Scholars Journal of Applied Medical Sciences (SJAMS) **ISSN 2320-6691 (Online)**
Sch. J. App. Med. Sci., 2016; 4(7B):2423-2427 **ISSN 2347-954X (Print)**

(An International Publisher for Academic and Scientific Resources)
www.saspublishers.com DOI: 10.36347/sjams.2016.v04i07.025

Short Communication

Echocardiogram for Aortic Valve Stenosis, the Complex Interplay between Flow and Gradient and Insight into Stress Echocardiography and Transoesophageal Echo for Transcatheter Aortic Valve Implantation (TAVI)

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Abstract: Aortic valve stenosis (AS) is a relatively frequent pathology in the elderly and management is mainly dependent on the degree of stenosis and the potential presence of comorbidities. Transthoracic echocardiography (TTE) is the basic initial test for aortic valve imaging, yielding valuable measurements of aortic valve area, peak velocity, mean and peak gradients and dimensionless velocity index. TTE allows to classify the type of AS, as high gradient/normal flow (HG/NF), low gradient/normal flow (LG/NF), high gradient/low flow (HG/LF) and low gradient/low flow (LG/LF); the latter is also subdivided into regular or paradoxical LG/LF according to the value of the ejection fraction (EF). Transoesophageal echocardiography (TOE) has an added value compared to TTE for detailed anatomical visualization of the aortic valve and adjacent structures, also it is particularly useful as a perprocedural test during transcatheter aortic valve implantation (TAVI). Moreover, stress echocardiography (SE) is useful in cases where accurate assessment of the degree of stenosis is challenging, especially in LF/LG AS. In summary, appropriate assessment of AS is essential in order to guide decision making and echocardiography is the gold standard test for this purpose.
Keywords: Aortic valve stenosis (AS), Transthoracic echocardiography (TTE), echocardiography

INTRODUCTION

Aortic valve (AV) is formed from an annulus and three cusps, and it is located distal to the left ventricular (LV) outflow tract (LVOT) and proximal to coronary sinuses of valsalva at the aortic root. Aortic stenosis (AS) is consecutive to narrowing of the left ventricle outlet, and depending on the level of the obstruction, it is categorized as valvular, sub-valvular, or supra-valvular. The prevalence of valvular AS in the population aged 65 years or older is approximately 2% [1]. Aortic sclerosis is a thickening or calcification of the aortic valve without obstruction to left ventricular outflow and it is a more frequent finding compared to AS.

Cardiac echogram is the gold standard technique to assess AV and AS, and it is performed mainly via transthoracic echo (TTE) approach, however other approaches may be required such as transoesophageal echo (TOE) or stress echo (SE) [2].

BACKGROUND

AV is normally formed from 3 cusps (right coronary cusp, left coronary cusp and non coronary cusp), and main AV diseases consist of aortic regurgitation and aortic stenosis. When assessing AV by echocardiography, the sonographer is supposed to provide extensive details regarding AV and related structures (eg, subaortic structures, aortic annulus, aortic sinuses maximal diameter and height, sino-tubular junction, and ascending aorta diameter) (Figure 1). Of note, TTE is the routine procedure performed initially for AV assessment and – compared to TOE-TTE allows better measurement of peak aortic velocities and gradient [1, 2].

The type of management of AS depends on the grade of stenosis (mild, moderate or severe), also it depends on the associated cardiac or non cardiac morbidities (other valves status, coronary artery disease, pulmonary function, age…). In general, management is conservative in mild to moderate cases, especially when the patient is asymptomatic, whereas severe AS requires

interventional management which may consist of surgical AV replacement (SAVR), transcatheter AV implantation (TAVI) or balloon valvuloplasty as stand-alone approach when more advanced techniques are not feasible or contraindicated [2].

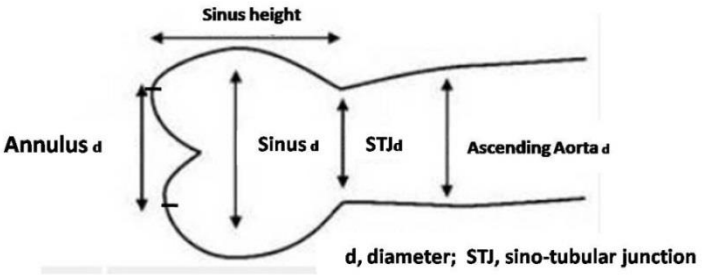

Fig-1: Basic parameters pertinent to AS to be explored via TTE

TRANSTHORACIC ECHOCARDIOGRAPHY

TTE is the basic exam initially performed for AS assessment, it allows a qualitative estimate (visual assessment) of AV shape and morphology, also it allows to visualize cusps mobility, the potential presence of calcifications, and associated regurgitation. Moreover, TTE allows to measure systolic and diastolic function, LV shape and dimensions, also it allows to document the presence of associated valvular lesions (eg, mitral regurgitation, etc…). Besides the qualitative estimate, TTE allows a quantitative analysis of AV, including AV area (AVA) using planimetry and continuity equation, peak aortic velocity, mean and peak gradients, velocity time integral (VTI) and dimensionless index.

AS is graded as mild, moderate or severe, and such classification is based on one or more criteria according to the American Society of Echocardiography [2]- (table 1).

Table 1: Criteria for grading the severity of AS, according to European Association of Echocardiography/American Society of Echocardiography guidelines (2)

Peak aortic jet velocity (m/s)	**Mild** 2.0–2.9	**Moderate** 3.0–3.9	**Severe** ≥4.0
Mean pressure gradient (mmHg)	<20	20–39	≥40
Aortic valve area (cm^2)	>1.5	1.0–1.5	≤1.0
Indexed aortic valve area (cm^2/m^2)	>0.85	0.60–0.85	<0.60
Dimensionless index	>0.50	0.25–0.50	<0.25

There is a complex interplay between gradients and flow, also gradients are mainly dependent on AS severity along with systolic function, whereas flow is dependent on both systolic and diastolic function; moreover, gradient is correlated to flow while the reverse is not true. Of note, low gradient (LG) is considered as such when it is <40 mm Hg and low flow (LF) is considered as such when indexed stroke volume <35 mL/m^2 as assessed by TTE (3).

Severe AS is defined as a peak aortic jet velocity >4.0 m/s, a mean gradient >40 mmHg, and/or an aortic valve area (AVA) <1.0 cm^2 (4). The interplay between gradient and flow is complex and it makes the diagnosis of severity of AS difficult sometimes, and therefore management decisions become a challenging clinical scenario. In practice, AS is divided by echocardiography as HG/NF, LG/NF, HG/LF and LG/LF; the latter subtype usually needs to be extensively explored to rule out true severe AS from pseudosevere AS [3, 4].

LV hypertrophy, fibrosis, and remodeling play important role in the genesis of these different subtypes of AS; a higher level of fibrosis and hypertrophy compromises LV filling and therefore reduces flow. AS of the HG/NF type is classically categorized as severe and usually poses no specific diagnostic challenge; similarly, AS of the LG/NF type is classically non severe given the presence of a normal flow, therefore it is usually a patent non severe AS and it does not require extensive explorations unless some parameters discordance is shown on echocardiography. LF/LG AS is a more challenging situation and could result from confounding situations (eg, small body size, measurement errors of indexed stroke volume (SVI), underestimation of LVOT diameter, etc.) [3].

LF/LG AS needs to be extensively explored, usually with stress echo (SE), in order to rule out true severe AS from pseudosevere AS; patients with LF/LG AS have a poor prognosis if treated medically, also a high operative mortality if treated surgically. The paradoxical form of LF/LG AS is associated with an ejection fraction >50%. The pathophysiology is related to a restrictive pattern in some patients with severe AS (i.e., <1.0 cm2 and/or indexed AVA of <0.6 cm2/m2), resulting in lower transvalvular flow rates (i.e., stroke volume index <35 ml/m2) and lower than expected

transvalvular gradients (i.e., <40 mm Hg) despite a preserved LVEF [5].

STRESS ECHOCARDIOGRAPHY

Severe symptomatic AS is an indication for AV replacement and exercise testing is usually contraindicated. In patients with classical LF/LG AS, dobutamine stress echocardiography (DSE) should be used to distinguish patients with true severe AS from those with pseudo-severe AS [6]. DSE in AS aims to increase cardiac output without precipitating significant myocardial ischemia; accordingly, a low dose dobutamine (up to 20 μ/kg/min) protocol is implemented. Dobutamine infusion is started at a low dose (2.5/kg/min), then the dose is increased every 3-5 min to a maximum of 10 to 20 mg/kg/min. The infusion should be stopped when heart rate rises more than 20 bpm over baseline or exceeds 100 bpm, also infusion should be stopped if blood pressure drops, if significant arrhythmias occur or if the patient exhibits significant symptoms [7].

The classical view where data are acquired is A3C or A5C view, however the same window should be used throughout the test to allow comparison of data across the different stages. Stroke volume is measured by subtracting LV end-systolic volume from LV end-diastolic volume. At every stage of the test, AV/VTI, LVOT/VTI, transvalvular mean and peak gradients, stroke volume and LVEF are acquired and stored. The LVOT diameter is measured at baseline at mid-systole and the same diameter is used to calculate by continuity-equation the valve area at each stage; whether LVOT diameter should be remeasured during the test and AVA recalculated accordingly is debated, given that LVOT diameter is a dynamic parameter and it may vary (increase or decrease) according to changes in LV end diastolic volume and pressure [8, 9].

Adequate contractile reserve is considered present when stroke volume or LVEF increases by more than 20% with dobutamine infusion; a noncompliant aortic valve may be moderately stenotic at rest but severely stenotic during stress given that cusps fail to open further. Consequently, if the mean gradient increases to >40 mmHg but the AVA remains <1.0 cm2, DSE indicates true severe AS; whereas if the AVA increases to >1.0 cm2, and even with some increase in gradients, DSE implies pseudo-severe AS [10] (table 2). Truly severe AS shows only small changes in valve area with increasing flow rate, but a significant increase in gradients, whereas pseudo-severe AS shows a marked increase in valve area but only minor changes in gradients. DSE may help to grade AS severity also in paradoxical LF/LG AS. In these cases, DSE should be used with caution and could be potentially contraindicated if the LV has severe hypertrophy, given the high likelihood of dobutamine-induced LVOT obstruction and drop in blood pressure during the test [11].

SE is an interventional, though non invasive procedure, during which the heart rate is increased using either pharmacological intervention or physical exercise. Accordingly, the test may be associated with side effects related either to the drug (Dobutamine), and/or to the underlying cardiac conditions (i.e stress arrhythmia, angina). In this respect, it is essential to conform with international standards regarding the indications and precautions of the test appropriate use criteria [9]. Moreover, if there is no significant contractile reserve (i.e. stroke volume and LVEF do not appreciably increase with dobutamine), distinction between true-severe and pseudo-severe AS cannot be made [9]. Aortic valve replacement should be considered in symptomatic patients with LF/LG with reduced EF, and with evidence of contractile (or flow) reserve [9, 10].

Table 2: Changes in Echo parameters during stress; (+), minor increase; (+++), significant increase; (=), similar; (-), decrease

	True severe AS	Pseudo-severe AS
Stroke volume and LVOT velocity	+	+
Transvalvular gradients	+++	+
Aortic valve area	= or (-)	+

TRANSOESOPHAGEAL ECHOCARDIOGRAPHY

TOE provides definitely a better anatomical view of the AV and related structures, also it allows a more precise measurement of the LVOT and annulus diameter, these parameters are important when there is a management perspective for TAVI. Moreover, TOE is useful to monitor per-procedural TAVI process and to diagnose potential complications related to the procedure, like cardiac tamponade, left ventricular dysfunction, severe aortic regurgitation [12]. Aortic valve anatomy and morphology should be assessed in detail: bicuspid aortic valve is generally considered a relative contraindication to TAVI; moreover, extensive or asymmetric calcification, especially of the commissures and of the edge of the leaflets may result in unfavorable deployment of the valve and complications like paraprosthetic regurgitation [13].

In fact, several steps of the TAVI procedure may be guided by TOE, especially aortic valve crossing, balloon dilatation, and positioning and deployment of the prosthesis. Of note, there are two types of prostheses commonly implanted: the shorter,

balloon-expanded Edwards Sapien prosthesis (Edwards Life Science), which is anchored at the annulus and extends to a level below the sino-tubular junction, and the longer self-expandable Core Valve (Medtronic), which extends from the annulus into the proximal ascending aorta; the positioning of the latter should aim a ventricular edge placed 5–10 mm below the aortic annular plane. In addition, it is important to confirm that all the prosthetic cusps are moving well, that the valve stent is well deployed (using 2D or 3D views), and that there is no significant transprosthetic or paraprosthetic regurgitation [14, 15].

Severe hypotension, cardiac arrhythmias, and acute ECG changes may occur during all phases of the TAVI procedure and TOE can immediately identify potential complications. Occlusion of the coronary ostia may occur by fragment embolization or by an obstructive portion of the valve frame, sealing cuff, or native cusp. 3D TOE may directly visualize the distance of the left main coronary ostium to the implanted valve showing whether the prosthesis reaches or overlaps the coronary ostium. Rarely, a tear or rupture of the aortic root may be observed during balloon valvuloplasty or prosthesis deployment [14]. Major complications of TOE include laryngospasm, arrhythmias, oesophageal perforation, and haemorrhage from oesophageal varices [15].

The following diagram (figure 3) shows the main views acquired via TOE relevant to Aorta and Aortic valve.

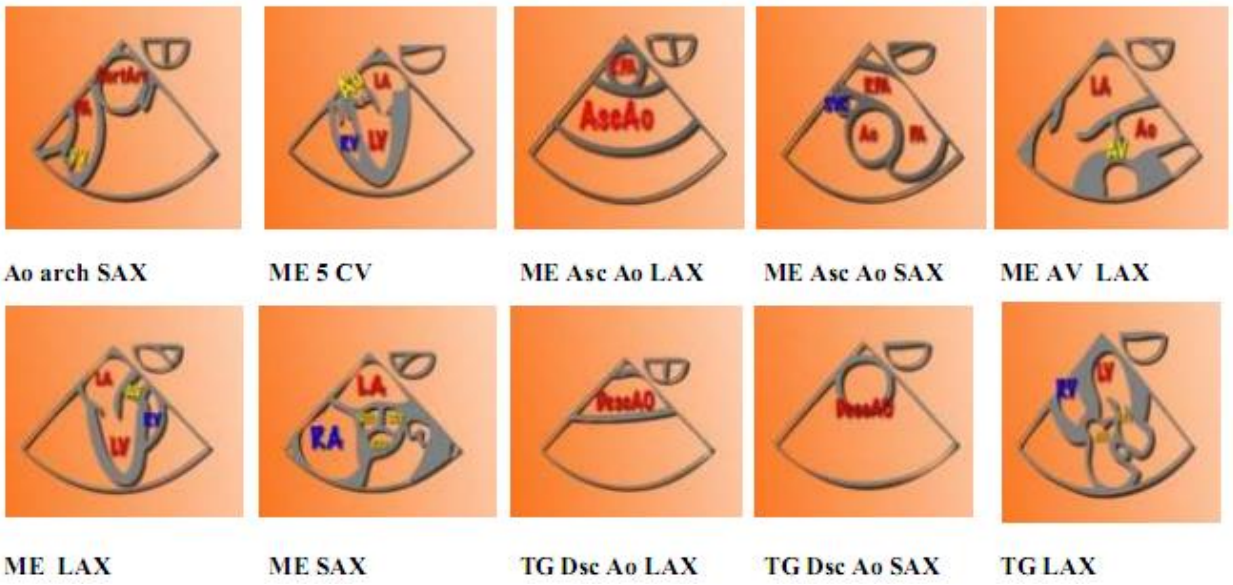

Fig-3: Main views relevant to Aortic valve and Aorta via TOE. Ao, Aorta; SAX, short axis; CV; chamber view; ME, mid esophageal; Asc, ascending; LAX, long axis; AV, aortic valve; Dsc, descending; TG, transgastric

CONCLUSION

TTE provide basic data for diagnosis and management of AS, however, other advanced echo techniques like SE may be needed in special cases like LF/LG AS, also TOE is often required in cases where TTE signal quality is not optimal, also for per-procedural guiding and for monitoring potential complications during TAVI procedure. TOE and SE are advanced echocardiographic techniques described more than 15 years ago, however they may be poorly implemented even in institutions where equipment is not the issue; the reluctance to the use of these valuable echo techniques may be related to impediments stemming either from the operator awareness and skills, or from the institutional capability and policy.

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