncertain or suspected cardiac etiology	A (9)	R (3)	R (1)	R (1)	R (1)	R (1)		R (1)	R (1)	R (1)
11.	■ Assessment of volume status in a critically ill patient	M (6)	R (2)	R (1)	R (1)	R (1)	R (1)		R (1)	R (1)	R (1)
12.	■ Suspected acute mitral or aortic regurgitation	A (9)	M (6)	R (3)	R (1)	R (1)	R (1)		R (1)	R (1)	R (2)
Respiratory Failure											
13.	■ Respiratory failure or hypoxemia of uncertain etiology	A (8)	M (4)	R (2)	R (1)	R (1)	R (1)		R (1)	R (1)	M (5)
14.	■ Respiratory failure or hypoxemia AND ■ Noncardiac etiology of respiratory failure has been established	M (4)	R (1)	R (1)	R (1)	R (1)	R (1)		R (1)	R (1)	R (1)

Doherty J.U. et al. J Am Soc Echocardiogr 2018;31:381-404

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5.3. Transcatheter Intervention for VHD

TABLE 7A Pre-TAVR Evaluation

Indication	TTE	TEE (With Possible 3D)	3D TTE	Ex.-SE	DSE	Low-Dose DSE	RVG	MPI (SPECT/PET)	CMR	CCT	ANG	Fluoro
72. ■ Assessment for concomitant coronary artery disease	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	M (4)	R (1)	M (5)	A (9)	R (1)
73. ■ Accurate assessment of annular size and shape*	R (3)	A (7)	M (4)	R (1)	R (1)	R (1)	R (1)	R (1)	A (7)	A (9)	R (1)	R (1)
74. ■ Assessment of number of cusps and degree of calcification	A (7)	A (7)	M (6)	R (1)	R (1)	R (1)	R (1)	R (1)	M (4)	A (9)	R (1)	R (1)
75. ■ Measurement of the distance between annulus and the coronary ostia	R (1)	M (6)	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	M (5)	A (9)	M (4)	R (1)
76. ■ Precise coaxial alignment of the implant within the centerline of the aortic valve	R (1)	R (3)	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	R (2)	A (8)	R (1)	R (1)
77. ■ Assessment of aortic dimensions	R (1)	M (4)	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	A (7)	A (9)	R (2)	R (1)
78. ■ Assessment of aortic atherosclerotic burden	R (1)	M (5)	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	M (4)	A (9)	M (4)	R (1)
79. ■ Assessment of iliofemoral vessels	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	R (1)	M (5)	A (9)	M (5)	R (1)

*Multimodality imaging might improve the accuracy of the measurements (1).

3D = 3-dimensional; A = appropriate; ANG = invasive coronary angiography/ventriculography/aortography; CCT = cardiac computed tomography; CMR = cardiovascular magnetic resonance imaging; DSE = dobutamine stress echocardiography; Ex.-SE = exercise stress echocardiography; Fluoro = fluoroscopy; M = may be appropriate; MPI = myocardial perfusion imaging; PET = positron emission tomography; R = rarely appropriate; RVG = radionuclide ventriculography; SPECT = single photon emission computed tomography; TAVR = transcatheter aortic valve replacement; TEE = transesophageal echocardiography; and TTE = transthoracic echocardiography.

Doherty J.U. et al. J Am Soc Echocardiogr 2018;31:381-404

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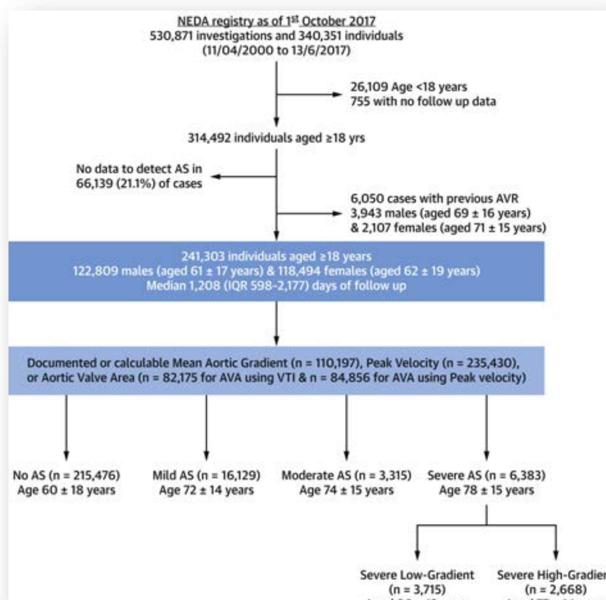
VOL. 74, NO. 15, 2019

ORIGINAL INVESTIGATIONS

Poor Long-Term Survival in Patients With Moderate Aortic Stenosis

Geoff Strange, PhD,[a] Simon Stewart, PhD,[b] David Celermajer, MD, PhD,[c] David Prior, MBBS, PhD,[d] Gregory M. Scalia, MBBS (Hons), MMedSc,[e] Thomas Marwick, MBBS, PhD,[f] Marcus Ilton, MD,[g] Majo Joseph, MBBS,[h] Jim Codde, PhD,[i] David Playford, MBBS, PhD,[a] on behalf of the National Echocardiography Database of Australia contributing sites

National Echocardiographic Database of Australia (NEDA), with the capacity to individually link echocardiographic findings with long-term mortality, in a large, unselected patient group



Strange G et al J Am Coll Cardio. 2019;74(15)1851-63cc

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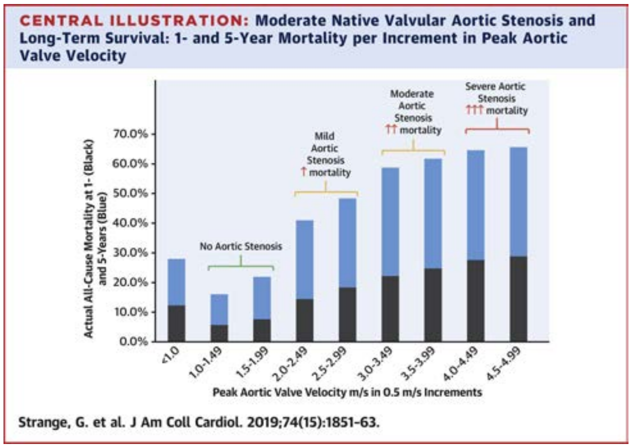
Moderate Aortic Stenosis



- In this large analysis of survival across the full spectrum of native valve AS severity, we found high rates of mortality associated with both moderate and severe AS during long-term follow-up
- Individuals presenting with a mean AV gradient >20.0 mm Hg or peak AV velocity >3.0 m/s (or DVI 0.25-0.3) had a high risk of dying in the longer term that was similar to the risk in patients presenting with severe AS at baseline.

Strange G et al J Am Coll Cardio. 2019;74(15)1851-63cc

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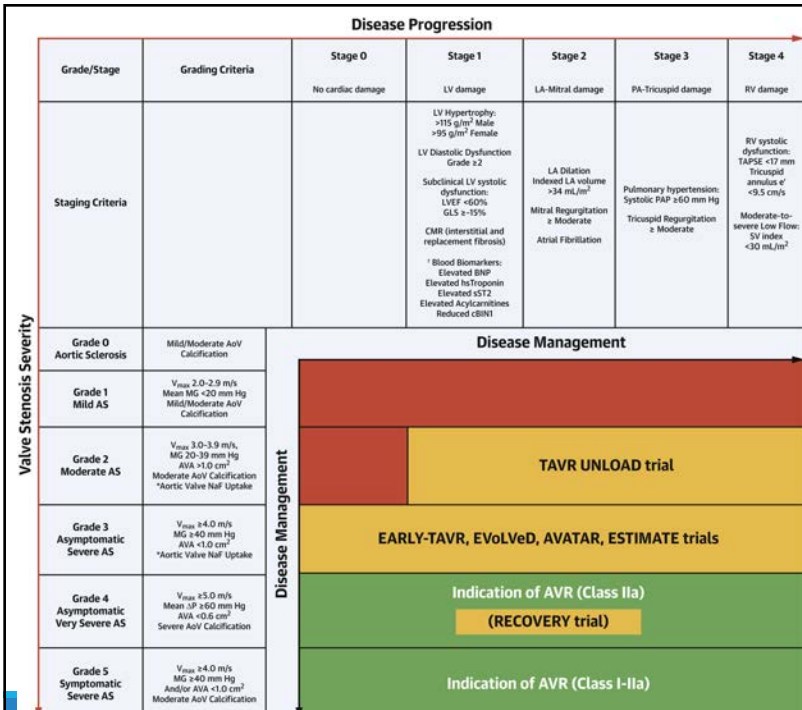

Algorithm for Treatment of AS

Red indicates conservative (follow-up) management.
Yellow indicates no evidence yet for intervention, but ongoing trials will be instructive.
Green represents current guideline-based indications for intervention in AS

Vannan M et al. J Am Coll Cardiol 2019;74(15);1864-67

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Comprehensive Echocardiographic Assessment of Normal Transcatheter Valve Function

Rebecca T. Hahn, MD,[a] Jonathon Leipsic, MD,[b] Pamela S. Douglas, MD,[c] Wael A. Jaber, MD,[d] Neil J. Weissman, MD,[e] Philippe Pibarot, DVM, PhD,[f] Philipp Blanke, MD,[b] Jae K. Oh, MD[g]

ABSTRACT

OBJECTIVES This study aims to establish parameters for identifying normal function for each of the 3 iterations of balloon-expandable valves and 2 iterations of self-expanding valves.

COMPETENCY IN PATIENT CARE AND PROCEDURAL SKILLS:

1. Tables of **normal reference values** for mean gradients and EOA for valve type and size provide actual hemodynamic data that may be useful for assessing initial and longitudinal THV function.
2. Because transcatheter valve expansion is dependent on native aortic annular anatomy, tables listing the expected EOA for each valve type are also reported by the native annular area or perimeter.

Hahn et al. JACC Cardiovasc Imaging 2018. DOI: 10.1016/j.jcmg.2018.04.010

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TABLE 2 Mean Gradient and EOA for Balloon-Expandable SAPIEN Valves

	Prosthetic Valve Size, mm					
Valve Iteration	20	23	26	29	All Sizes	p Value
SAPIEN						
EOA, cm^2	NA	1.56 ± 0.43 (1,212)	1.84 ± 0.52 (1,130)	NA	1.70 ± 0.49 (2,342)	<0.001
Mean gradient, mm Hg	NA	9.92 ± 4.27 (1,212)	8.76 ± 3.89 (1,130)	NA	9.36 ± 4.13 (2,342)	<0.001
DVI	NA	0.53 ± 0.13 (1,212)	0.53 ± 0.13 (1,130)	NA	0.53 ± 0.13 (2,342)	0.64
SAPIEN XT						
EOA, cm^2	NA	1.41 ± 0.30 (545)	1.74 ± 0.42 (675)	2.06 ± 0.52 (251)	1.67 ± 0.46 (1471)	<0.001
Mean gradient, mm Hg	NA	10.41 ± 3.74 (545)	9.24 ± 3.57 (675)	8.36 ± 3.14 (251)	9.52 ± 3.64 (1,471)	<0.001
DVI	NA	0.52 ± 0.10 (545)	0.54 ± 0.11 (675)	0.53 ± 0.11 (251)	0.53 ± 0.11 (1,471)	0.004
SAPIEN 3						
EOA, cm^2	1.22 ± 0.22 (47)	1.45 ± 0.26 (471)	1.74 ± 0.35 (626)	1.89 ± 0.37 (326)	1.66 ± 0.38 (1,470)	<0.001
Mean gradient, mm Hg	16.23 ± 5.01 (47)	12.79 ± 4.65 (471)	10.59 ± 3.88 (626)	9.28 ± 3.16 (326)	11.18 ± 4.35 (1,470)	<0.001
DVI	0.42 ± 0.07 (47)	0.43 ± 0.08 (471)	0.43 ± 0.09 (626)	0.40 ± 0.09 (326)	0.43 ± 0.09 (1,470)	<0.001

Values are mean ± SD (n). This table shows the mean gradients and EOA for each balloon-expandable valve iteration by valve size implanted. All mean valve areas and EOAs were significantly different for each valve size for a given valve type (range $p < 0.03$ to $p < 0.0001$).

DVI = Doppler velocity index; EOA = effective orifice area; NA = not available.

TABLE 3 Normal Reference Values for the SAPIEN 3 Valve by Pre-Procedural Native Annular Area by Quintiles of 3D Annular Areas for the Enrolled Patients

	248 to 384 mm^2 (n = 189)	385 to 439 mm^2 (n = 191)	440 to 488 mm^2 (n = 192)	489 to 537 mm^2 (n = 191)	538 to 678 mm^2 (n = 188)	p Values for Trend
EOA, cm^2	1.41 ± 0.27	1.58 ± 0.33	1.73 ± 0.36	1.79 ± 0.35	1.91 ± 0.42	<0.0001
EOAi, cm^2/m^2	0.80 ± 0.16	0.86 ± 0.19	0.92 ± 0.21	0.90 ± 0.20	0.93 ± 0.21	<0.0001
Mean gradient, mm Hg	13.96 ± 5.28	11.94 ± 4.82	10.93 ± 5.04	10.56 ± 4.16	9.17 ± 3.35	<0.0001
DVI	0.43 ± 0.1	0.44 ± 0.1	0.42 ± 0.09	0.43 ± 0.09	0.42 ± 0.09	0.13

3D = 3-dimensional; EOAi = effective orifice area indexed to body surface area; other abbreviations as in Table 1.

1. Use the normal EOA, mean gradient and DVI tables to assess initial and longitudinal THV function.
2. Use the EOA, mean gradient and DVI by native annular measurement to get a pre-procedural estimate of hemodynamic function

Avoidance of Prosthesis-patient mismatch

Hahn et al. JACC Cardiovasc Imaging 2018.
DOI: 10.1016/j.jcmg.2018.04.010

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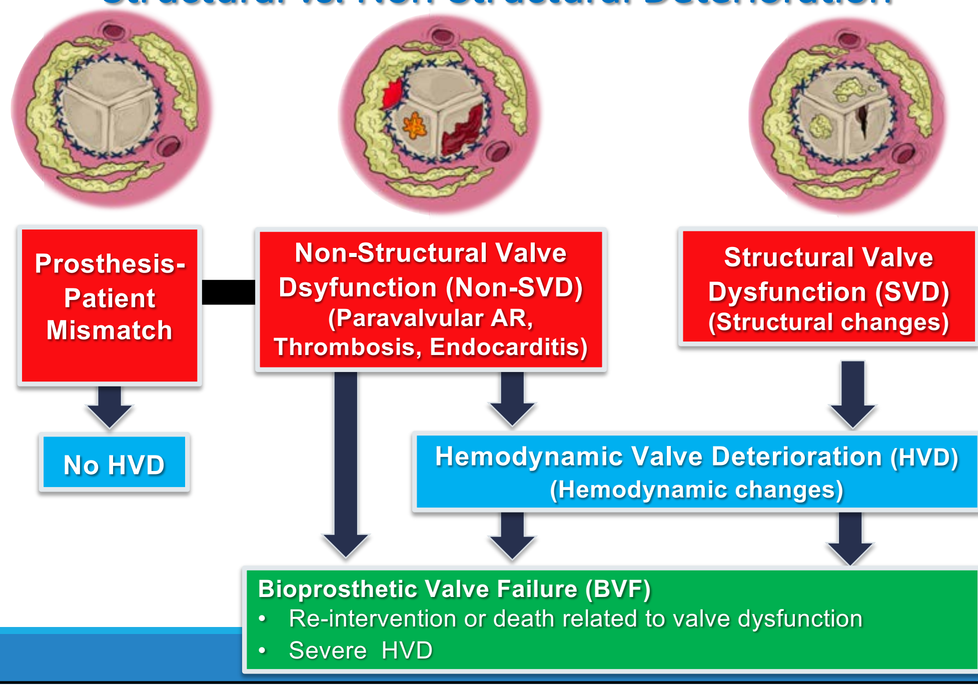
Structural vs. Non-Structural Deterioration



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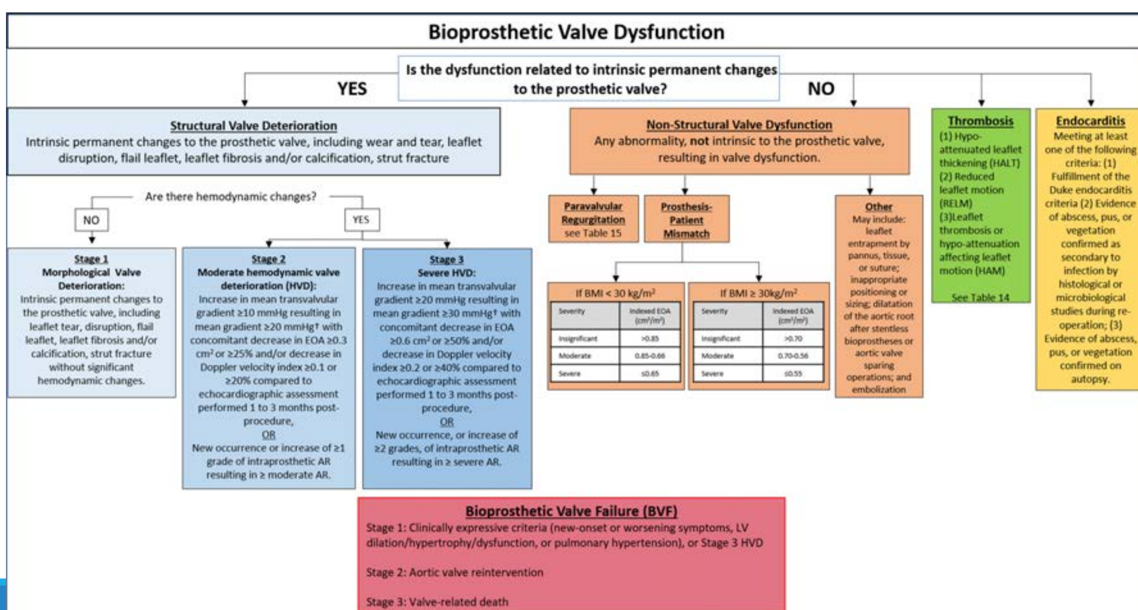
VARC 3 Proposed Definitions



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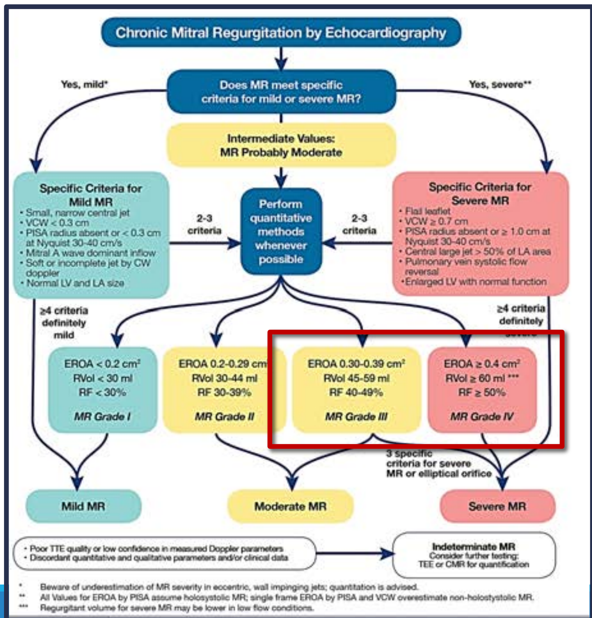
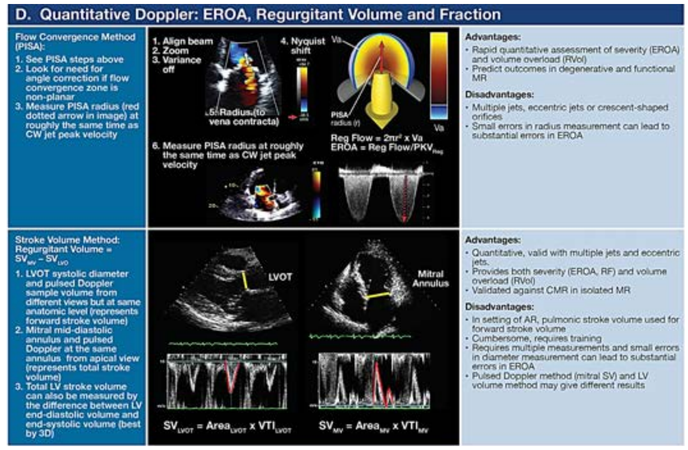
Grading of Mitral Regurgitation





Zoghbi WA et al. J Am Soc Echocardiogr 2017; 30: 303-371.

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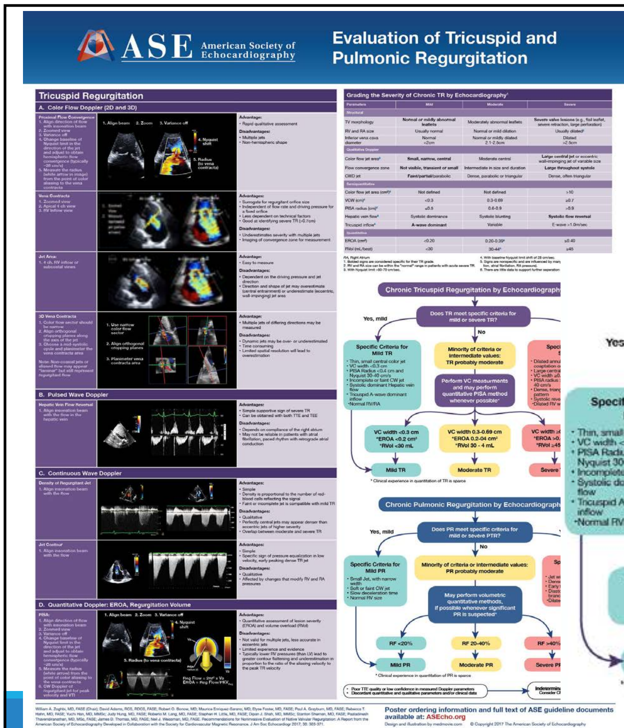
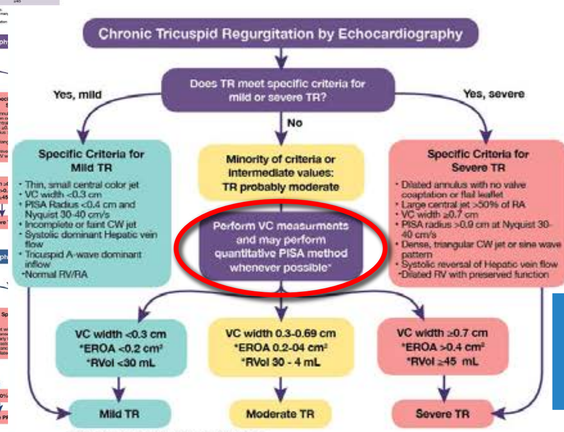


Zoghbi et al J Am Soc Echocardiogr April 2017
http://dx.doi.org/10.1016/j.echo.2017.01.007



Major Issue: Reliance on PISA

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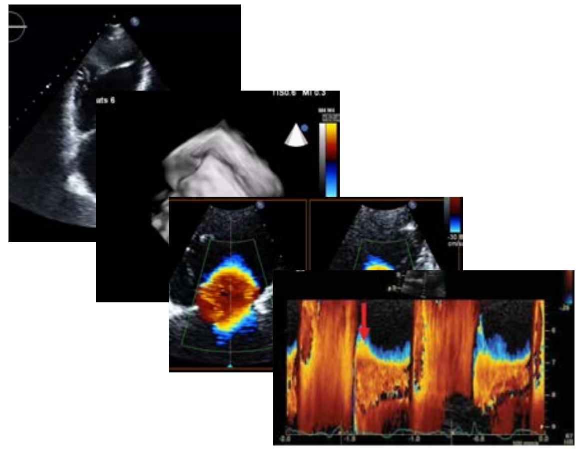
Current guidelines – PISA (EROA and regurgitant volume)

Typical assumptions are not accurate for Tricuspid Valve

- Assumes flat "surface" or leaflets
  - *Leaflets are usually tethered*
- Assumes circular orifice
  - *Orifice usually crescent shaped*
- Assumes a hemispheric proximal flow convergence
  - *PISA is usually hemi-elliptical*
- Measures single time point
  - *TR is frequently dynamic*



Hahn RT et al. J Am Coll Cardiol Img 2019;12:469–90

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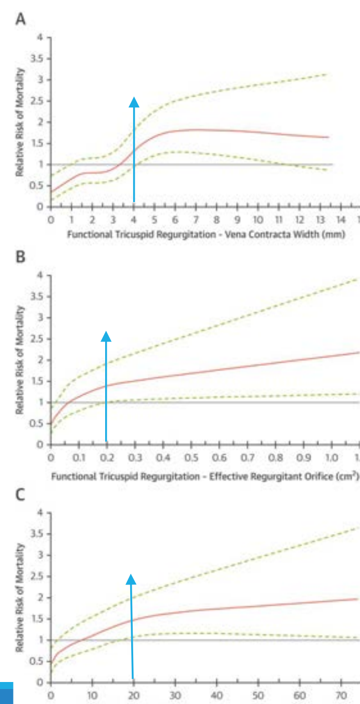
PISA TR severity and Outcomes in HFrEF

- 382 patients with HFrEF
- Quantitative metrics of TR severity were consistently associated with mortality with a hazard ratio of 1.009 (95% confidence interval: **1.004 to 1.013; $p < 0.001$) per 0.01 cm^2 increase of the EROA and of 1.013 (95% confidence interval: 1.007 to 1.020; $p < 0.001$) per 1-ml increase in regurgitant volume.**
- A spline curve pattern illustrates the association with mortality with thresholds for the **EROA ≥0.2 cm^2, and the regurgitant volume ≥20 ml with sustained excess mortality thereafter.**
  - EROA and RegVol by the proximal isovelocity surface area (PISA) method



Note the sustained increase in mortality associated with a larger EROA and RegVol but not VCW

Philipp E. Bartko et al. JIMG 2019;j.jcmg.2018.11.

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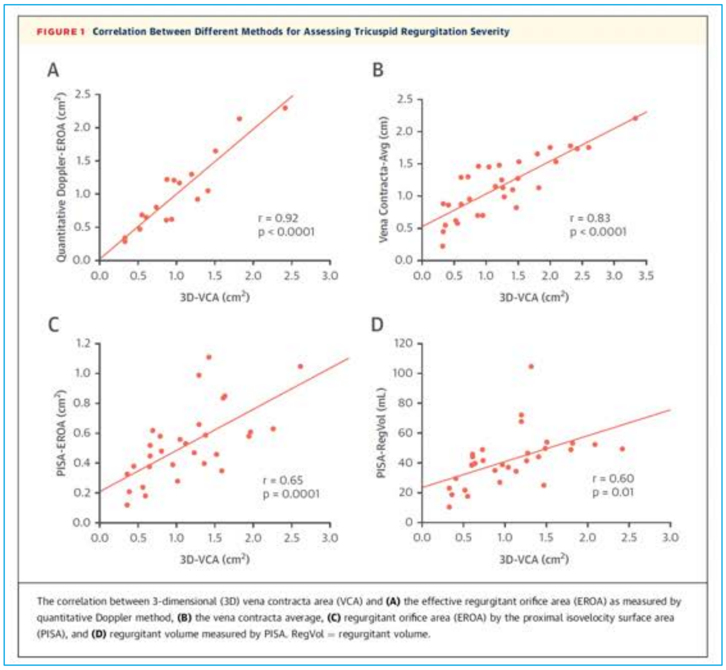

The correlation between 3-dimensional (3D) vena contracta area (VCA) and **(A)** the effective regurgitant orifice area (EROA) as measured by quantitative Doppler method, **(B)** the vena contracta average, **(C)** regurgitant orifice area (EROA) by the proximal isovelocity surface area (PISA), and **(D)** regurgitant volume measured by PISA. RegVol = regurgitant volume.

160 cases

The PISA method showed better correlation with the 3D-VCA method in less elliptical regurgitant orifices (VCmax/VCmin < 1.6)

- PISA-EROA and 3D VCA ($r = 0.87$; $p = 0.001$
- PISA-RegVol and 3D-RegVol ($r = 0.75$; $p = 0.01$)

PISA-EROA and PISA-RegVol were significantly lower than quantitative Doppler and 3D methods.

Using Youden's index, the best cutoff value for severe TR

- **PISA-EROA was ≥0.34 cm2 (sensitivity: 89%; specificity: 90%)**
- **3D-VCA, this cutoff was ≥0.60 cm2 (sensitivity: 92%; specificity: 75%)**
- **Doppler-EROA cutoff was ≥ 0.65 cm2 (sensitivity: 82%; specificity 94%),**
- **VC_{avg} cutoff was ≥9 mm (sensitivity: 85%; specificity: 97%).**

Dahou A. ….Hahn RT. Quantifying Tricuspid Regurgitation Severity. DOI: 10.1016/j.jcmg.2018.11.015

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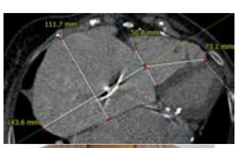
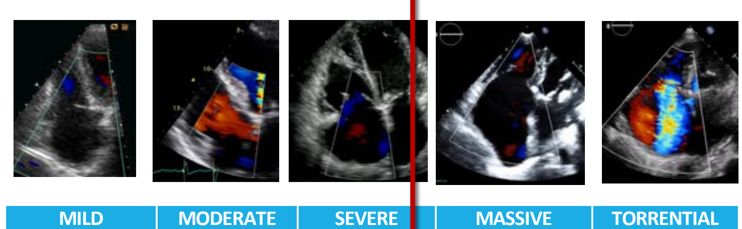
Extended Grading Scheme

Table 1 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 mm²	20–39 mm²	40–59 mm	60–79 mm²	≥80 mm²
3D VCA or quantitative EROA[a]			75–94 mm	95–114 mm²	≥115 mm²

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.





RT Hahn and JL Zamorano. European Heart (2017) 00, 1–2. doi:10.1093/ehjci/jex139

Range of TR Severity with signs and symptoms of "right heart failure"

66

ESC European Society of Cardiology
European Heart Journal - Cardiovascular Imaging (2019) 0, 1–8
doi:10.1093/ehjci/jez024

Mid-term outcome of severe tricuspid regurgitation: are there any differences according to mechanism and severity?

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Santoro C et al. European Heart Journal - Cardiovascular Imaging (2019) 0, 1–8

Outcomes according to new grading scheme for TR severity assessment.

(A) Kaplan–Meier survival curves for cardiovascular mortality (P< 0.007 for log-rank)
(B) Kaplan–Meier survival curves for the combined endpoint for cardiovascular mortality and re-hospitalization (P<0.012 for log rank)

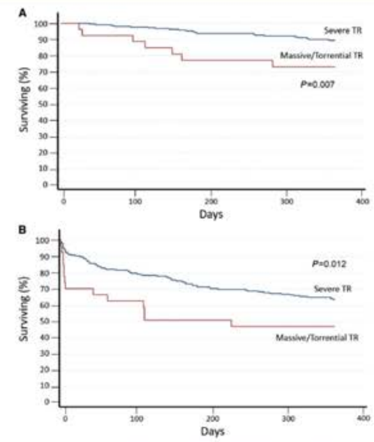

Figure 2 A 1-year follow-up survival curve according to the new classification scheme for TR severity. (A) Kaplan–Meier survival curves for cardio-vascular mortality ($P < 0.007$ for log-rank) and (B) of the combined endpoint for cardiovascular mortality and re-hospitalization ($P < 0.012$ for log rank) according to new grading scheme for TR severity assessment.

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Quantitative assessment of effective regurgitant orifice: impact on risk stratification, and cut-off for severe and torrential tricuspid regurgitation grade

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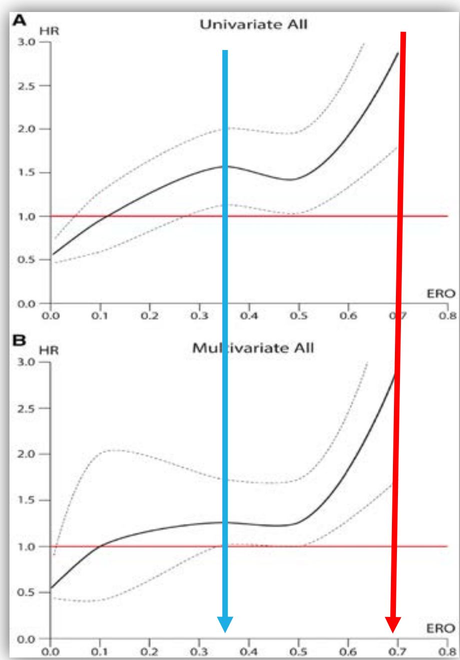
European Heart Journal - Cardiovascular Imaging (2019)

- The optimal cut-off value to separation survival between severe vs. lesser degree of TR was 0.35 cm^2 [$P < 0.0001$, HR =2.0 (1.5–2.7)].
- The optimal threshold to separation survival between severe vs. 'torrential' [**massive in the Hahn/Zamorano grading scheme**] TR was 0.7 cm^2 [$P = 0.005$, HR =2.6 (1.2–5.1)].



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Imaging Assessment of Tricuspid Regurgitation Severity

Rebecca T. Hahn, MD,[a] James D. Thomas, MD,[b] Omar K. Khalique, MD,[a] João L. Cavalcante, MD,[c] Fabien Praz, MD,[a,d] William A. Zoghbi, MD[e]

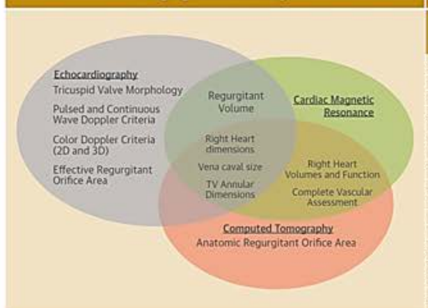
SUMMARY

Assessing the severity of tricuspid regurgitation remains a challenging task, and
choice, significant limitations of the current recommendations exist. Newer met
transcatheter devices and may improve our understanding of the disease process.
computed tomography angiography may play significant roles as adjunctive ima
imaging modalities currently used to quantify tricuspid regurgitation severity. (

Hahn RT et al. J Am Coll Cardiol Img 2019;12:469–90

CENTRAL ILLUSTRATION Multimodality Imaging for the Assessment of Tricuspid Regurgitation

Multi-modality Imaging for Assessment of Tricuspid Regurgitation Severity



Relative Utility of Each Imaging Modality

Parameters	Echocardiography (TTE or TEE) 2D/Doppler	Echocardiography (TTE or TEE) 3D/Color	Cardiac Magnetic Resonance	Computed Tomography Angiography
Structural Parameters				
TV Morphology	+++	+++	++	++
RV and RA size	++	+++	+++	+++
SVC and IVC Size	+++ (proximal cavae only)	+++	+++	+++
Comprehensive vascular assessment	-	-	+++	+++
Semi-Quantitative parameters				
Jet Area	+++	+++	++	-
Vena Contracta Width	+++	+++	++	-
Vena Contracta Area	-	+++	++	-
Anatomic Orifice Area	-	+	++	+++
Quantitative Parameters				
Effective Regurgitant Orifice Area	++ (PISA and Doppler SV)	- (see VCA)	-	-
Regurgitant Volume	++ (PISA and Doppler SV)	++ (from VCA)	++	-

Hahn, R.T. et al. J Am Coll Cardiol Img. 2019;12(3):469-90.

Although echocardiography remains the diagnostic modality of choice for the initial evaluation of the right heart and tricuspid valve, the Venn diagram illustrates the utility and complementary nature of the imaging modalities for certain parameters important in the assessment of tricuspid regurgitation severity. The table shows the relative strengths of each modality for the evaluation of specific parameters. IVC = inferior vena cava; PISA = proximal isovelocity surface area; RA = right atrium; RV = right ventricle; SV = stroke volume; SVC = superior vena cava; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography; TV = tricuspid valve; VCA = vena contracta area.

Multi-modality Imaging may be helpful!

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Advanced Imaging Modalities

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Semi-automatic quantification of 4D left ventricular blood flow

***Direct Flow*: Blood that enters the LV during diastole and leaves the LV during systole in the analyzed heart beat**

***Retained Inflow*: Blood that enters the LV during diastole but does not leave during systole in the analyzed heart beat**

***Delayed Ejection Flow*: Blood that starts and resides inside the LV during diastole and leaves during systole**

***Residual Volume*: Blood that resides within the LV for at least two cardiac cycles**

*Eriksson J , Carlhall CJ et al. Journal of Cardiovascular Magnetic Resonance*2010**12**:9

Left heart intra cardiac blood flow in a healthy 61 year old male, all four components visualized with pathlines and a semi-transparent 3-chamber image to provide morphological orientation. The pathlines are color coded

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Velocity Flow Mapping

NORMAL

DILATED CARDIOMYOPATHY

Color Doppler velocity data and generates the velocity fields on the 2D image.

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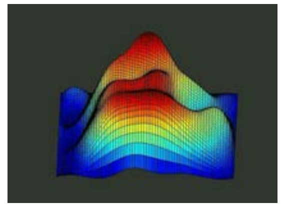
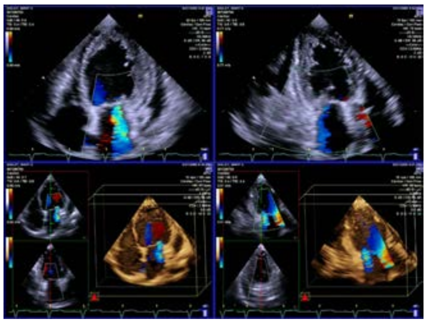
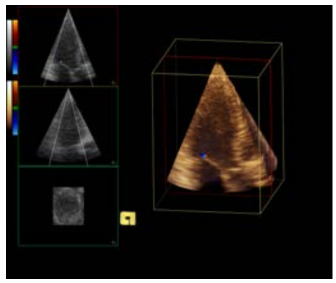


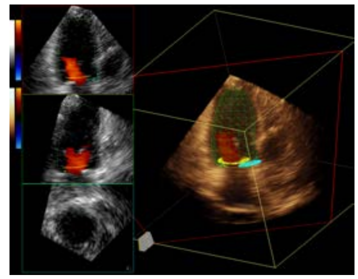
3-D PISA model

Quantification of Chronic Functional Mitral Regurgitation by Automated 3-Dimensional Peak and Integrated Proximal Isovelocity Surface Area and Stroke Volume Techniques Using Real-Time 3-Dimensional Volume Color Doppler Echocardiography : In Vitro and Clinical Validation

Paaladinesh Thavendiranathan, Shizhen Liu, Saurabh Datta, Sanjay Rajagopalan, Thomas Ryan, Stephen R. Igo, Matthew S. Jackson, Stephen H. Little, Nathalie De Michelis and Mani A. Vannan







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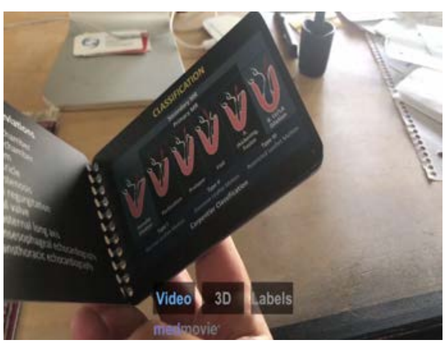
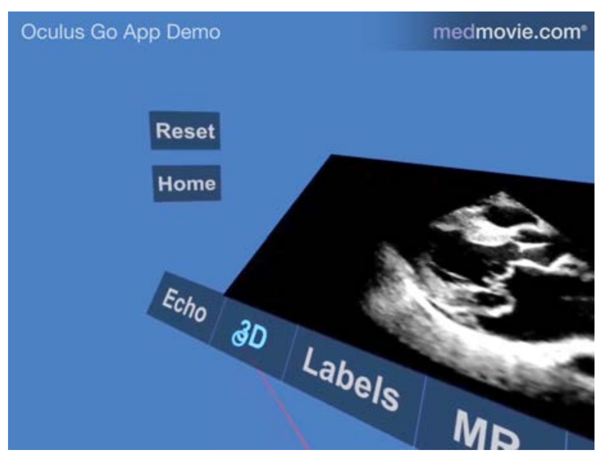
Medmovie Augmented Reality/Virtual Reality





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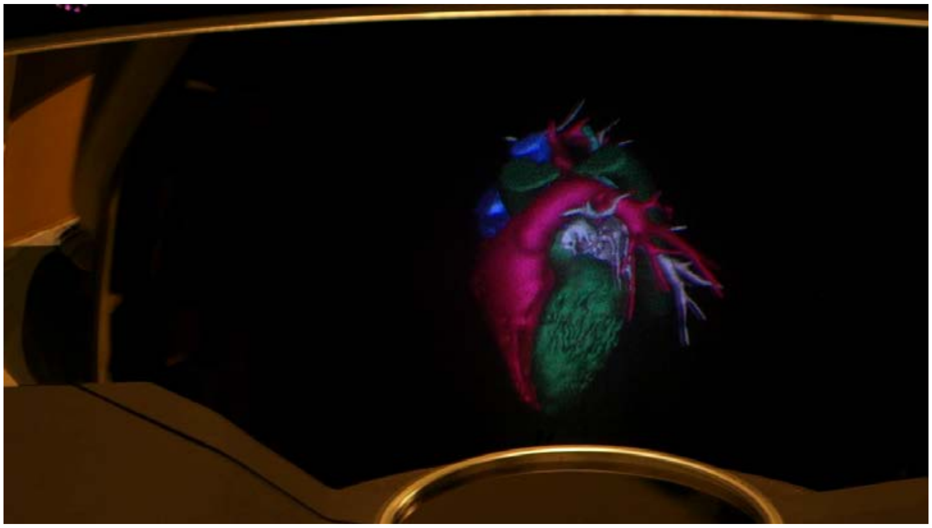
Medical Holography for Electrophysiology (LA)



Datasets Courtesy of St. Jude Medical

realView medical holography

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Valvular heart disease: A decade of progress

What will the next decade bring??

@hahn_rt

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