My Approach to Echocardiographic Evaluation of Valve Prosthesis

Como eu Faço Avaliação Ecocardiográfica das Próteses Valvares

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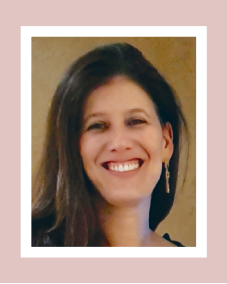

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Introduction

Approximately 280,000 valve replacements are performed each year worldwide; by 2050, this number is expected to triple as the population ages.[1] Despite advances in surgical techniques and prosthesis types, valve prosthesis implantation does not promote a complete cure. Prosthesis dysfunction is an old problem, and can manifest itself as prosthetic or paraprosthetic stenosis and regurgitation. There are several mechanisms involved in prothesis dysfunction, including thrombosis, pannus, mechanical failure, wound dehiscence due to ruptured stitches, calcifications, vegetations, or abscesses.[2] Furthermore, in 20% to 70% cases, mismatch may occur (when the prosthesis effective orifice area (EOA) though normal is smaller than the body surface area (BSA)).[3,4]

How to evaluate valve prostheses?

Valve prosthesis evaluation is complex and requires an integrated analysis of several clinical and echocardiographic parameters (Box 1).[5] The clinical parameters should be researched and noted in a report, even when requiring more than one visit, because these data are critical for the interpretation of Doppler findings. All echocardiographic parameters must be compared with those of prior studies and, preferably, with the first postoperative echocardiogram in which the prosthesis is normal; this examination is considered the identity of the prosthesis, and should preferably be performed within two to four weeks after the surgery (when the hyperdynamic state has been generally controlled) or before hospital discharge (when not possible otherwise). To facilitate future comparisons, the main data of this examination should be recorded on a card (similar to an identity card), so that patients can always carry it with them (Figure 1). Ideally, because hemodynamics vary with the prosthesis profile, the assessed Doppler and valve area values must be compared with the expected values for the brand, type, and size of the implanted prosthesis.[6,7] However, practically, these data are not always available. In this case, the values found can be compared with the mean normal values (Box 2)[5]; however, because they are not specific to the implanted prosthesis, they should be interpreted cautiously and within a clinical context, especially when altered. Prosthesis dysfunction should be suspected when at least one of the following alteration occurs on an electrocardiogram: abnormal two-dimensional prosthesis structure and/or movement, high maximum transvalvular gradient and/or velocity, and a reduced Doppler EOA.

Prosthesis evaluation—how do I analyze so many parameters?

Figures 2, 3, and 4 show a proposal for integrating and ranking various parameters recommended for valve prosthesis evaluation, starting with anatomy, gradient, and valve area.

Firstly (Figure 2), transthoracic echocardiogram (TTE) (three-dimensional whenever possible) should be performed to evaluate the valve anatomy thoroughly based on several incidences. An abnormal anatomy indicates dysfunction, regardless of the hemodynamic data. In such cases, due to therapeutic implications, the data should be readily complemented with another imaging method to better define the underlying mechanism for dysfunction.[8,9] Even if the anatomy is normal, dysfunction cannot be ruled out because TTE (especially two-dimensional TTE) cannot rule out changes in the prosthesis anatomy accurately.[9,10] Prosthesis hemodynamics should be evaluated on Doppler (Box 2); if all Doppler parameters are normal, combined with normal anatomy, the likelihood of prosthesis dysfunction is very low. However, if the parameters show discrepancies or clinical doubt persists, subclinical thrombosis can be investigated using other imaging methods. Conversely, if the Doppler data are altered, even if the anatomy appears normal, dysfunction or mismatch should be considered. However, a hyperdynamic state must be ruled out first, especially when performing TTE in the early postoperative period. In the absence of a hyperdynamic state, the Doppler parameters, especially gradient and valve area, should be compared with those from previous examinations and with the profile expected for the type and size of the implanted prosthesis (Figures 3 and 4).

Before comparing the prosthesis gradient and valve area with data from previous studies, the cardiologist should assess whether the hemodynamic, BSA, and left ventricular

Keywords

Heart Valve Prostheses; Echocardiography; Prosthesis malfunction.

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Editorial

Box 1 – Essential parameters for a full evaluation of valve prosthesis function that should be recorded in the echocardiogram report.

Clinical data	Reason for the study Related clinical symptoms and signs Valve replacement date Valve prosthesis brand, type, and size Height, weight, BSA, and BMI Blood pressure and heart rate
Valve prosthesis anatomy on two-dimensional (and three-dimensional where available) TTE/TEE, CT, or fluoroscopy	Spectral envelope shape Cusp, leaflet, or occluder mobility and texture Suture ring integrity and stability Calcification or abnormal structures in the various components of the prosthesis
Valve prosthesis hemodynamics derived from Doppler parameters	Gradients and maximum velocity VTI DVI PHT in mitral and tricuspid prostheses AT/ET in aortic prostheses Effective orifice area Presence, location, and severity of regurgitation
Hemodynamic repercussion and associated valve diseases	Size of the heart chambers Systolic and diastolic function SPAP Associated valve diseases
Previous postoperative studies and hemodynamic profile of the prosthesis (published in in vivo studies) when available	Comparison of all aforementioned parameters with those reported in previous studies, especially with the first postoperative echocardiogram Comparison of the prosthesis hemodynamic parameters with the hemodynamic profile expected for the type and size of the implanted prosthesis

*Adapted from Zoghbi et al.[7] * Transthoracic echocardiogram is the first examination; fluoroscopy can be useful for mechanical prostheses, especially in the aortic position. BSA: Body surface area; BMI: Body mass index; TTE: transthoracic echocardiogram; TEE: transesophageal echocardiogram; CT: computed tomography; VTI: velocity time integral; DVI: Doppler velocity index; PHT: pressure half time; AT: acceleration time; ET: ejection time; SPAP: systolic pulmonary artery pressure.*

Name of the patient:_____

Birthday: ___/___/___ **Valve replacement date:** ___/___/___

Echo date: ___/___/___ **BP (mmHg):**_____ **HR (bpm):**_____

Height (cm):_____ **Weight (kg):**_____ **BSA (m²):**_____

Surgery description (prosthesis type and size):

_____

Prosthesis photograph

Echocardiogram data:

LV mass/BSA_____ **RTLV**___ **LVEF (%):**_____ **LAVI (ml/m2):**_____ **RV (mm):** _____ **RA ↑ nl**

Prosthesis data:

Position	Type/size	EOAi cm²/cm²	Mean G (mmHg)	Vpeak (m/s)	VTITVP	AT/ET	PHT (ms)

Other data: PASP, regurgitation, other valve diseases…

This card does not replace the full report. Always present it to your physician.

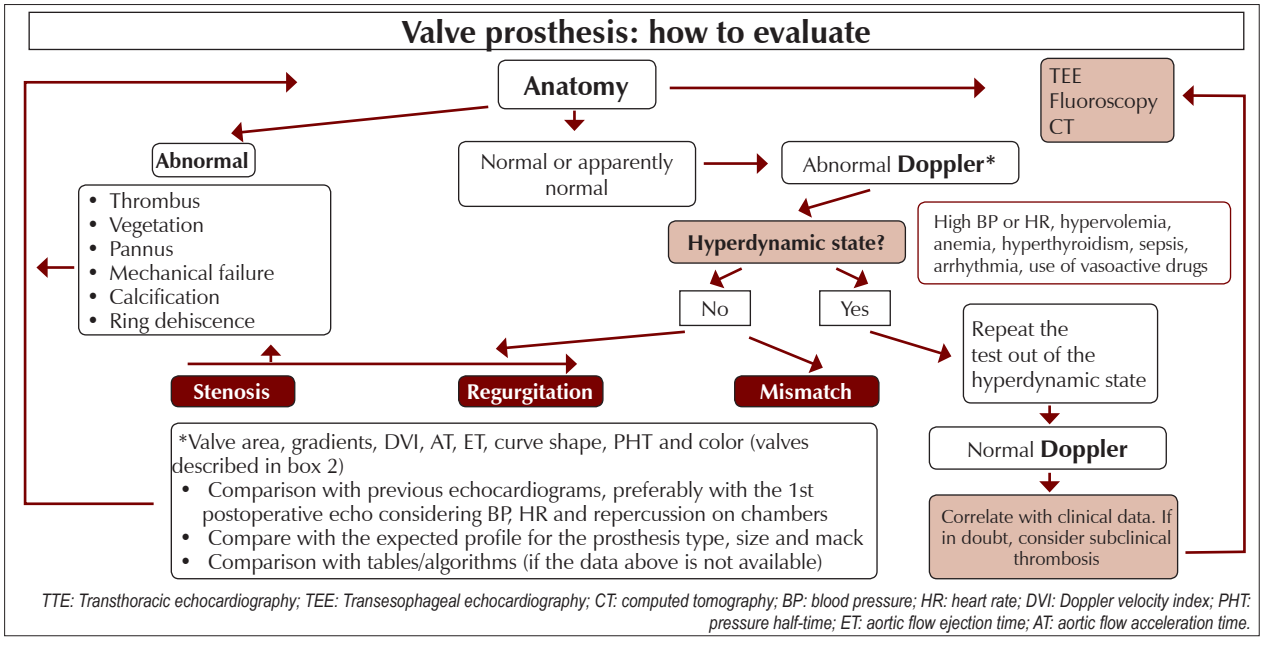
Figure 1 – *Prosthesis card.*

ejection fraction data are similar to previous literature to avoid interpretation errors. Aortic pressure recovery (in aortic prostheses with an ascending aorta ≤ 30 mm), high gradient in the central orifice (in bileaflet mechanical prostheses), and subvalvular acceleration must also be considered; in addition to hyperdynamic states, these can overestimate the gradients and underestimate the valve area in the absence of prosthetic dysfunction. Conversely, low flow states or left ventricular systolic dysfunction may underestimate the gradients. Even when the anatomy appears normal, deterioration of valve hemodynamics (increased gradients/velocities from the baseline on serial examinations) suggests prosthesis stenosis (if there is a concomitant reduction in EOA) or occult regurgitation (if EOA remains normal). In this case, the anatomy should be reevaluated using another imaging method. The onset of prosthesis-related hemodynamic repercussion in heart chambers, observed

Box 2 – Echocardiographic data for the analysis of valve prostheses.

Aortic prosthesis	Mitral prosthesis
Prosthesis structure and movement on TTE/TEE, CT, or fluoroscopy (normal vs abnormal) Doppler curve shape (triangular vs. symmetrical) Peak velocity (m/s) (< 3 vs. ≥ 4) MG (mmHg) (<20 vs. ≥ 35) DVI (LVOTVTI/VTIprot) (≥ 0.35 vs. < 0.25) AT (milliseconds) (< 80 vs. > 100) AT/ET (< 0.32 vs. > 0.37)* EOA (cm²) (> 1.1 vs. < 0.8) Difference (measured EOA-reference EOA) (cm²) (< 0.25 vs. > 0.35) ↑MG during stress (mmHg) (< 10 vs. > 20) Changes in parameters during the follow-up: - ↑MG during follow-up (mmHg) (< 5 vs. ≥ 10) - Decreased EOA (cm²) ≥ 0.3 or ≥ 25% - Decreased DVI ≥ 20% Presence, location, and importance of regurgitation LV dimensions, mass, and function; LA, RA, and RV dimensions; SPAP; aorta dimensions Other prostheses/valves: degree of stenosis/ regurgitation	Prosthesis structure and movement (normal vs. abnormal) Peak velocity (m/s) (< 1.9 vs. ≥ 2.5) MG (mmHg) (≤ 5 vs. ≥ 10) DVI (VTIprot/LVOTVTI) (<2.2 vs. > 2.5) PHT (ms)† (< 130 vs. > 200) EOA (cm²) (≥ 2 vs. < 1) Difference (measured EOA-reference EOA) (cm²) (< 0.35 vs. > 0.35) ↑MG during follow-up (mmHg) (< 3 vs. > 5) ↑MG during stress (mmHg) (< 5 vs. > 12) Presence, location, and importance of regurgitation‡ LV dimensions, mass, and function; LA, RA, and RV dimensions; SPAP Other prostheses/valves: degree of stenosis/ regurgitation
Pulmonary prosthesis	**Tricuspid prosthesis**
Prosthesis structure and movement (normal vs. abnormal) Color flow (linear vs. narrow and turbulent) Peak velocity (m/s) (< 2.5 vs. ≥ 2.5 homograft; < 3.2 vs. ≥ 3.2 bioprosthesis) MG (mmHg) (< 15 vs. ≥ 15 homograft; < 20 vs. ≥ 20 bioprosthesis) Presence, location, and importance of regurgitation‡ RV dimensions, mass, and function; SPAP; pulmonary artery dimensions Other prostheses/valves: degree of stenosis/ regurgitation	Prosthesis structure and movement (normal vs. abnormal) Peak velocity (m/s) (< 1.9 vs. ≥ 1.9) MG (mmHg) (< 6 vs. ≥ 6) DVI (VTIprot/LVOTVTI) (< 2 vs. ≥ 2 bileaflet mechanical prostheses or ≥ 3.2 biological prostheses) PHT (milliseconds) (< 130 vs. ≥ 130 mechanical prostheses < 200 vs. ≥ 200 biological prostheses) Presence, location, and importance of regurgitation RV dimensions, mass and function, inferior vena cava diameter, hepatic venous flow, and SPAP Other prostheses/valves: degree of stenosis/ regurgitation

*Adapted from Zoghbi et al.[7] Values in parentheses express normal ranges and ranges suggesting significant dysfunction (stenosis/insufficiency) for surgical prostheses (valid for normal ejected volume: 50 to 90 mL, flow: 200 to 300 mL/s, and heart rate: 50 to 80 bpm); however, these ranges may vary, depending on the prosthesis brand, size, and type and on the presence of mismatch. See Lancellotti et al.5 and Hahn et al.,[6] for normal EOA values for surgical prostheses and transcatheter devices, and Zoghbi et al., for valve regurgitation after transcatheter implantation.[12] *Cannot be used when mitral prosthesis is present. AT/ET > 0.58 is 100% specific to significant obstruction in the absence of high flow;[13] † PHT > 200ms is highly suggestive of stenosis and PHT < 130 ms can be observed in normal prostheses or in prosthetic insufficiency. TTE: transthoracic echocardiogram; TEE: transesophageal echocardiogram; CT: computed tomography; MG: mean gradient; DVI: Doppler velocity index; LVOTVTI: Left ventricular outflow tract velocity time integral; VTIprot: prosthesis velocity time integral; AT: acceleration time; ET: ejection time; EOA: effective orifice area; MG: mean gradient; LV: Left ventricle; AE: left atrium; RA: right atrium; RV: right ventricle; SPAP: systolic pulmonary artery pressure; PHT: pressure half time.*



TTE: Transthoracic echocardiography; TEE: Transesophageal echocardiography; CT: computed tomography; BP: blood pressure; HR: heart rate; DVI: Doppler velocity index; PHT: pressure half-time; ET: aortic flow ejection time; AT: aortic flow acceleration time.

Figure 2 – *Hierarchical evaluation of valve prosthesis.*

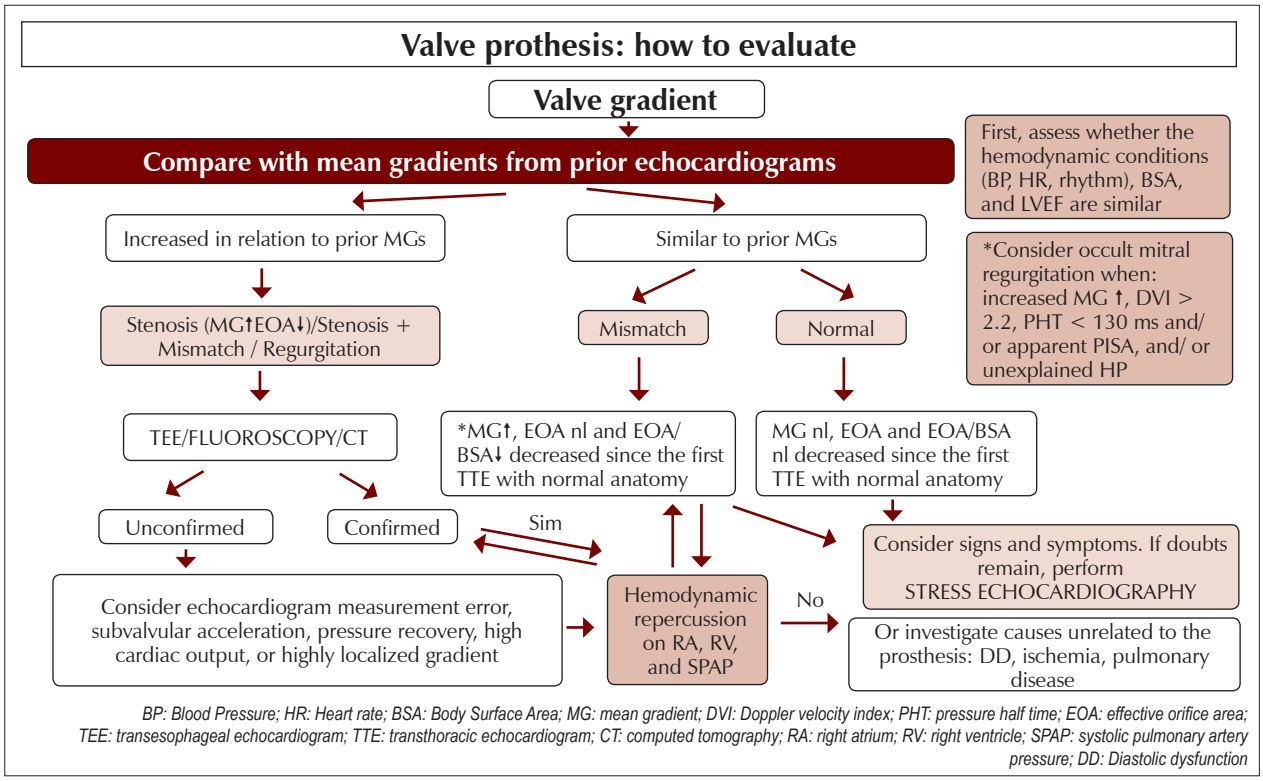


Figure 3 – *Comparative and serial evaluation of the valve prosthesis gradients.*

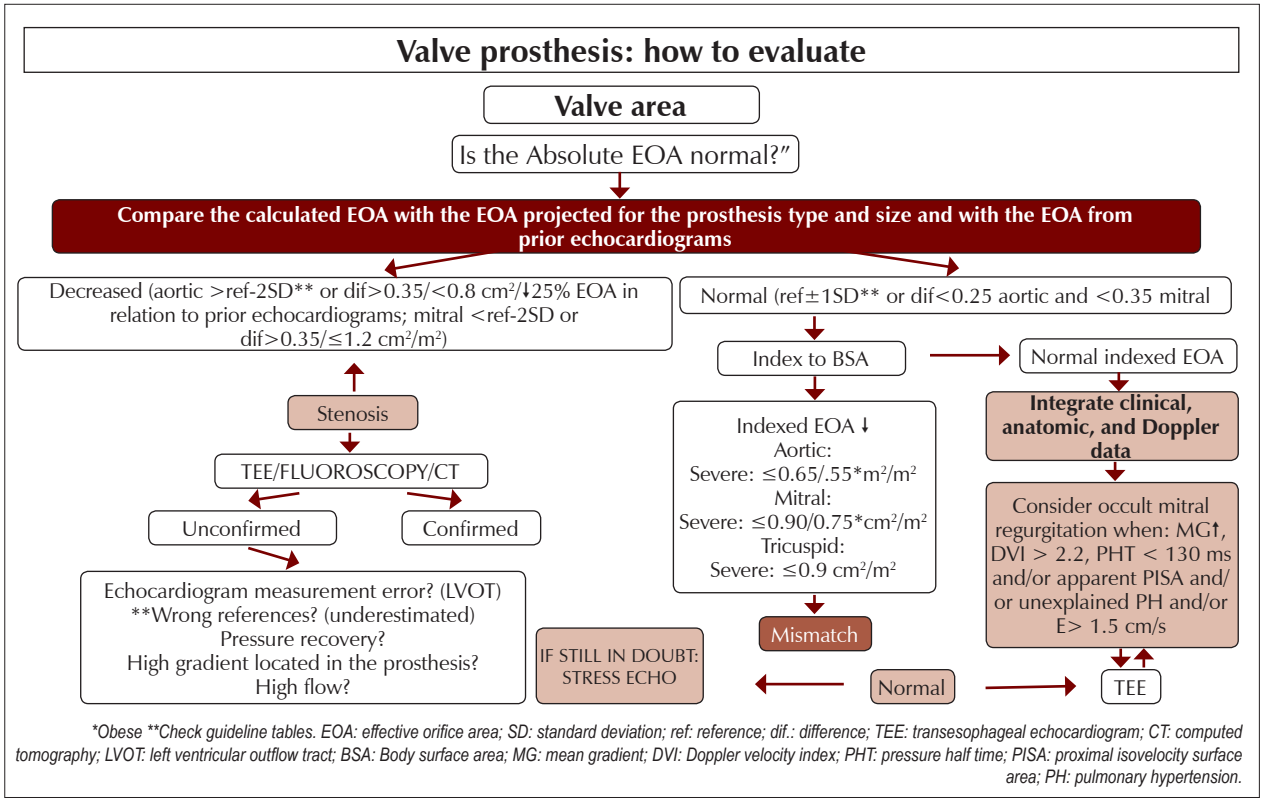


Figure 4 – *Comparative and serial evaluation of the valve prosthesis area.*

during serial evaluation, further corroborates prosthesis stenosis (if the anatomy is altered), mismatch or occult regurgitation (if the anatomy is normal).When valve hemodynamics remain similar to the baseline but the gradients are elevated since the beginning and the anatomy and EOA are normal, a mismatch is likely; in this case, the EOA/BSA is reduced (Box 3).[5,11] Prosthesis dysfunction and mismatch may coexist during valve hemodynamics deterioration in prosthesis with a high gradient and normal EOA (observed during prior examinations). However, the gradient and valve area do not always change simultaneously because their relationship is non-linear. In an obstructed valve prosthesis, the gradient remains virtually unchanged until the valve area reduces to more than 50%.[4] Therefore, the EOA of the prosthesis should be analyzed even when the gradient is normal (Figure 4). Other Doppler parameters, specific to each prosthesis type, should be analyzed together (Box 2). The technical aspects and limitations of some parameters should also be noted (Box 4). Lastly, the findings should always be correlated with clinical

Box 3 – Prosthesis-patient mismatch.

Aortic prosthesis			
	Mild EOAi (cm²/m²)	**Moderate EOAi (cm²/m²)**	**Severe EOAi (cm²/m²)**
BMI < 30 kg/m²	> 0.85	0.85-0.66	≤ 0.65
BMI ≥ 30 kg/m²	> 0.70	0.70-0.56	≤ 0.55
Mitral prosthesis			
	Mild EOAi (cm²/m²)	**Moderate EOAi (cm²/m²)**	**Severe EOAi (cm²/m²)**
BMI < 30kg/m²	> 1.2	1.2-0.91	≤ 0.90
BMI ≥30kg/m²	> 1.0	1.0-0.76	≤ 0.75

Measured absolute valve effective orifice area—reference (cm²) < 0.25 (aortic) or < 0.35 (mitral) (reference ± 1 standard deviation) and normal anatomy. See Lancellotti et al.5 and Hahn et al.,6 for normal reference values of valve effective orifice area for different models and sizes of surgical prosthesis and transcatheter devices. Gradients/ velocities frequently increase, since the first postoperative study, but remain constant (except when associated with stenosis or high-flow states). The other Doppler parameters are usually normal. EOAi: valve effective orifice area indexed to the body surface area; BMI: body mass index.

Box 4 – Technical aspects, limitations, and pitfalls.

Technical aspects
Assess Doppler parameters based on the average of 3–5 beats for sinus rhythm and 5–10 bats for irregular rhythm Document the incidence at which the velocities were obtained Note the sample location, size, and volume and the Doppler alignment Collect all Doppler parameters in unforced expiratory apnea Record the left ventricular diameter and outflow tract velocity in the same anatomical site. Use the same diameter in all examinations. If the measurement is not feasible, use only the DVI If the left ventricular outflow tract velocity is > 1.5 cm/s (subvalvular acceleration), use Bernoulli's equation in its complete form (4 × ($V2^2$-$V1^2$)) for the maximum gradient (in this situation, the mean gradient cannot be estimated)
Limitations and pitfalls
In aortic prostheses, do not use AT or AT/ET if a mitral prosthesis is also present In mitral prostheses, do not calculate EOA using the continuity equation or DVI if mitral regurgitation or aortic regurgitation, other than the mild form, occurs (in this case, the RV outflow tract can be used) Conclude mismatch only after 3–6 months of postoperative follow-up (alternatively report prosthesis with high gradients and normal anatomy) The prosthesis EOA can be underestimated upon increased gradient due to aortic pressure recovery, increased gradient assessed in the central orifice of the prosthesis, or subvalvular acceleration

LV: Left ventricle; DVI: Doppler velocity index; AT: acceleration time; ET: ejection time; EOA: effective orifice area; RV: right ventricle.

data, and when doubts persist, measurement errors should be ruled out and/or the prosthesis anatomy reassessed using imaging methods such as transesophageal echocardiography (preferably three-dimensional), computed tomography, and/or fluoroscopy (for mechanical prostheses). Stress echocardiogram can be used when observing discrepancies between prosthesis hemodynamics and patient symptoms.

Conclusion

Serial comparison of hemodynamic parameters, combined with adequate visualization of valve anatomy (using more than one imaging method, if necessary), remains the best strategy for assessing prosthesis function. These data must be interpreted within a clinical context.

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