

Evaluating the Use of MSCT and Fluoroscopy in Transcatheter Mitral and Tricuspid Valve Interventions

A presentation of MSCT-derived fluoroscopic angulations to help guide practitioners performing complex mitral and tricuspid valve repair and replacement procedures.

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With the development of specific transcatheter techniques for the treatment of both mitral and tricuspid valves, anatomic planning for percutaneous valve interventions has become crucial. The use of multislice CT (MSCT) multiplanar reconstruction allows for the identification of optimal fluoroscopic viewing angles of left- and right-sided heart structures, particularly the most challenging anatomic structures: the mitral and tricuspid valve complexes.¹⁻⁴ In this article, we describe the role of MSCT and fluoroscopy in transcatheter interventions for treating the mitral and tricuspid valves.

ATTITUDINAL ORIENTATION

Cardiac structures in this article are described according to their attitudinal orientation as explained by Thériault-Lauzier et al.³ These descriptions provide a consistent nomenclature for both fluoroscopic and MSCT imaging of the heart. With the patient facing the observer and standing upright, structures closer to the observer are described as anterior and those farther away as posterior. Components positioned closer to the head are superior (ie, cranial), with those toward the feet described as inferior (ie, caudal). Structures on the right-hand side of the patient are right sided and vice versa for left-side structures.³

MULTIMODALITY MSCT AND FLUOROSCOPIC IMAGING OF THE HEART

Fluoroscopy is an imaging technique affected by parallax, which is a consequence of its two-dimensional (2D) nature. As such, the operator needs to select multiple viewing angles to achieve accurate and exhaustive three-dimensional (3D) spatial information. Conversely, MSCT is a 3D volume acquisition technique that is not affected by parallax, which preserves the spatial resolution in all imaging planes. For any particular structure, and in this specific setting for the orifices of atrioventricular valves, an optimal fluoroscopic viewing angle can be calculated to achieve minimal errors in device positioning due to parallax. In this fluoroscopic projection, the source-to-detector direction is orthogonal to the axis of symmetry of the anatomic structure of interest. The direction of structures can be obtained by accurate analysis of the MSCT images with the creation of an optimal projection curve (ie, S-curve),^{5,6} which allows for the selection of an optimal fluoroscopic angle of a given anatomic structure of interest. In addressing structural procedures targeting both the mitral and tricuspid valves, the surrounding cardiac structures (eg, papillary muscles, coronary sinus) must be distinguished for the accurate implantation-specific

TABLE 1. FLUOROSCOPIC CHAMBER VIEWS AND CORRESPONDING MSCT IMAGING OF TRICUSPID AND MITRAL VALVES

Tricuspid Valve				Mitral Valve			
Nomenclature	Fluoroscopic Angle	Fluoroscopic View	MSCT	Nomenclature	Fluoroscopic Angle	Fluoroscopic View	MSCT
One-chamber (short-axis) view	LAO, 55°; CAU, 15°			One-chamber (short-axis) view	LAO, 50°; CAU, 20°		
RH two-chamber view	RAO, 60°; CAU, 50°			Three-chamber view	RAO, 60°; CAU, 45°		
RH three-chamber view	RAO, 25°; CRA, 15°			Two-chamber view	RAO, 30°; CRA, 15°		
Four-chamber view	LAO, 5°; CRA, 60°			Four-chamber view	LAO, 10°; CRA, 60°		

Abbreviations: CAU, caudal; CRA, cranial; LAO, left anterior oblique; MSCT, multislice CT; RAO, right anterior oblique; RH, right heart.
Color-coded chamber views: one-chamber view (blue); two-chamber view (yellow); three-chamber view (red); four-chamber view (green).

devices by using specific fluoroscopic angulations that provide maximal separation between such structures.

In this article, we present general fluoroscopic angulations obtained by analyzing multiple MSCT scans that could play a role in guiding the operator during complex mitral and tricuspid procedures. However, although cardiac structures across patients are similar in orientation, exact fluoroscopic views are prone to some extent of variability on a patient-by-patient basis.⁴ Precise fluoroscopic angulations for procedural planning should be obtained for each patient by using dedicated MSCT software packages. FluoroCT version 3.2 (Circle CVI) was used to create the fluoroscopic and MSCT images presented in this article.

Table 1 and Figure 1 summarize the main fluoroscopic chamber views of the left and right heart together with their corresponding angulations and MSCT counterparts with potential interest for the guidance of interventions targeting the mitral and tricuspid valves. Table 2 summarizes the potential role of MSCT and fluoroscopic views in the planning of and guidance for transcatheter mitral and tricuspid valve repair or replacement procedures.

MSCT Imaging Acquisition of the Left and Right Sides of the Heart

A quality contrast-enhanced image of the left heart is essential for preprocedural assessment before transcatheter mitral valve (TMV) repair or replacement. An adjunct noncontrast acquisition of the mitral valve with the same imaging parameters of a coronary artery cal-

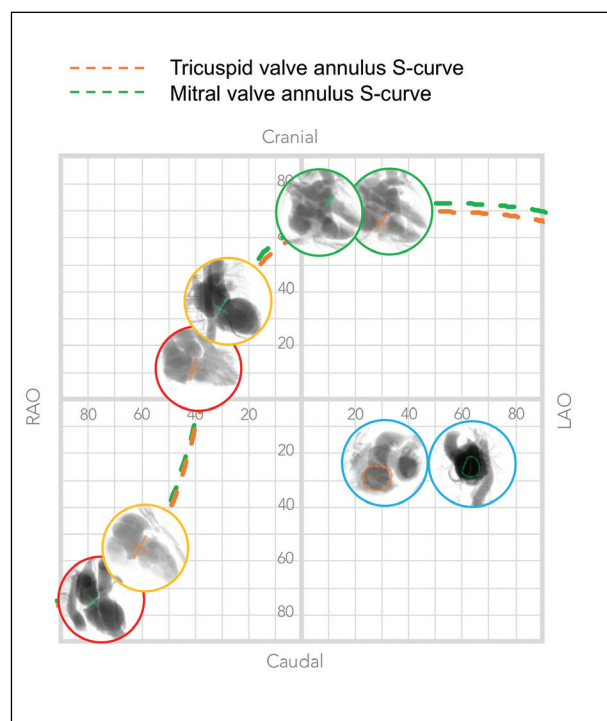


Figure 1. Optimal projection curves and fluoroscopic chamber views of the mitral and tricuspid valves. The optimal projection curve of the mitral annulus is plotted as a green dashed line and the tricuspid annulus is plotted as an orange dashed line. The region of fluoroscopic images corresponding to each of the chamber views are indicated by color-coded circles corresponding to the one-chamber (blue), two-chamber (yellow), three-chamber (red), and four-chamber (green) views.

TABLE 2. ROLE OF MSCT AND FLUOROSCOPY IN GUIDING TRANSCATHETER INTERVENTIONS FOR MITRAL AND TRICUSPID VALVES

Interventional Actions	Mitral Valve		Tricuspid Valve	
	MSCT	Fluoroscopy	MSCT	Fluoroscopy
Manipulation of devices in the atrium	Left atrium linear dimensions	Four-chamber view: AS and MA both in plane	Right atrium linear dimensions	RH two-chamber view
Transseptal puncture	Preferred site, angulation, and height for the puncture	Four-chamber view: visualization of the AS in plane; three-chamber view: visualization of the AS en face	—	RH two-chamber view: visualization of the AS en face
Navigation into the ventricular cavity and apex	Position of the papillary muscles	Two-chamber view: maximal separation between IA-SP papillary muscles	Position of the papillary muscles	RH two-chamber view: maximal separation between A-P papillary muscles
LVOT and RVOT obstruction	Angle between the mitral and aortic valves	Three-chamber view: (maximal separation between mitral and aortic valves)	Angle between the tricuspid and pulmonary valves	—
Coaptation	—	Two-chamber view: separation of the scallops; three-chamber view: differentiate A-P leaflets	—	RH two-chamber view: separation A-P leaflets; RH three-chamber view: differentiate P-S leaflets; four-chamber view: differentiate AS leaflets
Anchoring devices onto the annuli	Distance to the CS	One-chamber view: en face view of the mitral annulus plus visualization CS	Distance to the RCA	One-chamber view: en face view tricuspid annulus plus visualization of the RCA
Valve replacement	Linear dimensions, quantification, and presence/severity of annular calcifications	Two-chamber view, three-chamber view: visualization of the MA in plane	Linear dimensions	RH three-chamber view, RH two-chamber view: visualization of the TA in plane

Abbreviations: A-P, anterior-posterior; AS, atrial-septum; CS, coronary sinus; IA-SP, inferoanterior and superoposterior; LVOT, left ventricular outflow tract; MA, mitral annulus; MSCT, multislice CT; P-S, posterior-septal; RCA, right coronary artery; RH, right heart; RVOT, right ventricular outflow tract; TA, tricuspid annulus.

cium score can be performed before the angiographic study to quantify the extent of valve calcification. Contrast-enhanced MSCT can be obtained by (1) using prospective electrocardiography (ECG) triggering to obtain images in the optimal phase of the cardiac cycle, or (2) scanning throughout the cardiac cycle and using ECG synchronization with postprocessing reconstruction of the images in the desired phase. Scan timing is guided by a bolus triggering, with a region of interest activated by a preselected minimum Hounsfield unit (HU)—typically 150 HU. Preassessment scans for TMV repair or replacement are triggered from the left ventricle, allowing optimal enhancement of the left heart and interatrial septum. For pre-TMV repair or replacement CT, an ECG-gated acquisition is limited to the heart. Should a transapical approach be considered, an additional nongated low-dose CT chest scan can be performed to aid apex localization and septal puncture.⁷

Because of the complexity and dimensions of the tricuspid valve, the acquisition of high-quality MSCT images is often challenging with the need for specific protocols to obtain adequate opacification. Protocols are less standardized for the study of the right heart and tricuspid annulus. The following strategies were proposed by van Rosendael et al for using MSCT to plan tricuspid valve therapies: (1) three phases of ionic contrast medium through the antecubital vein including 60 to 80 mL of contrast with a flow rate of 5 to 6 mL/s, a 20-mL mixture of one part contrast to one part saline, and 25 mL of saline; (2) initiation of scanning synchronized to the arrival of the contrast material in the left ventricle using automated peak enhancement detection with a threshold of 180 HU; and (3) reconstruction of the MSCT data of the entire cardiac cycle, triggered by the ECG, at each 10% of the RR interval and additionally at 30% to 35% and 75%

for systole and diastole.⁸ Other protocols suggest using a combination of the patient's weight, left ventricular ejection fraction, and heart rate.⁹

TMV REPAIR AND REPLACEMENT

Mitral regurgitation (MR) is one of the most prevalent valvular heart diseases, with a prevalence of moderate and severe MR in 2 to 2.5 million people in the United States and affecting around 10% of those older than 75 years.¹⁰ Surgical mitral valve repair or replacement is the gold standard treatment for MR. In particular, because of strong data on superior long-term outcomes after repair, the treatment of degenerative MR has evolved from mitral valve replacement to mitral valve repair.¹¹ A proportion of patients are affected by secondary or functional MR, for which the benefit over mitral valve replacement is less certain. However, recent randomized trials highlight percutaneous mitral valve repair; in particular, the COAPT trial showed superior outcomes for short-term mortality and improvement in quality of life.¹²

Although surgery remains the gold standard treatment for significant MR, mitral valve surgery is deferred in a large number of patients because of the high surgical risk, with some studies finding that up to one-half of the patients with severe symptomatic MR were not referred for surgery.¹³ This phenomenon is partly related to a decrease in the prevalence of rheumatic valve disease that is associated with a prolonged life expectancy and has led to an increase in the prevalence of degenerative mitral valve disease. Therefore, symptomatic patients presenting with severe MR who are potential candidates for surgery are often characterized by advanced age, comorbidities, and left ventricular dysfunction, which lead to increased mortality and refusal of surgical treatment, particularly in octogenarians.¹⁴

TMV repair and replacement may have the potential to become an alternative to treat severe MR in patients who are at high surgical risk because of its potential to reduce MR to a similar extent as surgery while reducing procedural risks. The mitral valve complex is a functional unit that depends on the integrity and interplay of its different components (ie, the tendinous cords, papillary muscles, left atrioventricular junction, and valvular leaflets). The mitral valve presents two leaflets that can be defined using a classical (anterior, aortic, or anterosuperior) or attitudinal (posterior, mural, or posteroinferior) description.

Although the mitral valve has a nonplanar saddle-shaped configuration consisting of two elevated peaks that attach to the anterior and medial fibrous trigones, the aortomitral continuity, area, and perimeter of the valve can be readily assessed using MSCT.¹⁵ By using MSCT, the operator is able to investigate landing zone

calcification and determine its severity, distribution (localized or diffused), and extent on the valve leaflets. Moreover, it can differentiate the pattern and quality of mitral annular calcification that is important for guiding device selection, although its characterization is still largely operator dependent.⁷ This assessment is achieved using specialized software to systematically place seeding points at regular intervals along the mitral valve annulus. Once the mitral valve annulus has been delineated, it is possible to obtain standard measurements including the 2D area, perimeter, and intercommissural, septal-lateral, and intertrigonal distances. The role of each measurement depends on the specific device in use, with different annular sizing methods integrated into the different manufacturers' guidelines.

The optimal projection curve of the mitral valve annulus demonstrates a steep slope in the right anterior oblique (RAO) region and presents an en face view in a left anterior oblique (LAO)/caudal view. Given the significant variation in patient anatomy, the atrioventricular valve orifices' orientations can be derived from the specific MSCT study to predict appropriate fluoroscopic angles to cross the interatrial septum, predict the best coaxial projection to implant the device, and reduce procedure time, contrast medium volume, radiation exposure, and possible complications while ensuring precise positioning.

MSCT-Derived Fluoroscopic Views to Guide TMV Repair or Replacement

One-chamber view. The fluoroscopic one-chamber view shows the short axis of the mitral valve and the mitral valve annulus en face. It can be obtained by achieving a moderate LAO projection with a mild caudal angulation (average angulation: LAO, 50°; caudal, 20°). This projection elongates the coronary sinus path, the trajectory of which can be of interest for the placement of dedicated annuloplasty devices.

Two-chamber view. The fluoroscopic two-chamber view shows the major axis of the mitral valve and allows for differentiation among the overlapped A1/P1, A2/P2, and A3/P3 segments, an aspect of particular importance during the placement of clips. It can be obtained using a mild RAO projection with a mild cranial angulation (average angulation: RAO, 30°; cranial, 15°). This projection shows the inferoanterior and superoposterior papillary muscles maximally separated, which reduces the likelihood of complications while steering devices in the left ventricular cavity.

Three-chamber view. A fluoroscopic three-chamber view shows the maximal separation between the anterior and posterior leaflets of the mitral valve and could play a role in achieving correct grasping of the two

leaflets when used together with echocardiographic guidance. It can be obtained using an extreme RAO projection with moderated caudal angulation (average angulation: RAO, 60°; caudal, 45°). In this view, both the anterior (A1-A2-A3) and posterior (P1-P2-P3) scallops are overlapped, preventing precise positioning of the device along the mitral commissure. In this fluoroscopic projection, the aortic and mitral valves are separated and in plane and it is possible to observe the aortic-mitral curtain separated from the left atrium and the aortic root. The three-chamber view could be useful to assess any possible interaction between the prosthesis and left ventricular outflow tract (LVOT) during TMV replacement or valve-in-valve interventions, preventing the potential risk of LVOT obstruction.

Four-chamber view. The fluoroscopic four-chamber view allows the full separation between the right and left atria and ventricles to be observed. It can be obtained by achieving a mild LAO/RAO projection with an extreme cranial angulation (average angulation: LAO, 10°; cranial, 60°). With some adjustments of the angulation, this projection shows the interatrial septum and the mitral valve annulus in plane.

TRICUSPID VALVE INTERVENTIONS

Isolated tricuspid regurgitation (TR) is prognostically significant.¹⁶ For a long time, surgical avoidance of tricuspid valve repair in patients with functional TR secondary to left heart disease was accepted based on the incorrect idea that TR would resolve once the primary left heart disease had been treated. Recently, the severity of TR has been shown to have a negative impact on prognosis after surgical and transcatheter interventions in the aortic and mitral valves.¹⁷ Additionally, guidelines have reported evidence in favor of a more aggressive surgical approach.¹¹ Moderate to severe TR affects 1.6 million patients in the United States, of whom only 8,000 undergo tricuspid surgery annually¹⁸; this results in a large number of untreated patients with significant TR. An analysis of national trends in surgery for TR has shown that between 2004 and 2013, tricuspid valve replacement was performed in 59.2% of patients, whereas tricuspid valve repair was performed in 40.8%.¹⁹ Percutaneous procedures become an attractive alternative to surgery for patients deemed to be high-risk candidates and different tricuspid transcatheter devices have been developed to treat functional TR.^{20,21} Although few data have been reported on first-generation transcatheter tricuspid valve replacement devices, current data have shown technical feasibility and early positive results on right ventricular remodeling and increased cardiac output.¹⁹

The tricuspid valve is the largest among the four cardiac valves. When compared with the mitral valve, the tricuspid valve is located more apically ~10 mm), anteriorly, and to the right. The tricuspid valve annular plane is oriented nearly vertically and is rotated around 45° from the sagittal plane.²² The tricuspid valve complex can be divided into four components: (1) the fibrous annulus with attached atrium and ventricle—a complex, saddle-shaped, dynamic structure with its higher points in the anterosseptal and posterolateral portions and lower points in anterolateral and posteroseptal portions; (2) the three leaflets; (3) the papillary muscles; and (4) the chordal attachments. Considering the attitudinal orientation of the heart, the tricuspid valve leaflets can be designated as posterior, anterior, and inferior, corresponding to their classical definitions of septal, anterior, and posterior, respectively.²³ The three tricuspid leaflets vary in both circumferential (annular) and radial size. Three commissures (anteroseptal, anteroposterior, and posteroseptal) separate the leaflets.

For the tricuspid valve, the presence of severe regurgitation could affect the dimensions of the annulus, which often dilates in a septolateral direction,²⁴ and heightens the importance of performing an accurate analysis of the MSCT on a patient-by-patient basis during procedural planning. Transcatheter interventions targeting the tricuspid valve require accurate positioning of delivery catheters with particular care to the relationships with the tricuspid valve components (eg, clips or screws). Similar to the mitral valve, the optimal projection curve of the tricuspid valve annulus demonstrates a steep slope in the RAO region and presents an en face view in the LAO/caudal view.²⁵

MSCT-Derived Fluoroscopic Views to Guide Transcatheter Tricuspid Interventions

One-chamber view. The one-chamber view can be obtained by achieving an LAO projection with a variable degree of caudal angulation (average angulation: LAO, 55°; caudal, 15°). It corresponds to the en face view of the tricuspid valve and short axis of the right ventricle. In this view, it is possible to appreciate the trajectory of the right coronary artery. The proper distance between the right coronary artery and the tricuspid valve annulus is essential to avoid complications during the placement of screws (eg, percutaneous annuloplasty).

Two-chamber view. The two-chamber view can be obtained by placing the C-arm in an RAO projection with a variable degree of caudal angulation (average angulation: RAO, 60°; caudal, 50°). This view can help identify the attachments of the anterior and posterior

leaflets of the tricuspid valve to the atrioventricular junction. The components of the subvalvular apparatus (ie, the anterior and posterior papillary muscles) are maximally separated in the two-chamber view. Therefore, this particular angulation can facilitate the placement of dedicated devices targeting the right ventricular apex by navigating the ventricular space safely while lowering the risk of entrapment in the subvalvular structures when the papillary muscles are maximally separated. The right-heart two-chamber view shows the interatrial septum en face and could be useful in ruling out a possible overlap with the aortic root during transeptal puncture.

Three-chamber view. The three-chamber view is in an RAO projection with a mild degree of cranial angulation (average angulation: RAO, 25°; cranial, 15°). It allows the visualization of the attachments of the posterior and septal leaflets. In this view, the anterior and posterior tricuspid papillary muscles appear overlapped.

Four-chamber view. The four-chamber view can be obtained using an LAO (or a minimal RAO) projection with an extreme cranial angulation (average angulation: LAO, 5°; cranial, 60°). An extreme cranial angulation with the tricuspid valve in plane allows for the visualization of the anterior and septal leaflet attachments.

CONCLUSION

Although precise angulations should be obtained on a patient-by-patient basis, this article provides a general set of fluoroscopic angles and chamber views derived by the analysis of multiple MSCT scans. A multi-imaging approach may improve the understanding of the cardiac anatomy through different imaging modalities, provide guidance during structural procedures, and lay the foundation for a common language among operators involved in these complex interventions. ■

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Disclosures: None.

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Disclosures: Consultant to and proctor for HighLife, Medtronic, MicroPort; consultant to Cephea Valve Technologies.