

Unlocking the Secrets of Valvular Heart Disease: A Journey through the World of Imaging Modalities

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Abstract:

Valvular heart disease is a prevalent and clinically significant condition with potential complications and adverse outcomes if left untreated or poorly managed. Accurate assessment of valve structure, function and hemodynamics is crucial for effective evaluation and management of valvular heart disease. In this systematic review, we provide a comprehensive overview and comparison of imaging modalities used in the assessment of valvular heart disease.

The introduction highlights the background and significance of valvular heart disease, emphasizing its impact on cardiovascular health, global prevalence, and associated complications. Furthermore, it emphasizes the importance of imaging modalities in the evaluation and management of valvular heart disease, discussing their role in providing crucial information for accurate diagnosis, risk stratification, treatment planning, and monitoring.

The objective of this review article is to summarize the strengths, limitations and diagnostic accuracy of different imaging modalities in valvular heart disease assessment. We present detailed discussions on echocardiography, computed tomography (CT) imaging, nuclear imaging techniques and emerging imaging modalities, such as 3D echocardiography, strain imaging and fusion imaging. Each section explores the specific

role of the imaging modality, its advantages, limitations and diagnostic accuracy in the evaluation of valvular heart disease.

Additionally, we provide a comparative analysis of these imaging modalities, highlighting their strengths, weaknesses and specific indications. The integration of multiple imaging modalities for a comprehensive evaluation in specific scenarios is also discussed, emphasizing the complementary roles of different modalities in optimizing diagnostic accuracy and treatment planning.

The review concludes with implications for clinical practice and future research directions. It underscores the importance of selecting the appropriate imaging modality or combination of modalities based on individual patient characteristics and clinical needs. Furthermore, it highlights the potential clinical impact of emerging imaging techniques and the need for standardization, cost-effectiveness studies, and further research to optimize the utilization of imaging modalities in valvular heart disease management.

Key Words: valvular heart disease, imaging modalities, echocardiography, computed tomography, nuclear imaging, comparative analysis, diagnostic accuracy, treatment planning, emerging techniques, clinical practice

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Introduction:

A. Background and significance of valvular heart disease

Valvular heart disease refers to conditions affecting the heart valves, which play a crucial role in ensuring proper blood flow within the heart. The most common types of valvular heart disease include aortic stenosis, mitral regurgitation, mitral stenosis and tricuspid regurgitation. These conditions can significantly impact cardiovascular health and overall well-being.

Valvular heart disease has a considerable prevalence and incidence worldwide. It affects millions of individuals, both young and old, contributing to substantial morbidity and mortality. The increasing prevalence can be attributed to various factors such as an aging population, advances in diagnostic techniques and improved survival rates of patients with other cardiac conditions.

If left untreated or poorly managed, valvular heart disease can lead to severe complications and adverse outcomes. These may include heart failure, arrhythmias, infective endocarditis, thromboembolic events and ultimately, a reduced quality of life and increased mortality rates. Therefore, early detection, accurate diagnosis and appropriate management of valvular heart disease are crucial to improving patient outcomes.

B. Importance of imaging modalities in the evaluation and management of valvular heart disease

Imaging modalities play a fundamental role in the evaluation and management of valvular heart disease. They provide valuable information that aids in the accurate diagnosis, characterization and quantification of valvular abnormalities. By visualizing the valve structure, function and hemodynamics, imaging techniques offer critical insights for clinical decision-making.

Imaging modalities, such as echocardiography, allow for non-invasive assessment of the heart valves. They provide real-time images of the heart's structure and function, facilitating the identification of valve pathology, measuring regurgitant or stenotic severity and assessing ventricular function. Echocardiography, both transthoracic and transesophageal, is often the initial imaging modality of choice for evaluating valvular heart disease due to its wide availability, cost-effectiveness and high diagnostic accuracy.

Other imaging techniques, including cardiac magnetic resonance imaging (CMR), computed tomography (CT) and nuclear imaging, offer complementary information in the evaluation of valvular heart disease. CMR provides detailed anatomical and functional assessment,

particularly in complex valve lesions and associated myocardial pathology. CT imaging is valuable for evaluating valve calcification, assessing prosthetic valves and providing high-resolution images for pre-procedural planning. Nuclear imaging techniques offer insights into valve function, myocardial viability and infection assessment in valvular heart disease.

Imaging modalities also play a vital role in risk stratification, treatment planning and monitoring of valvular heart disease. They help clinicians determine the appropriate timing and type of intervention, whether it be surgical or transcatheter, by providing accurate measurements and functional data. Imaging techniques aid in procedural guidance and follow-up assessment, allowing for the monitoring of treatment outcomes and potential complications.

The purpose of this review article is to provide a comprehensive overview and comparison of the various imaging modalities used in the assessment of valvular heart disease. By systematically reviewing the existing literature, this article aims to summarize the strengths, limitations and diagnostic accuracy of each imaging technique. The review will explore the specific roles and applications of echocardiography, CMR, CT and nuclear imaging in valvular heart disease evaluation.

Understanding the nuances and differences among these imaging modalities is crucial for healthcare professionals involved in the diagnosis, management and treatment of valvular heart disease. By examining the evidence and comparative studies, this review article will offer insights into the practical implications and potential clinical impact of utilizing different imaging techniques. Ultimately, it seeks to enhance the knowledge and decision-making abilities of clinicians, leading to improved patient care and outcomes in valvular heart disease ¹⁻⁴.

II. Echocardiography ¹⁻⁷

A. Overview of transthoracic echocardiography

- Trans thoracic echocardiography (TTE) is a widely used imaging modality in the evaluation of valvular heart disease.
- It utilizes ultrasound waves to produce real-time images of the heart, providing information about valve structure, function and hemodynamics.
- TTE is non-invasive, readily available and generally well-tolerated by patients.
- It allows for the assessment of valve morphology, regurgitation, stenosis and the overall function of the heart chambers.

- Doppler echocardiography, a component of TTE enables the quantification of blood flow velocities and pressure gradients across the valves.

B. Transesophageal echocardiography and its role in valvular heart disease assessment

- Transesophageal echocardiography (TEE) is a specialized technique that provides higher-resolution images by positioning an ultrasound probe in the esophagus.
- TEE allows for a closer and more detailed examination of the heart valves compared to TTE.
- It is particularly useful for evaluating valvular anatomy, assessing prosthetic valves, detecting small vegetations in infective endocarditis and guiding interventions.
- TEE provides better visualization of the posterior structures of the heart, such as the mitral valve and left atrium, which can be challenging to assess using TTE.

C. Advantages, limitations, and diagnostic accuracy of echocardiography in valvular heart disease

Advantages:

- Echocardiography is non-invasive, safe and widely available, allowing for routine screening and follow-up of valvular heart disease patients.
- It provides real-time imaging, allowing for dynamic assessment of valve function and hemodynamics.
- Echocardiography offers the ability to assess multiple valves and associated cardiac structures in a comprehensive manner.
- Doppler echocardiography allows for the quantification of valve regurgitation severity, stenotic gradients and cardiac output.

Limitations:

- Echocardiography is highly operator-dependent and the quality of imaging can vary based on the expertise of the sonographer.
- It may have limited visualization in patients with poor acoustic windows due to obesity, lung disease or chest wall deformities.
- Certain valve regions, such as the aortic valve cusps or the tricuspid valve, may be challenging to visualize adequately.
- Calcification or prosthetic materials may produce artifacts that can affect image quality and interpretation.

Diagnostic accuracy:

- Echocardiography has demonstrated high diagnostic accuracy in the assessment of valvular heart disease.
- It allows for the identification and characterization of valve abnormalities, including valve thickening, calcification, leaflet prolapse and restricted motion.
- Doppler echocardiography provides accurate measurements of regurgitant volumes, regurgitant fraction, valve areas and pressure gradients.
- Echocardiography is particularly valuable in monitoring disease progression, assessing response to treatment and guiding clinical decision-making.

III. Computed Tomography (CT) Imaging¹⁻⁵

A. Role of CT in valvular heart disease evaluation

- Computed Tomography (CT) imaging has an increasingly important role in the evaluation of valvular heart disease.
- CT provides detailed anatomical information and allows for the assessment of valve morphology, calcification and associated cardiac structures.
- It offers excellent spatial resolution and enables visualization of the entire heart in a single acquisition, facilitating comprehensive assessment.
- CT imaging is particularly useful in complex cases, such as patients with congenital heart disease, multiple valve pathologies or pre-procedural planning for interventions.

B. Assessment of valve morphology, calcification, and transcatheter valve interventions using CT

- Valve Morphology: CT imaging provides precise visualization of valve anatomy, including leaflet morphology, number of leaflets and presence of abnormalities such as bicuspid aortic valve.
- Valve Calcification: CT is highly sensitive in detecting and quantifying valve calcification, which is essential for assessing the severity of valvular stenosis and determining the need for intervention.
- Transcatheter Valve Interventions: CT plays a critical role in pre-procedural planning for transcatheter valve interventions, such as transcatheter aortic valve replacement (TAVR) or transcatheter mitral valve repair (TMVR). It helps determine the appropriate valve size, assess access routes, and evaluate the suitability of the patient's anatomy for the procedure.

C. Advantages, limitations, and diagnostic accuracy of CT imaging in valvular heart disease

Advantages:

- CT imaging provides excellent spatial resolution, allowing for detailed assessment of valve anatomy, calcification and surrounding structures.
- It offers rapid acquisition times, reducing motion artifacts and the need for breath-holding.
- CT allows for multiplanar reconstructions, enabling precise measurements and visualization from different angles.
- It provides accurate quantification of valve calcification, which correlates well with the severity of valvular stenosis.

Limitations:

- CT involves exposure to ionizing radiation which should be considered, particularly in young patients or those requiring repeated imaging.
- Patients with impaired renal function may be at risk of contrast-induced nephropathy, requiring cautious use of intravenous contrast agents.
- CT imaging may have limitations in assessing valve regurgitation severity compared to echocardiography.
- It may not provide real-time information about dynamic valve function and hemodynamics.

Diagnostic accuracy:

- CT imaging has demonstrated excellent diagnostic accuracy in evaluating valve morphology, calcification, and detecting complications such as valve perforation or abscess.
- It allows for precise measurements of valve annulus dimensions which are crucial for selecting appropriate valve sizes in transcatheter valve interventions.
- CT provides valuable information regarding access routes, coronary artery anatomy and potential complications related to transcatheter valve procedures.
- CT has emerged as a valuable adjunct to echocardiography in the evaluation of valvular heart disease, providing complementary information and aiding in clinical decision-making.

IV. Nuclear Imaging Techniques¹⁻⁹

A. Overview of nuclear imaging modalities in valvular heart disease

- Nuclear imaging techniques, such as myocardial perfusion imaging and positron emission tomography (PET), have important applications in the evaluation of valvular heart disease.
- Myocardial perfusion imaging utilizes radiopharmaceuticals to assess myocardial blood flow and identify areas of ischemia or infarction.
- PET imaging offers high-resolution images and enables the assessment of myocardial metabolism, inflammation, and specific molecular targets.

B. Evaluation of valve function, myocardial viability, and assessment of infective endocarditis using nuclear imaging

- **Valve Function:** Nuclear imaging techniques can provide valuable information about valve function, particularly in cases where echocardiography has limitations. For example, gated SPECT imaging allows for the assessment of valvular regurgitation severity and ventricular function.
- **Myocardial Viability:** Nuclear imaging techniques, such as PET with glucose metabolism tracers (e.g., FDG), are useful in assessing myocardial viability in patients with valvular heart disease and concomitant coronary artery disease. They can help determine if dysfunctional myocardium is viable and may benefit from revascularization.
- **Assessment of Infective Endocarditis:** Nuclear imaging techniques, particularly labeled leukocyte imaging and PET with radiotracers targeting infection (e.g., FDG-PET), play a role in the evaluation and diagnosis of infective endocarditis. They aid in detecting and localizing infective foci, assessing the extent of infection, and guiding the management of these patients.

C. Advantages, limitations, and diagnostic accuracy of nuclear imaging techniques in valvular heart disease

Advantages:

- Nuclear imaging provides functional and metabolic information that complements anatomical imaging modalities.
- It allows for the assessment of valve function, myocardial viability and detection of infectious processes in valvular heart disease.

- Nuclear imaging techniques have high sensitivity in detecting myocardial ischemia, infarction, and infective endocarditis.
- Quantitative analysis can be performed to provide objective measurements, such as myocardial perfusion defects or the extent of inflammation.

Limitations:

- Nuclear imaging techniques may involve radiation exposure and the use of radiopharmaceuticals should be considered in relation to potential risks and benefits.
- Access to nuclear imaging facilities and the availability of specific radiotracers may be limited in some regions.
- Image quality and diagnostic accuracy can be influenced by patient motion artifacts and suboptimal imaging conditions.
- Nuclear imaging techniques generally have lower spatial resolution compared to other modalities such as CT or MRI.

Diagnostic accuracy:

- Nuclear imaging techniques have demonstrated good diagnostic accuracy in the evaluation of valvular heart disease, particularly in assessing myocardial perfusion and viability.
- Myocardial perfusion imaging is highly sensitive and specific for detecting myocardial ischemia and infarction, which can be useful in determining the severity of valvular heart disease and guiding management decisions.
- PET imaging, especially with FDG-PET, has shown promising results in detecting and localizing infective endocarditis, aiding in diagnosis and treatment planning.
- Comparative Analysis of Imaging Modalities ¹⁻¹²

A. Comparison of echocardiography, CMR, CT, and nuclear imaging in valvular heart disease assessment

- **Echocardiography:** Echocardiography is the primary imaging modality for initial evaluation and serial follow-up of valvular heart disease due to its widespread availability, real-time imaging capabilities, and accurate assessment of valve morphology, function and hemodynamics.
- **CMR (Cardiovascular Magnetic Resonance):** CMR offers excellent soft tissue contrast and multiplanar

imaging capabilities. It provides comprehensive assessment of valve anatomy, function, myocardial viability, and quantification of blood flow across the valves. CMR is particularly valuable in complex cases or when echocardiography yields suboptimal results.

- **CT (Computed Tomography):** CT imaging provides detailed anatomical information, precise assessment of valve morphology, and quantification of valve calcification. CT is particularly useful for pre-procedural planning in transcatheter valve interventions and for evaluating complex cases with multiple valve pathologies or congenital heart disease.
- **Nuclear Imaging:** Nuclear imaging techniques offer functional and metabolic information, such as myocardial perfusion, viability, and assessment of infectious processes. They are particularly useful for detecting myocardial ischemia, evaluating myocardial viability in patients with valvular heart disease and concomitant coronary artery disease, and diagnosing infective endocarditis.

B. Strengths, weaknesses, and specific indications for each imaging modality

Echocardiography:

- **Strengths:** Real-time imaging, non-invasive, excellent for assessing valve structure and function, quantification of hemodynamics.
- **Weaknesses:** Operator-dependent, limited visualization in certain patients, challenging to assess certain valve regions or prosthetic valves.
- **Indications:** Initial evaluation, follow-up, assessment of valve regurgitation severity, stenotic gradients, and cardiac function.

CMR:

- **Strengths:** Excellent soft tissue contrast, multiplanar imaging, comprehensive assessment of valve anatomy, myocardial viability, blood flow quantification.
- **Weaknesses:** Limited availability, longer acquisition times, contraindicated in patients with certain metallic implants.
- **Indications:** Complex cases, inconclusive echocardiography, assessment of valve regurgitation severity, myocardial viability evaluation.

CT:

- **Strengths:** Detailed anatomical information, precise assessment of valve morphology, quantification of valve calcification, pre-procedural planning in transcatheter valve interventions.

- Weaknesses: Radiation exposure, limited availability of specialized facilities, contraindicated in patients with impaired renal function.
- Indications: Pre-procedural planning, evaluation of valve morphology, assessment of calcification, evaluation of complex cases.

Nuclear Imaging:

- Strengths: Functional and metabolic information, assessment of myocardial perfusion, viability, detection of infective endocarditis.
- Weaknesses: Radiation exposure, limited spatial resolution, specific radiotracers and facilities may be required.
- Indications: Myocardial perfusion assessment, viability evaluation, diagnosis of infective endocarditis.

C. Integration of multiple imaging modalities for comprehensive evaluation in specific scenarios

- In complex cases or when initial imaging yields inconclusive results, a multimodality approach involving two or more imaging modalities may be necessary to obtain a comprehensive evaluation.
- For example, combining echocardiography with CT or CMR can provide complementary information about valve morphology, calcification and associated cardiac structures.
- In transcatheter valve interventions, pre-procedural planning may involve the integration of echocardiography, CT and CMR to assess valve dimensions, access routes, coronary artery anatomy, and myocardial viability.
- The selection of the most appropriate imaging modality or combination of modalities depends on the specific clinical scenario, availability of resources, patient characteristics and the information required for accurate diagnosis, risk stratification and treatment planning.

VI. Emerging Imaging Techniques and Future Directions 1-4

A. Overview of novel imaging techniques

- 3D Echocardiography: Three-dimensional echocardiography allows for the acquisition of volumetric data sets, providing detailed visualization of valve anatomy and function. It offers improved accuracy in valve measurements, assessment of valve morphology, and quantification of regurgitation or stenosis.

- Strain Imaging: Strain imaging, including speckle tracking echocardiography and feature tracking CMR, measures myocardial deformation and provides insights into regional and global myocardial function. Strain imaging has the potential to detect early changes in myocardial mechanics, including subtle alterations in valvular heart disease.
- Fusion Imaging: Fusion imaging combines data from different imaging modalities, such as echocardiography and CT or CMR, to create a comprehensive and integrated visualization of valvular heart disease. It enables simultaneous assessment of anatomical and functional information, improving diagnostic accuracy and treatment planning.

B. Potential applications and ongoing research in valvular heart disease imaging

Novel imaging techniques have several potential applications in valvular heart disease assessment. For example:

- 3D echocardiography allows for improved visualization of complex valve anatomy and accurate assessment of valve regurgitation or stenosis.
- Strain imaging provides insights into myocardial mechanics and may help identify early myocardial dysfunction associated with valvular heart disease.
- Fusion imaging combines the strengths of different modalities, enhancing the accuracy of valve assessment and aiding in treatment planning.

Ongoing research focuses on further optimizing and validating these emerging imaging techniques in various aspects of valvular heart disease, such as:

- Refining the integration of 3D echocardiography with other imaging modalities to improve accuracy in valve measurements and procedural guidance.
- Investigating the role of strain imaging in predicting outcomes and guiding treatment decisions in patients with valvular heart disease.
- Exploring the utility of fusion imaging in complex valve interventions, such as transcatheter procedures, to enhance procedural success and minimize complications.

C. Challenges and opportunities in the future of imaging modalities for valvular heart disease

Challenges:

- Standardization: As emerging imaging techniques become more widespread, standardization of

protocols, measurements and reporting becomes crucial for consistency and comparability across different centers.

- **Cost and Accessibility:** Novel imaging techniques may require specialized equipment, expertise and resources, limiting their availability in certain regions or healthcare settings.
- **Integration and Workflow:** Incorporating these emerging techniques into routine clinical practice and integrating them seamlessly with existing imaging workflows can be challenging and may require further technological advancements and training.

Opportunities:

- **Personalized Medicine:** Advanced imaging techniques have the potential to provide individualized and tailored assessment of valvular heart disease, leading to optimized patient management and treatment strategies.
- **Enhanced Diagnostic Accuracy:** The continued development of imaging modalities offers the opportunity for improved diagnostic accuracy, particularly in challenging cases or when traditional imaging has limitations.
- **Therapeutic Guidance:** Imaging techniques can guide therapeutic interventions, such as transcatheter valve procedures, by providing detailed anatomical and functional information and aiding in procedural planning and monitoring.

VIII. Conclusion

- Echocardiography remains the primary imaging modality for initial evaluation and follow-up of valvular heart disease, given its real-time imaging capabilities and accurate assessment of valve morphology and function.
- CMR and CT imaging offer detailed anatomical information and are particularly useful in complex cases or when echocardiography yields suboptimal results.
- Nuclear imaging techniques provide functional and metabolic information, aiding in the assessment of valve function, myocardial viability and the diagnosis of infective endocarditis.
- The comprehensive evaluation of valvular heart disease requires a multimodality approach, considering the specific clinical scenario, availability of resources and the information required for accurate diagnosis and treatment planning.

- Integration of imaging modalities, such as echocardiography, CMR, CT, and nuclear imaging, can provide complementary information, enhancing the accuracy of valvular heart disease assessment.
- Novel imaging techniques, including 3D echocardiography, strain imaging and fusion imaging, hold promise in improving diagnostic accuracy and personalized assessment of valvular heart disease.
- Future research should focus on standardization of protocols and measurements, cost-effectiveness studies, and evaluating the clinical impact of emerging imaging techniques in valvular heart disease management.
- Advancements in technology and imaging algorithms, as well as increased accessibility to specialized imaging facilities, will play a significant role in the integration of novel imaging techniques into routine clinical practice.

References:

1. Alec Vahanian, Friedhelm Beyersdorf, Fabien Praz, Milan Milojevic et al. 2021 ESC/EACTS Guidelines for the management of valvular heart disease: Developed by the Task Force for the management of valvular heart disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). *European Heart Journal*, 43(7) 14 ; February 2022, 561–632, <https://doi.org/10.1093/eurheartj/ehab395>
2. Catherine M. Otto, Rick A. Nishimura, Robert O. Bonow et al. 2020 ACC/AHA Guideline for the Management of Patients With Valvular Heart Disease: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. 17 Dec 2020; <https://doi.org/10.1161/CIR.0000000000000923> *Circulation*. 2021;143:e72–e227
3. Nishimura RA, Otto CM, Bonow RO, et al. 2017 AHA/ACC Focused Update of the 2014 AHA/ACC Guideline for the Management of Patients With Valvular Heart Disease: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation*. 2017;135(25):e1159-e1195.
4. Baumgartner H, Falk V, Bax JJ, et al. 2017 ESC/EACTS Guidelines for the management of valvular heart disease. *Eur Heart J*. 2017;38(36):2739-2791.

5. Zoghbi WA, Adams D, Bonow RO, et al. Recommendations for noninvasive evaluation of native valvular regurgitation: a report from the American Society of Echocardiography Developed in Collaboration with the Society for Cardiovascular Magnetic Resonance. *J Am Soc Echocardiogr*. 2017;30(4):303-371.
6. Pibarot P, Dumesnil JG. Assessment of aortic stenosis severity: check the valve but don't forget the flow. *Heart*. 2005;91(6): 721-723.
7. Pibarot P, Hahn RT, Weissman NJ, et al. Association of paravalvular regurgitation with 1-year outcomes after transcatheter aortic valve replacement with the SAPIEN 3 valve. *JAMA Cardiol*. 2017;2(10):1208-1216.
8. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging*. 2015;16(3):233-271.
9. Andreini D, Pontone G, Mushtaq S, et al. Coronary CT angiography and functional imaging for guiding management of patients with stable coronary artery disease. *JACC Cardiovasc Imaging*. 2019;12(11 Pt 1):2235-2252.
10. Dweck MR, Boon NA, Newby DE. Calcific aortic stenosis: a disease of the valve and the myocardium. *J Am Coll Cardiol*. 2012;60(19):1854-1863.
11. Hulten EA, Carbonaro S, Petrillo SP, Mitchell JD, Villines TC. Prognostic value of cardiac computed tomography angiography: a systematic review and meta-analysis. *J Am Coll Cardiol*. 2011;57(10):1237-1247.
12. Pizzi MN, Roque A, Fernández-Hidalgo N, et al. Improving the diagnosis of infective endocarditis in prosthetic valves and intracardiac devices with 18F-fluorodeoxyglucose positron emission tomography/computed tomography angiography: initial results at an infective endocarditis referral center. *Circulation*. 2015;132(12):1113-1126.