My Approach To Manage Valve Prosthetic Dysfunction: What is the Role of Tomography?

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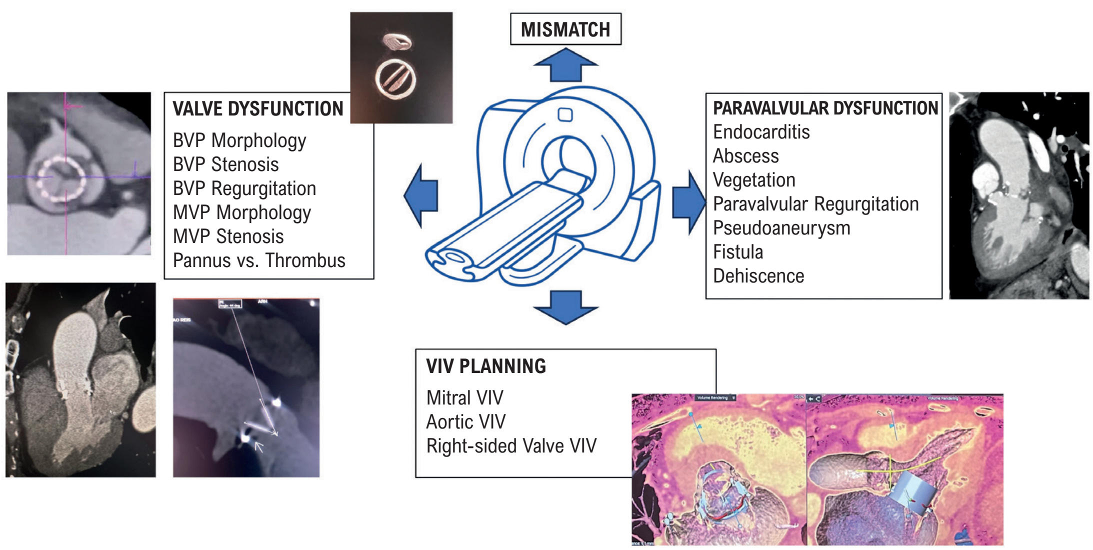
Central Illustration: My Approach To Manage Valve Prosthetic Dysfunction: What is the Role of Tomography?



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Utility of CT in Valve Prosthesis Dysfunction. BVP: Biological valve prosthesis, MVP: Mechanical valve prosthesis, VIV: Valve-in-valve; CT: computed tomography.

Abstract

The prevalence of valvular heart disease remains significant worldwide, as does the resulting use of valve replacement devices. Currently, mechanical valve prostheses (MVP), biological valve prostheses (BVP), and transcatheter valve prostheses are available. Computer tomography (CT) provides excellent spatial resolution and plays a critical role in the diagnostic process for prosthetic valve dysfunction (PVD). CT allows proper visualization of leaflet calcification/thickening (biological) or leaflet motion and angulation (mechanical). CT plays a fundamental role in the diagnosis of pannus and/or thrombus and in the characterization of paravalvular complications (e.g., dehiscence, fistula, leak, abscess, and pseudoaneurysm). Finally, CT has an established role as a necessary tool for planning percutaneous (valve-in-valve [VIV]) or surgical interventions to replace dysfunctional biological prostheses (Central Figure).

Keywords

Heart Valve Diseases; Emission-Computed Tomography; Heart Valve Prosthesis Implantation

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Abbreviations: CT: Computed tomography; TTE: Transthoracic echocardiography; TEE: Transesophageal echocardiography; MRI: Magnetic resonance imaging; PVD: Prosthetic valve dysfunction; THV: Transcatheter heart valve; BVP: Biological valve prosthesis; MVP: Mechanical valve prosthesis; TAVI: Transcatheter aortic valve implantation; EOA: Effective orifice area; HALT: Hypoattenuated leaflet thickening; RLM: Reduced leaflet motion; HAM: Hypoattenuation affecting motion; VIV: Valve-in-valve; LVOT: Left ventricular outflow tract; VTC: Virtual to coronary ostium; HU: Hounsfield units.

Introduction

In 2014, the global prevalence of valvular heart disease in the U.S. was 33 million, with approximately 120,000 valve replacement procedures performed at a total cost of approximately $5.7 billion.[1] Prosthetic valve dysfunction (PVD) is a significant challenge in clinical practice because it is associated with high morbidity and mortality and is often difficult to diagnose. In PVD, the difficulty of establishing a correct relationship between clinical symptoms and observed functional and morphological changes is widely recognized. Therefore, complementary imaging modalities are often required to assess stenosis, regurgitation, endocarditis, thrombosis, or paravalvular complications, for example. Transthoracic echocardiography (TTE) is the initial modality of choice, but it is sometimes necessary to expand the diagnostic armamentarium with advanced imaging modalities such as transesophageal echocardiography (TEE), computed tomography (CT), and magnetic resonance imaging (MRI).

Currently, there are three types of prostheses in our therapeutic armamentarium. Mechanical valve prostheses (MVPs) are made of durable synthetic materials and are designed to resist wear over time. One of the major challenges with mechanical prostheses is the risk of thrombosis and the need for lifelong anticoagulation. Biological valve prostheses (BVPs), currently the most used, are made from biological tissues, such as bovine or porcine pericardium or preserved human heart valves. BVPs generally have a lower risk of thrombosis, but are known to degenerate, often requiring replacement after 10 to 15 years. An advantage of these prostheses is the ability to use the metal ring from stented models as a support for transcatheter implant prostheses in a valve-in-valve (VIV) procedure. Transcatheter heart valve (THV) prostheses are biological prostheses with metallic stent-like support structures and offer a minimally invasive alternative for patients with heart valve disease. The procedure for implanting THV VIV prostheses requires careful planning, including CT to select the appropriate prosthesis size and to better define other aspects related to the procedure.[2]

CT

Cardiac-gated CT provides high spatial resolution and four-dimensional (4D) volumetric imaging of the prosthesis and ventricles, which can be combined with complete images of the cardiac cycle, allowing both functional and anatomical assessment. If there are no contraindications, beta-blockers can be administered to reduce heart rate to a target of 65 beats per minute to minimize motion artifacts[3] (Table 1). The main indication for CT is when PVD is detected on TTE, but the etiology is unclear and more detailed morphologic evaluation is needed or structural intervention (surgical or VIV) is planned. Noncontrast imaging can help detect calcifications and postoperative changes, and in mechanical prostheses, it can adequately visualize the mobility and morphology of the intervertebral discs. Therefore, it is routinely recommended to perform an initial noncontrast acquisition, a standard contrast-enhanced acquisition, and reconstruction of the cardiac phases. An additional late phase acquisition (60-90 seconds) may be useful in evaluating abscesses and thrombi.

Table 1 – Suggested protocol for tomography

Heart rate control	Ideally, HR < 65 bpm. If contraindicated (significant aortic stenosis, severe asthma, significant LV dysfunction), beta-blockers should be avoided.
Early phase noncontrast acquisition	Cardiac synchronization. No need for reconstruction, consider prospective acquisition.
Main phase acquisition	Cardiac synchronization. Retrospective with functional assessment (0%-90% or 5%-95%), intervals of 10%.
Dose of contrast	Dose of 1.0-1.5 mL/kg of nonionic, organo-iodinated contrast.
Use of contrast	Biphasic injection: 5.0-6.0 mL/s flow, followed by a 40-50 mL bolus of 0.9% saline. Triphasic injection (protocol for right-sided prostheses): . First phase: Half the contrast dose . Second phase: The other half of the contrast plus 0.9% saline . Third phase: Bolus with 40 mL of 0.9% saline
Contrast trigger	ROI positioned in the descending aorta Automatic trigger when density reaches 100 HU
FOV	Usually, the FOV is the same as for coronary CT angiography. Expand the FOV to include the entire aorta if endocarditis is suspected.
Radiation	Acquisition without dose modulation if a reasonable effective radiation level can be achieved. Tube voltage: 120-140 kV
Reconstruction	Cardiac cycle reconstruction with a minimum of 10 phases A minimum thickness of 0.9 mm and an increment of 0.45 mm.
Late phase acquisition	Cardiac synchronization. No need for reconstruction, consider prospective acquisition. 60-90 seconds after original acquisition if abscess and/or thrombus is suspected.

References (2, 3, 7). HR: heart rate; LV: left ventricle; ROI: region of interest; HU: Hounsfield units; FOV: field of view; CT: computed tomography.

Recently, surgeons have increasingly requested preprocedural CT angiography for valve replacement, similar to TAVI, to improve surgical prosthesis selection with respect to the valve annulus and adjacent structures. This approach helps to mitigate problems such as mismatch, leakage, dehiscence as well as allows for the selection of prostheses suitable for future percutaneous interventions.[3]

Mismatch

Mismatch refers to a situation where the prosthesis is too small relative to the patient's size, causing flow acceleration and gradient, which can also occur in low-flow patients without high gradient.[2] Diagnosis depends on the correct measurement of the effective orifice area (EOA), indexed to the patient's body surface area, combined with confidence the prosthesis does not have significant structural changes.[2,4]

PVD

CT allows evaluation of valve morphology, structural abnormalities, stenotic orifices, regurgitant orifices, annular complications, and paravalvular complications with equivalent quality in both mitral and aortic positions.[5] The accuracy of contrast-enhanced CT is comparable to 3D TEE for cardiac prostheses and may be superior for mechanical aortic and pulmonary valves[6] (Table 2). In MVPs with two normally functioning leaflets, the opening is because of the pendular movement of these leaflets caused by the pressure gradient difference, forming three opening orifices. The mobility of the discs and accurately measure the opening angles between them and in relation to the prosthetic annulus plane. The opening angle between the discs should be less than 30° (in most prostheses it is less than 20°), while the closing angle is about 120°. Relative to the prosthetic annulus, the opening angle should vary between 75° and 90°. Differences in angle values indicate impaired valve function, typically caused by thrombosis and/or pannus, as discussed below. Different prostheses have different normal ranges.[7] BVPs have three thin "biological" leaflets with typical motion. In cases of dysfunction, contrast-enhanced imaging allows detailed evaluation of prosthesis morphology with special attention to leaflet degeneration, providing a clear view of thickening, calcification, and motion as well as calcification of the bioprosthetic annulus.[8] Direct measurement of EOA (stenosis) and effective regurgitant orifice area is possible.[3]

Thrombosis and pannus

The incidence of thrombus in heart valve prostheses is approximately 0.3%-0.8% and is much higher in mechanical prostheses, with right-sided prostheses being more affected than left-sided prostheses.[3] Pannus is an abnormal layer of fibrovascular tissue or granulation tissue growth over the prosthesis structure (Figure 1). Detecting and potentially differentiating between thrombosis and pannus as the underlying cause of limited motion is one of the major contributions of this method. CT has similar accuracy to TEE and is superior to TTE in this context.[6] A recent study suggested a cutoff point greater than or equal to 145 Hounsfield units (HU) has a sensitivity of 87.5% and a specificity of 95.5% for differentiating pannus from thrombus and reported thrombi with attenuation less than 90 HU have a high probability of complete lysis with anticoagulation. Thrombi with attenuation between 90 and 145 HU are unlikely to achieve complete lysis.[9] The possibility of mixed involvement with both thrombosis and pannus, which accounts for nearly 10% of cases,[6] should be considered and adds another layer of complexity to this differential diagnosis (Table 3).

Table 2 – Imaging methods

	TC	RM	ETT	ETE
BVP Morphology	++++	+++	++	++++
BVP Stenosis	++++	+++	++	++++
BVP Regurgitation	+	++++	++	++++
MVP Morphology	++++	N/A	+	++ (VM 4+)
MVP Stenosis	+++	++	+++	++ (VM 3+)
MVP Regurgitation	N/A	+++	++	++++
Thrombi × Pannus	++++	+	+	+++
Dehiscence	++++	++	++	++++
Endocarditis	++	+	++	+++
Abscess	+++	++	++	+++
Pseudoaneurysm	++++	+++	++++	+++
VIV	++++	+	++	+++

Reference (2). VIV: valve-in-valve; CT: computed tomography; MRI: magnetic resonance imaging; TTE: transthoracic echocardiography; TEE: transesophageal echocardiography; BVP: biological valve prostheses; MVP: mechanical valve prostheses.

Subclinical thrombosis

Subclinical thrombosis is easily detected by CT in the leaflets of THV and BVP bioprostheses.[10] This finding, often observed in asymptomatic patients, has attracted considerable interest due to the uncertain risk of clinical events and the potential indication for anticoagulation. These findings have been standardized to facilitate understanding and potential clinical implications, with two important concepts: hypoattenuated leaflet thickening (HALT), which suggests the presence of leaflet-attached thrombosis (Figure 2), and reduced leaflet motion (RELM). The grading of HALT should be performed by looking at each leaflet sagittally and quantifying the hypoattenuated thickening of the leaflet from its proximal segment to the tip, divided into four segments (0%-25% of the most proximal segment only, 25%-50% up to the second proximal segment, 50%-75% up to the third segment, and greater than 75% if the entire leaflet is involved). The grading of RELM follows the same segment description pattern as HALT but using the leaflet mobility change. The combination of HALT and RELM determines hypoattenuation affecting motion (HAM), which appears to be the finding most related to clinical outcomes.[11-13]

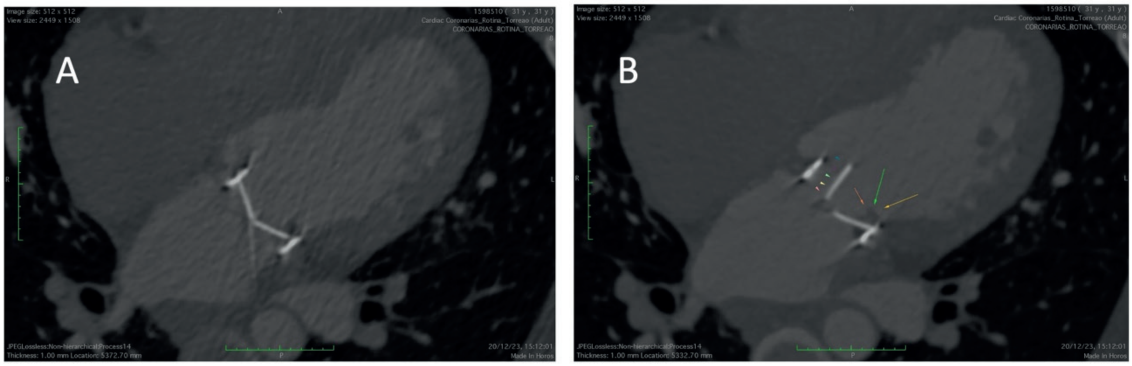

Figure 1 – *A 27-year-old female patient, status post valve replacement with a mechanical prosthesis in the aortic position, with reduced mobility of the posterior leaflet and an image consistent with the density and morphology of pannus. (A) Systole. (B) Diastole.*

Table 3 – Differential diagnosis

	Pannus	Thrombus
Time after surgery	From 12 months Typically after 5 years	It can happen at any time.
Anticoagulation	No response	It responds well when < 90 HU
Location	More common in the mitral valve and then the aortic valve	Mainly in the tricuspid valve. Equal prevalence in mitral and aortic valves.
Relationship to the prosthesis	Involvement of annulus and suture Ventricular side of the prosthesis	Involvement of annulus and suture with extension to the intervertebral discs Projection to the aortic and mitral surfaces of the prosthesis
Morphology	Small, central growth with more regular margins. Calcification may be present.	Larger than pannus, irregular edges, Greater mobility and independence from valve motion
Density (HU)	> 200 UH* > 145 UH**	< 200 UH* < 145 UH**

** = REF 3, ** = REF 7. HU: Hounsfield units.*

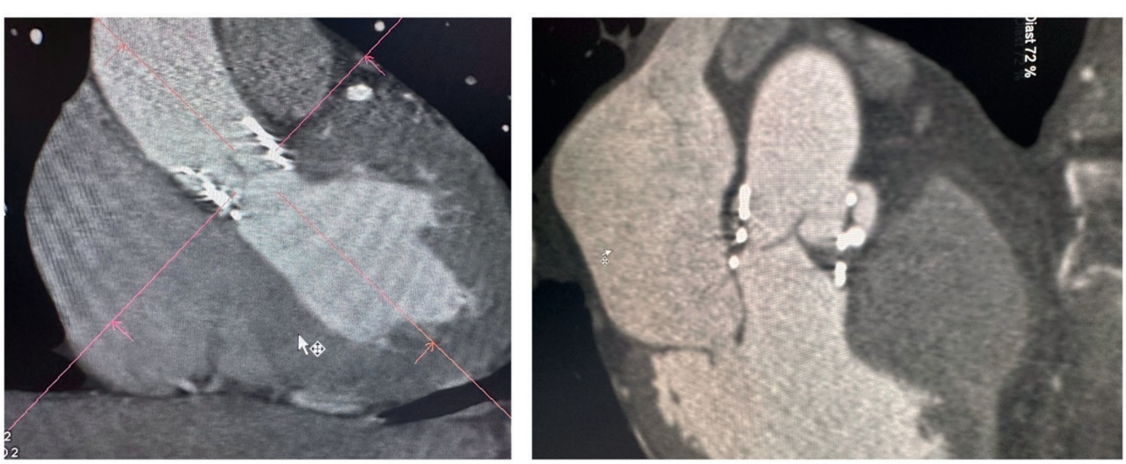

Figure 2 – *A 72-year-old female patient, status post aortic TAVI, with reduced anterior leaflet mobility and an image consistent with HALT (50% to 75%).*

Paravalvular dysfunction

Endocarditis (vegetation, abscess)

CT has excellent sensitivity for detecting vegetations larger than 10 mm but struggles with those smaller than 4 mm. Vegetations appear as small, hypodense, mobile masses adhering to the prosthesis leaflets. An abscess seen on CT appears as a closed collection with fluid density content adjacent to the prosthesis (Figure 3) and may show peripheral enhancement in the late acquisition phase. The presence of attenuation compatible with gas is rare but highly suggestive when present. Surrounding areas of the prosthesis should be examined for evidence of inflammation and/or degeneration associated with infection.[3]

Paravalvular regurgitation ("leak")

Paravalvular regurgitation is caused by improper positioning of the prosthesis relative to the valve annulus. This can result from dehiscence of the anastomotic suture, endocarditis, or natural degeneration of the annulus.[3] CT provides critical information about the location and characteristics of the paravalvular leak, including measurements of the orifices on the ventricular and atrial/aortic surfaces as well as the morphology and length of the cavity. The position of the leak in relation to the prosthetic valve annulus should be described using a clock model to guide fluoroscopic visualization during the percutaneous closure procedure. In the mitral position, 12 o'clock represents the surface adjacent to the aortic valve, 9 o'clock represents the left atrial appendage, 3 o'clock represents the atrial septum, and 6 o'clock represents the posterior surface. In the aortic position, 12 o'clock represents the surface adjacent to the mitral valve; 9 o'clock, the noncoronary sinus of Valsalva; 3 o'clock, the left coronary sinus of Valsalva; and 6 o'clock, the right coronary sinus of Valsalva.[14,15]

Pseudoaneurysm

Pseudoaneurysms usually occur when an abscess ruptures into adjacent cavities, most commonly in the aorta. Traumatic or idiopathic lesions may occur but are rare. CT has excellent accuracy in diagnosing pseudoaneurysms, which present as saccular or fusiform lesions filled with contrast material and continuous with another cavity. Pseudoaneurysms typically have a narrow neck and may expand and contract during the cardiac cycle. CT can also evaluate associated complications such as coronary compression, thromboembolism, and rupture. To differentiate a pseudoaneurysm from a periprosthetic abscess, an abscess does not communicate with a cardiac chamber and does not show early opacification with contrast.[3]

Fistula

Fistula is a rare complication resulting from the rupture of an abscess or pseudoaneurysm into adjacent cavities. Fistulas most commonly occur between the right coronary sinus and the right ventricle (RV). CT provides better quality detection and characterization of fistulas compared to TEE.[3]

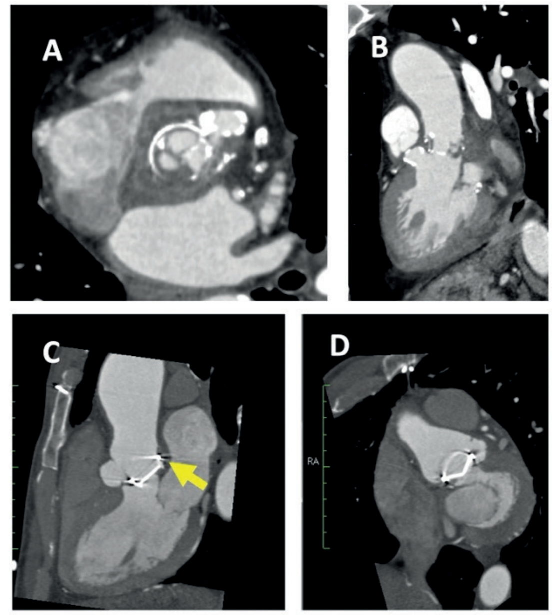

Figure 3 – *Paravalvular dysfunction. A, B: 71-year-old patient with a bioprosthesis in the aortic position with paravalvular abscess extending to the mitral-aortic intervalvular fibrosa, pseudoaneurysm, and vegetation on the bioprosthetic leaflet. C, D: Metal prosthesis in aortic position with misalignment associated with a paravalvular leak (3 o'clock), suspected dehiscence, and small pseudoaneurysms in the right and left sinuses of Valsalva.*

Dehiscence

Dehiscence occurs when there is a loss of continuity between the prosthesis suture and the tissue annulus. Static CT can detect gaps between the valve annulus and the prosthesis (Figure 3). Retrospective volumetric acquisition with reconstruction of cardiac function and cycle helps to identify the rocking motion of the prosthesis in relation to the annulus axis.[3]

Evaluation of right-sided prostheses and congenital heart disease (CHD)

To adequately evaluate right ventricular prostheses, it is recommended that the entire cardiac cycle be imaged with proper opacification of the right atrium (RA) and RV, preferably with no contrast mixing artifacts. This requires the use of a triphasic contrast injection protocol and timing of acquisition to opacify the right heart rather than the left heart (Table 1). CT may be useful for precise localization and sizing of prosthetic and periprosthetic lesions in the right valves. In cases of right-sided BVP, CT may characterize their location, length, and width to facilitate planning of potential percutaneous procedures. There are specific scenarios in CHD in which cardiac CT is useful for evaluating prostheses outside their usual location. These situations include the assessment of valvular stent fractures, valved conduits (e.g., Rastelli valved conduit), or percutaneously implanted prostheses (e.g., Melody valve). CT characterizes the morphology of these conduits, describes the presence of thrombi and calcifications, and identifies concomitant subvalvular or supravalvular stenosis.[2]

VIV planning

Advances in noninvasive imaging have been fundamental to the growth and maturation of percutaneous structural interventions. CT is advantageous for preprocedural planning of THV implantation in BVP, including the VIV procedure, as it is less affected by metal-induced artifacts. The virtual THV is a three-dimensional representation of the prosthesis to be implanted percutaneously, created using postprocessing imaging software based on measurements of the original BVP annulus.

The morphology and size of the left ventricular outflow tract (LVOT) must be carefully evaluated when planning a VIV implantation in the mitral position, as there is a significant risk of obstruction, especially with thickened interventricular septum and large prostheses. The neo-LVOT represents the remaining area of the native LVOT after mitral prosthesis implantation. We can acceptably estimate the future neo-LVOT by using postprocessing to position the virtual THV in the mitral position (Figure 4). Areas smaller than 189-170 mm^2 represent an increased risk of outflow obstruction after implantation.[16, 17] For aortic VIV procedures, the distance between the virtual THV annulus and the coronary ostia can also be estimated using postprocessing to position the virtual THV in the aortic position. Patients with large, heavily calcified prosthetic leaflets and a short distance between the virtual THV annulus and the coronary ostia are at higher risk (Figure 4). Values below 4 mm indicate an increased risk of coronary occlusion.[18]

CT can also determine the risk of annular injury and provide an estimate of the coplanar fluoroscopic angle to be used during the procedure. Other advantages of CT include evaluation of the access route and vascular pathway (including alternative accesses such as subclavian and carotid), determination of the risk of complete atrioventricular block (CAVB) after the procedure (by measuring the membranous septum). CT acquisition protocols for planning aortic and mitral CABG procedures differ little from those already established, with the additional step of obtaining CT angiography of the thoracic and abdominal aorta and pelvic arteries if peripheral arterial access is required (for aortic CABG and occasionally for mitral CABG).

The evaluation of aortic VIV in a stentless prosthesis uses the same measurements of the aortic valve annulus and adjacent structures as recommended for conventional TAVI:

- Characterization of the aortic valve annulus (dimensions, area, and perimeter)
- Coronary sinus height (<12 mm, higher risk of coronary occlusion)
- Assessment of sinuses of Valsalva (risk of coronary occlusion)
- Assessment of aortic valve (grade of stenosis, if possible)
- LVOT calcification (risk of annular rupture)
- Measurement of the membranous septum (risk of CAVB)

When evaluating aortic VIV in a prosthesis with a metal ring, the following measurements are performed:

- Evaluation of the aortic prosthesis metal ring (dimensions, area, and perimeter)
- Coronary sinus height (<12 mm, higher risk of coronary occlusion)
- Projection of the virtual THV (risk of coronary occlusion) in the aortic position
- Distance from the virtual THV to the coronary ostium (VTC)

The evaluation of mitral VIV in a prosthesis with a metal ring includes the following measurements:

- Evaluation of the metallic ring of the mitral prosthesis (dimensions, area, and perimeter)
- CT projection of virtual THV in mitral position
- Assessment of risk of LVOT obstruction based on virtual THV projection (neo-LVOT)
- Distance from the ostium of the left atrial appendage to the circumflex artery (risk of circumflex artery obstruction)

Ancillary testing

The protocol for contrast-enhanced synchronized CT, as recommended for the evaluation of prosthetic valves, differs little from that traditionally used to evaluate the

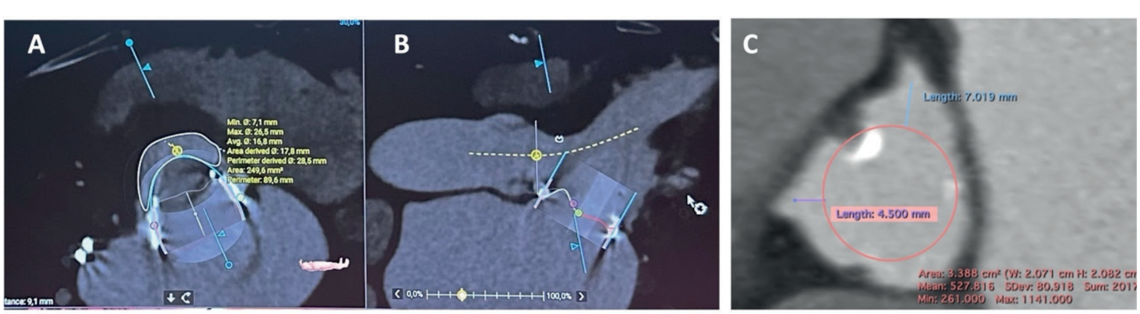

Figure 4 – *VIV. A, B: Virtual THV in mitral position and neo-LVOT to assess the risk of LVOT obstruction. B: Virtual THV and distance to the coronary sinus to assess the risk of coronary artery occlusion. C: Virtual THV and distance to coronary sinuses to assess the risk of coronary artery occlusion.*

coronary arteries. Therefore, as an added benefit of CT, we can detect new or monitor existing coronary obstructions, taking advantage of its excellent accuracy.[19] In addition, CT allows for the assessment of the thoracic aorta, pericardium, pulmonary artery, ventricles, ventricular function, and other ancillary findings.

Limitations

CT has some technical limitations since blooming and beam hardening artifacts from the valve ring or disk can affect the evaluation. These metallic artifacts can be reduced by using a higher tube voltage. CT does not allow for hemodynamic assessment and uses organo-iodinated contrast media. The protocol recommended herein uses higher doses of ionizing radiation (Table 4).

Conclusion

CT provides detailed, high-resolution anatomical and structural images that reveal information on many significant, potentially fatal complications of prosthetic heart valves. CT is particularly indicated for evaluating prosthetic valve morphology and paravalvular complications when TTE has limitations such as acoustic window limitations, interobserver variability, or discrepancies between echocardiographic findings and the patient's clinical presentation. CT may also be considered a second-line imaging modality for identifying the etiology of prosthetic dysfunction in mechanical or bioprosthetic valves (surgical or percutaneous) in the aortic, tricuspid, or pulmonary position (Figure 5). CT provides valuable noninvasive information to guide clinical management and appropriate therapeutic decisions. As such,

Table 4 – Summary of advantages and disadvantages of ct in pvd[2,3,7]

Advantages
Excellent spatial resolution
Good visualization of leaflet or annulus motion, pannus or thrombus, and leaflet calcification/thickening regardless of valve position.
Identification of paravalvular complications (dehiscence, abscess, pseudoaneurysm)
Useful in the context of multiple prosthetic valves where artifacts can affect the quality of TEE.
Disadvantages
Lack of hemodynamic assessment
The severity of regurgitation is determined by the anatomical defect; mild regurgitation or shunts may not be detected.
Beam hardening artifacts, especially in mechanical valves, can interfere with the identification of vegetation, thrombi, pannus, dehiscence, etc.
Organo-iodine contrast is required for angiography (non-contrast CT can be used to assess mechanical valve motion).
Full R-R acquisitions and multiple acquisitions contribute to higher radiation dose.
Temporal resolution may be limited.

PVD: prosthetic valve dysfunction; CT: computed tomography; TEE: transesophageal echocardiography.

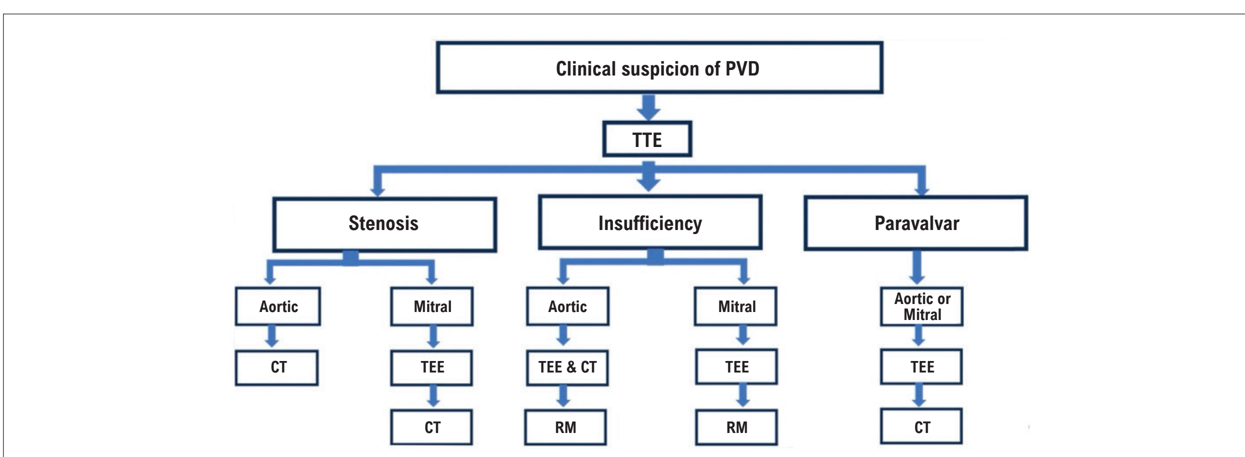

Figure 5 – *Suggested flowchart for the indication of CT in the diagnosis of prosthetic heart valve dysfunction. CT may be incorporated into the flow for complementary diagnostic purposes as well as for planning new valve replacement or percutaneous VIV procedures. PVD: prosthetic valve dysfunction; CT: computed tomography; TEE: transesophageal echocardiography; MRI: magnetic resonance imaging.*

it represents a significant advancement in the care of patients with PVD (Central Figure).

Author Contributions

Conception and design of the research, acquisition of data, analysis and interpretation of the data, statistical analysis, obtaining financing, writing of the manuscript, critical revision of the manuscript for intellectual content: Torreão JA.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants or animals performed by any of the authors.

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