Current Cardiology Reports (2019) 21: 154
https://doi.org/10.1007/s11886-019-1241-6

VALVULAR HEART DISEASE (TL KIEFER, SECTION EDITOR)

Cardiac Computed Tomography (CT) Evaluation of Valvular Heart Disease in Transcatheter Interventions

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Published online: 25 November 2019

Abstract

Purpose of Review To establish the actual role of CT in the growing field of transcatheter valve interventions (THV).
Recent Findings The development of empirical CT measurements, which are linked with outcomes.
Summary CT is a reliable technique for assessing risk and planning transcatheter valve interventions for mitral and aortic valves. Pulmonic and tricuspid valve assessment with CT imaging is still in the early stages but there is room for development.

Keywords TAVR · TMVR · neo-LVOT · VTC · THV · aVIV

Introduction

Cardiac computed tomography (CT) has played a complimentary role to echocardiography for the evaluation of valvular heart disease. Over the last decade, cardiac CT has asserted itself as the primary tool for the pre-procedural planning of transcatheter valvular interventions allowing precise measurements for device sizing and vascular access assessment, helping with landing zone characterization, defining patient-specific risk, and in reducing procedural complications (Fig. 1).

This article is part of the Topical Collection on *Valvular Heart Disease*

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Aortic Valve

A prime example is the important role of cardiac CT in planning transcatheter aortic valve replacement (TAVR) for the treatment of severe aortic stenosis. The expansion of clinical indications to include low risk surgical patients following the recent PARTNER 3 trial and low risk Medtronic trial demonstrated a lower event rate in TAVR subjects supported by pre-procedural CT imaging and thoughtful patient selection [1–4].

The improved temporal and spatial resolution with cardiac CT has provided the interventional cardiologist reliable information to plan procedures by enabling an improved understanding of the aortic annulus, guiding valve type and size selection, and recognition of high-risk anatomical factors that preclude TAVR. Alternative imaging modalities include magnetic resonance imaging (MRI) and 3D echocardiography. These modalities have limitations such as variable MRI availability and 3D-echocardiographic image quality being user- and patient-dependent. As a result, CT, with the capacity to simultaneously assess vascular access, has a primary role in TAVR planning. That being said, CT imaging has its own limitations, such as radiation exposure, contrast nephropathy, and iodine contrast–related allergic reactions such as anaphylaxis.

TAVR procedures have faced many challenges and the lessons learned from these experiences are useful in the development of other transcatheter heart valve interventions. An initial challenge was the formulation of a comprehensive protocol to accurately assess the aortic root and provide a reliable

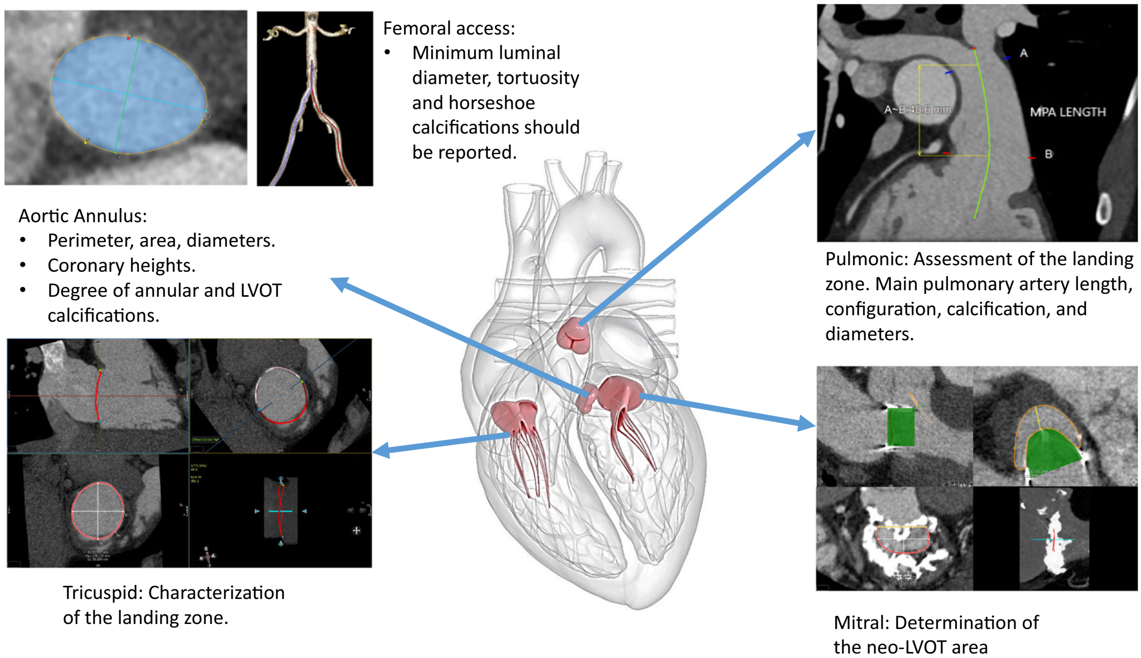

Fig. 1 Summary of the relevant measurements for the assessment of the patient-specific risk for each type of transcatheter valve intervention (with permission from Dreamstime.com LLC)

and reproducible measurement of the aortic annulus. For instance, several software platforms now include a smoothing technique for the aortic annulus perimeter measurement, reflecting lessons learned from initial variability in this measurement. While TAVR was originally performed based upon echocardiography measurements, CT is now the preferred approach to assess the native anatomy. The aortic annulus is a 3D elliptical structure, and echocardiography-guided valve size selection resulted in a greater incidence of aortic paravalvular leaks [5]. The risk of coronary occlusion is also well assessed by CT, with a reliable definition of the annular plane; the coronary heights can be measured with a well-known cutoff value of 11–12 mm [6••] particularly when seen in conjunction with narrow sinus of Valsalva (< 30 mm). Additionally, CT is the best technique for the evaluation of sub-annular calcification which has been shown to be related to annular rupture in prior analyses [6••].

CT imaging has also been instrumental in planning aortic valve-in-valve procedures (aVIV) for treatment of degenerated surgical bioprosthetic valves. This procedure has reduced the need for open re-do surgical aortic valve replacement and its associated operative risks. CT imaging facilitates the identification of the bioprosthetic valve type and size; the latter information is particularly useful when surgical/medical records are not available to ascertain the manufacturer and labeled valve size. A key role of CT is the assessment of potential coronary artery obstruction risk with the aVIV procedure. With a simple model of a cylinder based on the basal ring of the device, the VTC (Virtual THV to coronary) distance can be measured and has been reported to predict the risk of coronary occlusion as demonstrated by Ribeiro et al., taking 4 mm as a cutoff value [7••].

As well, cardiac CT imaging has introduced the concept of early post-implant valve thrombus. The clinical significance of this finding is still being investigated, but it has served to highlight the potential of CT to identify subjects with valve leaflet thrombosis as the etiology of elevated echocardiographic valve gradients [6••].

Mitral Valve

Percutaneous mitral valve replacement (TMVR) is the next logical frontier following the success TAVR. However, TMVR is unlikely to have the rapid success of TAVR for a number of reasons. First, the complex anatomy of the mitral valve, with its asymmetric saddle-shaped annulus, asymmetric leaflets, and a need to preserve the sub-valvular apparatus. Second, the larger size of the annulus requiring larger devices and in the case of transeptal access, delivery systems with high degree of flexibility. Thirdly, the target pathology is heterogeneous and is grouped broadly under primary regurgitation, that is inherent to the valve, and functional mitral regurgitation (MR), which is secondary to progressive LV dilation usually from an underlying cardiomyopathy. While surgical repair of primary regurgitation is the established “standard” with a long experience and excellent results, the role of TMVR may initially be limited to managing mitral regurgitation secondary to LV dilation. Herein lies the main difference in clinical potential of TMVR versus TAVR: TAVR treats the root pathology, whereas TMVR does not in cases of functional, secondary MR.

Nonetheless, there has been a recent surge of interest in TMVR. Population studies report that there is a substantial burden of mitral regurgitation especially in the aging population with almost 10% of adults 75 and older being affected [8]. Development of transcatheter heart valves (THV) has commenced with devices being classified according to shape, anchoring mechanism, and access point. There are two approaches for the shape of the valve itself, with some companies opting for a circular device that renders the procedure less difficult, whereas the alternative is creating a more tailored D-shaped device to mitigate LVOT obstruction. Presently, there are no commercially available mitral THVs. Clinical trials for these devices are in their infancy, ranging from trials in the early feasibility and safety testing phase to investigating clinical outcomes, namely the Apollo (Intrepid-Medtronic) and Summit (Tendyne-Abbott) trials. Experience from percutaneous mitral repair trials indicates that slow enrolment rates are a limiting factor.

The success of TMVR procedures relies in CT ability to segment the mitral annulus, assess the device landing zone, and predict the post procedural neo-LVOT area. Optimization of device sizing can be achieved through 2D planar projection of the 3D mitral annulus, giving area, perimeter, and linear dimensions of the valvular space. Proper characterization of the landing zone, especially with respect to mitral annular calcification (MAC), myocardial shelf (functional mitral regurgitation), and mitral annular disjunction (MVP), can have a significant impact on procedural outcomes. The neo-LVOT measurement developed and proposed on the basis of CT data has been shown to accurately discriminate the risk of LVOT obstruction and its associated poorer clinical outcomes [9]. Yoon et al. showed that a neo-LVOT area of ≤ 1.7 cm^2 predicted LVOT obstruction with a high sensitivity and specificity [10••, 11].

Furthermore, the use of TAVR valves for failed bio prosthetic heart valves or rings, and patients with severe mitral annular calcification requiring valve in valve (ViV), valve in ring (ViR), and valve in mitral annular calcification (ViMAC), has required the development of tailored imaging protocols. Preliminary results indicate that while the outcomes of ViV are encouraging, ViR and ViMAC are more technically challenging and associated with worse outcomes especially with respect to paravalvular regurgitation in ViR and LVOT obstruction with ViMAC [11]. The TMVR in MAC global registry rates of LVOT obstruction was 11.2% and was associated with 30-day and 1-year survival of 48% and 15%, respectively [12]. Several approaches of mitigating risk of neo-LVOT obstruction are under investigation for this high-risk subset including anterior mitral leaflet laceration (Lampoon) [13], resection of anterior mitral leaflet (AML) and myomectomy in case of trans atrial access [14], alcohol septal ablation [15], or devices designed to grasp the AML. CT is routinely used to understand patient-specific anatomy and risk of these complications. There is also growing interest in the potential of computational fluid dynamics (CFD) based on CT imaging data in assessing the dynamic nature of the neo-LVOT [16].

It is unlikely that the future of TMVR will be resolved by the use of a one-size-fits-all device. The nature of the pathology being heterogeneous will require multiple devices and treatment strategies to help tackle the many drivers of mitral regurgitation. There are devices that address (1) leaflet non-coaptation such as MitraClip and Pascal, (2) annular distention—direct and indirect percutaneous annuloplasty devices that help cinch the annulus and reduce septal-to-lateral distention, and (3) valve replacement. This will require utilization of multimodality imaging in order to identify reproducible parameters leading to improved device selection, and hopefully, positive clinical outcomes. Additionally, positive outcome of the COAPT study may require future investigators to put TMVR in head-to-head comparison with transcatheter repair. The burden of proof remains in determining wherein ends the added benefit of each approach, but it is certainly CT that will be front line in this determination, as it is already the preferred modality for pre-procedural planning and identification of unfavorable anatomy. Currently, TMVR trials have rejection rates of up to 70%, partially due to CT highlighting unsuitable anatomy [17].

Tricuspid Valve

Increased awareness of the morbidity and mortality from right heart failure due to severe tricuspid regurgitation has refocused attention to the "forgotten valve." The burden of tricuspid regurgitation is significant with estimates showing that 1.2–1.5% of the general population in the USA has more than moderate valvular incompetence [18]. Secondary or functional regurgitation is the etiology in the vast majority. There is still a lot to learn about the rate of progression, optimal timing, and optimal intervention of tricuspid regurgitation. Isolated tricuspid valve surgery has the highest mortality of all isolated valve surgery possibly due to the nature of co-morbidities in this population, late referral, and prior cardiac surgery [19]. Due to the high surgical risk and building on the experiences of TAVR and TMVR, there is burgeoning interest in a less invasive THV treatment approach in the tricuspid space.

There are several technical advantages to THV interventions in the tricuspid position as compared with TMVR. Several access points like transjugular, transatrial, and transapical are more feasible for the right side of the heart. Central veins are more accommodating to the larger devices. The lower pressure system may render anchorage more feasible. Finally, the tricuspid-pulmonic discontinuity mitigates the risk of right ventricular outflow tract (RVOT) obstruction, in contrast to the mitral valve and LVOT.

In comparison with the mitral annulus (MA), the tricuspid annulus (TA) is larger, and while also saddle-shaped, is more planar at baseline and, like functional MR, gets more planar with progression of tricuspid valve disease [20]. Off-label use of mitral annular segmentation software to analyze the tricuspid annulus has been reported and CT is likely to be the preferred method for valve sizing [21]. CT can easily discern surrounding structures like the coronary sinus and IVC. Additionally, due to the functional nature of the pathology, the TA should be assessed as a component of a more comprehensive assessment of the right ventricle, pulmonary vasculature, and left-sided pathology.

To our knowledge, the Gate Navigate (NaviGate Cardiac Structures Inc., Irvine, California) is the only THV specifically designed to manage secondary tricuspid regurgitation. It is a self-expanding bioprosthetic valve with a truncated conical frame. Human implantations have already occurred under compassionate care with the largest valve being 52 mm implanted through the jugular vein [22]. It is important to note that the development of THV specific to the tricuspid valve is in conjunction with the growing off-label use of MitraClip in the percutaneous repair of tricuspid regurgitation. Like in the mitral space, CT will have an indispensable role in optimal therapy selection [23]. The evolution of transcatheter tricuspid valve therapies appears inevitable.

Pulmonic Valve

Similarly, transcatheter approaches for the treatment of pulmonary valve disease have emerged and demonstrated good patient outcomes [24–26]. While TAVR has been utilized in an older patient population, pulmonary transcatheter heart valve (THV) interventions target a younger patient population, requiring long-term structural valve durability. In 2000, Bonhoeffer et al. described the pulmonary THV procedure in a 12-year-old patient [27]. The patient cohorts undergoing pulmonary THV intervention typically have a background of congenital heart disease, such as surgically corrected Tetralogy of Fallot (TOF) and subsequent development of RVOT, pulmonary valve, or surgical conduit pathology. Longer term sequelae of TOF corrective surgery include free pulmonary regurgitation if a transannular patch was performed, conduit regurgitation or stenosis if a surgical conduit was utilized, or a dysfunctional bioprosthetic pulmonary valve [28]. In treating this younger patient population with pulmonary THV procedures, the treatment goal is to reduce the number of surgical interventions over the patients' lifetime. Cardiac imaging can guide the interventional planning, by providing detailed pulmonary valve anatomy, along with main pulmonary artery size and configuration (length, diameters, and calcifications). The imaging description of the so-called "landing zone" is crucial for the success of the procedure. There are anatomical variations and different conduits and RVOT patch repair methods and this must be known a priori for optimal valve type and size selection [28]. Examples of pulmonary THV currently available include the Melody valve (Medtronic), Sapien XT, and the Sapien 3 (Edwards) [29]. These are bovine tissue valves attached to a stent frame, mounted in a balloon catheter. The Melody valve tissue originates from bovine jugular vein tissue, and the Sapien valves are manufactured from pericardial bovine tissue. The Sapien valves are available across a broader size range, which permits its use in a larger native RVOT. With improving technology and broader indications, it is anticipated that a larger patient cohort will have suitable anatomy for pulmonary THV procedures [30]. Newer devices currently being investigated include the Venus p-valve (Medtech, Shenzen, China), Harmony TPV (Medtronic), Pulsta, and Alterra (Edwards Lifesciences) [31]. The latter is a valve-less stent, which permits deployment of the Sapien 3 valve in anatomical situations with irregular landing zones.

Conclusions

We are in the beginning of a new wave of implementation of THV interventions in the management of valvular heart disease. The role of cardiac CT to carefully plan these interventions for optimal outcomes is well established and has grown exponentially over the last decade and it will undoubtedly continue to grow.

Compliance with Ethical Standards

Conflict of Interest Marcelo Godoy, Ahmed Mugharbil, and Malcom Anastasius declare that they have no conflict of interest.

Jonathon Leipsic reports receiving institutional support from Edwards, Medtronic, and Abbott. He is also a consultant for Circle CVI and Heartflow.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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