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Aortic annulus measurements: should we use multislice computed tomography, 3D echocardiography or MRI?

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"...with the recent emergence of transcatheter aortic valve replacement, optimal image-based patient selection and sizing of the aortic valve prosthesis has been increasingly drawing attention."

Cardiac images are important because they depict anatomy and function and thus allow noninvasive visualization of a variety of pathologies. Moreover, these images are increasingly used to measure cardiac structures to objectively characterize severity of disease and aid in planning an individual patient's treatment. An example of the rapidly expanding use of imaging is the assessment of valve geometry prior to repair or replacement surgery, and more recently, the percutaneous transcatheter procedures. The availability of accurate measurements allows the surgeon to plan the optimal approach, select appropriately-sized implantable devices and minimize procedural complications. Specifically, with the recent emergence of transcatheter aortic valve replacement (TAVR), optimal image-based patient selection and sizing of the aortic valve prosthesis has been increasingly drawing attention [1].

One of the major questions in this context is the choice of imaging modality that would best address this need [2]. Notably, cardiovascular magnetic resonance (CMR), multislice computed tomography (MSCT) and 3D echocardiography (3DE) can all provide realistic views of the aortic valve, suitable for detailed measurements of valvular size and shape. However, there is no conclusive evidence in the literature to support the use of one of the three modalities over the other two. To answer the question of which one is the best, it is important to recognize the factors that determine what the optimal technique is, and to assess how each of the existing techniques fares on these factors.

Needless to say, the main criterion is accuracy, closely followed by reproducibility, the two traits on which few would be willing to compromise. It is well known that both accuracy as well as reproducibility are directly affected by image quality, including spatial and contrast resolution. These two properties of the imaging technique of choice are especially important in the case of the aortic annulus measurements, because the annulus is a thin structure that is not very different in its magnetic, acoustic or x-ray attenuation properties from the surrounding tissues. Accordingly, it cannot be taken for granted that in every patient, the annulus would be optimally visualized and suitable for accurate measurements. This is particularly true in the case of aortic valve stenosis, wherein excessive calcium frequently negatively affects the visualization of the valve.

Is echocardiography the best option?

The strengths of echocardiography are its wide availability and extensive validation. Furthermore, its portability makes it natural for real-time guidance of procedures. However, it is quite well established that echocardiographic visualization of

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the aortic valve from the transthoracic approach is difficult to guarantee, and that in many patients transesophageal images are needed to obtain reliable, detailed information [3]. Of course, this is one of the main limitations of echocardiography in this area compared with the other two truly noninvasive imaging modalities. Echocardiography is also limited by its relatively narrow field of view, which can make it difficult to understand the spatial relationship between the aortic root and surrounding structures. In addition, the accuracy of 2D echocardiographic measurements was found to be limited because of the oval annular shape, and 3DE showed considerably improved accuracy [4,5]. Also, because of the relatively low spatial resolution, 3DE is not ideal for visualization of the coronary arteries, in particular the location of the origin of the left main artery, which is extremely important during pre-TAVR evaluation to prevent the prosthesis from affecting coronary circulation. While echocardiography does not necessarily 'jump' to the top of the list of contenders because of these limitations, it has its strengths that become obvious when considering the weaknesses of the other two techniques.

Is MSCT the best option?

The strength of MSCT is that it is already commonly used to help select appropriate patients for TAVR [6]. Not only does it provide accurate measurements of the aortic annulus and its surrounding structures [7–11], it clearly depicts the origin of the coronary arteries and also allows for visualization of the entire aorta and iliac arteries, which also need to be carefully evaluated to decide on the best access strategy for TAVR (i.e., femoral approach or left ventricular apical approach). Needless to say, high quality MSCT images are associated with exposure to ionizing radiation. Indeed, it is hard to weigh the discomfort associated with esophageal intubation and sedation against these potential risks. It is true that the radiation dose can be minimized to levels that are lower than those routinely used for either cardiac catheterization or radionuclide myocardial-perfusion imaging, and that the risks are accordingly low. In addition, one might argue that because harmful effects of radiation take decades to manifest, this issue is not relevant in the majority of TAVR patients, because of their age. Nevertheless, even the strongest proponents agree that MSCT is not an ideal option for patients with compromised renal function, for whom iodine is contraindicated.

Is CMR the best option?

Thus, one might conclude that CMR 'wins' over the other two contenders [12–14], since it is completely noninvasive, does not require contrast enhancement and does not use ionizing radiation. However, it is important to remember that the confined space of the MRI scanner frequently triggers claustrophobia, and also is not compatible with implanted pacemakers and defibrillators, thus ruling out CMR as an option in a sizable proportion of patients. Additional weakness of CMR in this regard, compared with its 'rivals', is that the commonly used pulse sequences do not provide intrinsically 3D imaging, but rather multislice imaging, with slice thicknesses that are far inferior to voxel sizes of MSCT and even 3DE. As a result, imaging of the aortic valve requires special targeted acquisition of the valve plane, which requires careful planning and the quality of which can be affected by even minimal respiratory motion. Inherently, 3D acquisitions, such as contrast-enhanced magnetic resonance angiography and a newer noncontrast 'whole-heart' magnetic resonance certainly exist but suffer from their own limitations [1]. Contrast-enhanced magnetic resonance angiography has lower spatial resolution, when compared with the other modalities and is typically performed without ECG-gating, which leads to blurring of the highly mobile aortic root and makes measurements less precise. In addition, gadolinium-based contrast agents cannot be used in patients with severe renal dysfunction due to fear of causing serious complications, such as nephrogenic systemic fibrosis [15]. While the noncontrast 'whole-heart' imaging does not require contrast and does not suffer from these limitations, successful image acquisition can be prolonged and inconsistent in patients with irregular heart rhythms or respiratory patterns.

Is there a best option?

In view of everything stated above, this question is difficult to answer even theoretically, without looking at the literature. Unfortunately, doing so is not of much help either, since only few investigators looked specifically into aortic annulus measurements, and the majority of those who did, focused their attention on one imaging modality at a time [7–9], or at the most two, while using one of the two as a reference standard [5,12,14]. While most studies concluded that aortic annulus measurements are feasible and reproducible, and reported good intertechnique agreement, it is difficult to draw comparisons and extrapolate the published data to determine the modality of choice, because of the differences in study populations, reference standards and a variety of other factors.

The only study that compared the ability of all three imaging modalities, namely MSCT, CMR and 3DE, to quantify aortic annulus geometry was recently published by our group [16]. The complex design of this study, which involved *in vitro* measurements in manufactured calcium rings and cadaver hearts in addition to human subjects, reflected the difficulties with designing a study that would provide a definitive answer to the question which modality is the best. While MRI was found to be the most accurate in assessing the geometry of the calcium rings, and was subsequently used as a reference standard in cadaver hearts, it is important to remember that these images were obtained using an idealized sequence, which is usually used to image static organs, such as kidneys, liver or brain. This sequence resulted in truly 3D datasets of ultra-high spatial resolution, which was most likely responsible for the superior accuracy and reproducibility of MRI in this protocol. Unfortunately, these image sequences are not applicable to beating human hearts, leaving us with images of far lesser quality.

Another factor that needs to be taken into account when selecting the optimal imaging modality for the individual patient is the body weight and habitus. It is well known that in obese patients, both transthoracic echocardiography and MSCT images are of inferior quality, adversely affecting the accuracy of the aortic annulus measurements. While this is less of a problem for CMR, this imaging modality is not suitable for these patients simply because many of them cannot physically fit into the scanner. Also, claustrophobia is even more common in obese patients, who are considerably more uncomfortable in the limited space of the MRI scanner. Importantly, body weight and habitus are usually not an issue for transesophageal echocardiography, which can be successfully performed even in the most obese.

In summary, the ideal imaging technique aimed at measuring the aortic annulus as part of planning aortic valve replacement needs to: be fully noninvasive, be 3D to avoid foreshortened views and underestimated dimensions, use no potentially harmful radiation and contrast media, have high spatial and temporal resolution, be compatible with implanted pacemakers, defibrillators and other ferromagnetic objects and be able to image the majority patients irrespective of body habitus. Such an ideal imaging modality that incorporates all these traits and is suitable for every patient does not exist today. However, a reasonable approach is to select an imaging modality for each individual case, while taking into account the multiple factors discussed above. Since in many patients, one or even two of the three options are frequently eliminated automatically, the choice is less difficult to make. We should also keep in mind that when the clinically needed, high-quality information can be obtained using more than one technique, the final choice of test becomes immaterial, and should be made based on availability, convenience and even the patient's personal preference.

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