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EDITORIAL COMMENT

The utility of computed tomography in the context of aortic valve disease

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Continuous technical advances in cardiac computed tomography (CT) have created a variety of new applications in the field of cardiac imaging. Through improvements in temporal and spatial resolution, detailed visualization of valvular morphology and function has become feasible. Within the past few years, numerous studies have investigated the potential of CT in evaluating aortic valve disease, focusing on aortic stenosis. In this issue, a meta-analysis by Shah et al. [1] on the performance of cardiac CT for measurement of the anatomic aortic valve orifice area (AVA) in aortic stenosis is presented, in which 9 studies including a total of 437 patients were pooled together. This meta-analysis shows an excellent correlation of both 16-and 64-multidetector row CT with the clinical reference method transthoracic echocardiography. Moreover, in this issue, another original research article by Li et al. [2] confirms the good accuracy of CT for measurement of the AVA by using new dual source CT technology. Additionally, an improved performance of dual source CT in the diagnosis of aortic regurgitation is reported [2], attributed to higher temporal resolution of >83 ms.

Aortic stenosis (AS) is the second most common cardiac disease with a prevalence of 2–6% in the elderly population. Its diagnosis is based on estimation of the size of the aortic valve orifice area (AVA), as provided by various imaging modalities. An AVA of less than 1 cm^2 [3] is regarded as severe stenosis, and accurate sizing is of importance in order to define further management. However, there are fundamental methodical differences among various methods for estimation of the AVA, which is essential to be aware of. On transthoracic echocardiography (TTE), the AVA is calculated indirectly based on Doppler flow measurements and left ventricular outflow tract (LVOT) size over the so-called Doppler "Continuity Equation" using velocity time integral (VTI), which in fact allows for calculation of the "effective" orifice area. This "effective" orifice area (EOA) corresponds to the site where the cross-sectional area of the systolic ejection jet downstream is minimal. Under certain hemodynamic circumstances accurate calculation of the AVA over the "Continuity Equation" is impaired [4]. These are patients with low-flow, and low-transvalvular pressure gradient, which account for up to 25% of patients with severe AS [5]. In these patients, the anatomic "geometric" AVA provides a more "stable" parameter, since its quantification is flow-independent. Accurate quantification of severity or AS is crucial in these patients, in order to improve outcome through aortic valve replacement

Editorial comment to the articles of Shah et al. (doi: 10.1007/s10554-009-9464-z and Li et al. (doi: 10.1007/s10554-009-9456-z)

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[5]. Further, the "Continuity Equation" assumes circular geometry of the aortic root, which holds not true especially in patients with aortic stenosis having rather an "elliptic" excentic LVOT shape [6] enhanced by septal hypertrophy developing along with LV-hypertrophy. This eccentricity of the LVOT may further negatively influence the accuracy of AVA measurement by TTE.

Another modality for calculation of the AVA is fluoroscopy, using the "Gorlin-formula". This formula yields the "Gorlin area", representing the function of the mean systolic flow rate and the transvalvular pressure gradient. Compared to the Doppler EOA by TTE, the Gorlin Area systematically "understimates" the orifice area, which in enhanced the smaller the aortic root size [7].

Contrary, the true "anatomic" AVA (or so-called "geometric" orifice area, GOA), that refers to the real anatomic area of valve opening, can be measured directly by computed tomography (CT), independent from extra-valvular or hemodynamic factors. Transesophageal echocardiography, and magnetic resonance (MR) imaging provide these measurement as well. However, transesophageal echocardiographic planimetry of the anatomic AVA can be difficult in the presence of severe valvular calcification causing artifacts that hamper image quality. Compared to cardiac MR, CT offers the advantage of higher spatial (z-axis) resolution with $\sim$0.4 mm^3 voxel size (cardiac MR $\sim$>1.2 mm^3).

Overall, there is a tendency towards a systematic slight "overestimation" of the "anatomic" AVA by CT compared to the "effective" AVA by TTE, likely explained by methodical differences. However, this overestimation is rather small, ranging between +0.04 and +0.18 cm^2 [2, 8, 9].

In clinical practice, there are 2 possible implementations of cardiac CT in patients with aortic stenosis: First, the AVA should be measured [2, 8–11, 25] in all patients undergoing coronary or cardiac CT for any clinical indications, if aortic valve calcification is visible. Virtually 100% of patients with aortic stenosis will exhibit calcification, and vice versa at least 13% of patients with intermediate pre-test probability referred to coronary CT angiography (mean age 57 years) [12] will present with valvular calcification, with a rising prevalence with age. In these patients, the AVA should be measured in order to distinguish between non-stenotic valve sclerosis and definite aortic stenosis. If the AVA is less than 2–3 cm^2, a transthoracic echocardiography (including measurement of transvalvular pressure gradient) should be appended.

Second, CT can be used as second alternative modality if indirect echocardiographic measurements are limited, as outlined above.

Another useful clinical application of CT in patients with aortic stenosis is for planning of percutaneous aortic valve replacement (PAVR) [24]. In order to define a patient's eligibility for either the transfemoral transcatheter or the transapical approach, evaluation of great vessel size is mandatory, and exclusion of iliac artery stenosis of iliac vessels a "sine-que-none". Besides, accurate aortic root sizing [2] is obligatory for planning of the stent valve size, and further details about aortic root morphology, such as coronary ostia height [24] are of interest. The article of Li et al. [2] shows a good correlation between echocardiography and CT in measuring the dimensions of aortic annulus, sinus of Valsalva, and the ascending aorta [2, 13].

Beside, Li et al. [2] demonstrate that the accuracy of CT for identification of patients with *aortic regurgitation* (*AR*) is excellent and improved with dual source CT compared to previous studies using 16- and 64-slice CT [13–16]. By selecting end-diastolic CT data sets, the anatomic regurgitant orifice area [ROA] can be visualized as "central valvular leakage area", reflecting an incomplete coadaption of cusps. Several studies could demonstrate the ability of CT to detect moderate and severe AR [14–16]. One limitation of 16-and 64-slice CT is the diagnosis of mild AR, which can be missed especially in the presence of dense valvular calcification, or bicuspid valves [15, 16]. A controversial debated issue is the accuracy of CT for the graduation of severity of AR. One study on 30 pts [13] suggests a good performance of CT in differentiating moderate [cut-off: ROA $>$ 25 mm^2] and severe AR [cut-off: ROA $>$ 75 mm^2] based on quantifying the ROA. However, another study by Li et al. [2] in 32 patients points at an inaccuracy of CT in distinguishing several degrees of AR based on the ROA. The most likely reason for these controversial findings are valvular calcification, which were not present in the study by Alkadhi et al. [13] but exhibited in patients enrolled for the other study [2], suggesting a more accurate sizing of the ROA in the absence of valvular calcium. Interestingly, the latter study [2] shows that the overall diagnostic accuracy in identifying patients with AR is clearly improved by using dual-source CT compared to previous studies utilizing 16- and 64-slice CT [13–16], even for patients with mild AR, reaching an overall excellent sensitivity of 94% and a specificity of 98% [2]. Aside measurement of the ROA, newly introduced software modules enables RV-volume segmentation [17], hence this algorithm may provide a quantification tool for functional calculation of the aortic regurgitation fraction. In summary, the current use of CT is not in the primary diagnosis of AR, but the aortic valve should be reviewed in all patients undergoing CT angiography for possible concomitant underlying AR, in particular if no recent echocardiography exam was performed. In case of an evident ROA, the patients should be further followed-up with echocardiography.

Another clinical use of CT in patients with aortic valve disease is during the pre-operative triage. CT allows for differentiation between bicuspid and tricuspid valve morphology, and offers the advantage of simultaneous, accurate sizing of aortic root and the ascending aorta [2, 13], as well as the evaluation of coronary arteries [18–20] within one scan. This information is often required pre-operatively [3].

Especially patients with infective endocarditis benefit from non-invasive evaluation of coronary artery disease pre-operatively in many ways, since invasive angiography and the unnecessary increased risk of embolization through catheter manipulation originating from aortic valve vegetations, can be avoided. Beyond, cardiac CT itself has recently shown promising results in depicting valvular abnormalities in *infective endocarditis* [20], in particular evaluation of paravalvular involvement may be improved by CT. CT may also provide a better morphological differentiation between valvular calcification and "soft tissue" lesions such as vegetations. On the other hand, recently published data by Tsai et al. [21] on 25 patients indicate an excellent performance of CT in detecting prosthetic valve dysfunction, as compared to surgery. Mechanic prosthesis often cause heavy acoustic shadowing artifacts hampering image quality on echocardiography, hence leading to a low-mediocre detection rate of prosthetic valve dysfunction, which is low with ~49% for the transesophageal approach only [22].

In summary, the main advantage of CT in clinical practice is the complementary assessement coronary arteries and LV-function. Accurate quantification of LV-function [2, 13, 23] is important to define further optimal management of patients, e.g., to define the optimal time point of surgery. Comparative studies yielded a high correlation of CT with the gold standard magnetic resonance (MR) imaging, with narrower limits of agreement between CT with MR compared to other methods such as echo or fluoroscopy [23].

When choosing the ECG-gating technique, one needs to keep in mind that prospective ECG-triggering ("step-and-shot") allows for image acquisition exclusively during end-diastole, which enables evaluation of valvular morphology during diastole, or evaluation of aortic regurgitation. However, it does not allow for image reconstruction during systole, as required for measurement of the AVA, or for evaluation of global or regional LV-function or prosthetic valve dysfunction. For these evaluations, retrospective ECG-gating is should be applied.

To conclude, cardiac CT offers various new promising clinical applications in aortic valve disease, with most data available in the context of aortic stenosis; but a promising capacity of CT is emerging for other valvular disease entities such as aortic regurgitation, infective endocarditis or prosthetic valves. The main advantage of CT over other imaging modalities is comprehensive non-invasive evaluation of coronary artery disease, which is frequently indicated e.g., in the pre-operative setting. Ongoing CT scanner technology development will possibly create new prospects and perspectives in the field of functional cardiac imaging.

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