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# Preprocedural planning of transcatheter mitral valve interventions by multidetector CT: What the radiologist needs to know

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ABSTRACT

Mitral regurgitation is the most common valve disorder in the Western world, and although surgery is the established therapeutic gold standard, percutaneous transcatheter mitral interventions are gaining acceptance in selected patients who are inoperable or at an exceedingly high surgical risk. For such patients, multidetector computed tomography (MDCT) can provide a wealth of valuable morphological and functional information in the preoperative setting. Our aim is to give an overview of the MDCT image acquisition protocols, post-processing techniques, and imaging findings with which radiologists should be familiar to convey all relevant information to the Heart Team for successful treatment planning.

## 1. Introduction

Although surgery is the gold standard treatment for patients with symptomatic mitral regurgitation (MR), transcatheter mitral valve interventions have emerged over the last decade as a viable option in selected patients with unacceptably high surgical risk [1,2]. According to the 2017 ESC Guidelines, transcatheter mitral valve repair (TMVRep) may be considered for symptomatic patients with severe chronic MR who are at high surgical risk or are inoperable, and should be discussed by the Heart Team to avoid futile treatment [2]. Similarly, the 2017 update of the 2014 American College of Cardiology/American Heart Association (ACC/AHA) has stated that TMVRep may be considered for severely symptomatic patients (NYHA class III to IV) with chronic severe primary MR (stage D) who have favourable anatomy for the repair procedure and a reasonable life expectancy, but have a prohibitive surgical risk because of serious comorbidities and remain symptomatic despite optimal management and therapy for heart failure [3].

While surgery can be performed through direct or videoendoscopic guidance, transcatheter-based approaches cannot, making periprocedural imaging a key step for treatment planning. In this context, multidetector computed tomography (MDCT) has proved to be a robust imaging modality that can yield valuable information for accurate and safe treatment planning.

Our purpose is threefold:

- to explain the rationale for the use of MDCT in the preoperative planning of transcatheter mitral valve interventions
- to describe suitable MDCT image acquisition protocols and post-processing techniques for treatment planning
- to discuss the main MDCT findings that radiologists need to assess and convey to the Heart Team.

## 2. Pathophysiology of MR

MR is defined as the abnormal backflow of blood from the left ventricle into the left atrium due to malfunction (either primary or secondary) of the mitral valve system, and is the most common manifestation of valve dysfunction in the Western world.

In organic (or primary) forms, MR is caused by anatomical changes affecting one or more components of the mitral valve complex. MR has most often a degenerative aetiology, including mitral prolapse, flail mitral leaflet, post-endocarditic or (once common, but now rare in industrialised countries) post-rheumatic sequelae. On the other hand, functional (or secondary) MR is characterised by the presence of mitral regurgitation in the absence of organic lesions. In this latter case, MR is secondary to both regional and global ventricular remodelling (usually

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secondary to ischaemic or dilated idiopathic cardiomyopathy) [4–7].

The mechanism of MR has been classified by Carpentier et al. on the basis of the opening and closing motions of the mitral leaflets into the following four types:

- Type I: normal leaflet motion (annular dilatation, leaflet perforation)
- Type II: excessive leaflet motion (leaflet prolapse)
- Type IIIa: restricted leaflet motion during both diastole and systole, often associated with leaflet thickening and commissural fusion (as typically found in rheumatic disease)
- Type IIIb: restricted leaflet motion during systole (leaflet tethering due to left ventricular remodelling and displacement of papillary muscles) [8].

Under normal conditions, the mitral valve is hermetically closed during systole, thus preventing retrograde blood flow from the left ventricle into the left atrium. In contrast, in patients with MR, a fraction of the left ventricular blood volume flows back into the left atrium during systole and is returned into the left ventricle during diastole, progressively leading to left ventricular volume overload. As a consequence, left ventricular remodelling with dilation and compensatory hypertrophy will occur, and the amount of blood pumped into the aorta (effective cardiac output) will tend to decrease, resulting into a reduction in cardiac output. On the left atrial side, MR can lead to different alterations in relation to its severity, but above all depending on its onset being acute or chronic:

- In acute MR (e.g. secondary to rupture of chordae tendineae or a papillary muscle due to acute myocardial infarction), there is no progressive adaptation of the left atrium to the sudden volume overload, and hence no left atrial dilation. This leads to a rapid increase of left atrial and pulmonary venous pressures that typically evolves towards acute pulmonary oedema.
- Chronic MR is characterised by a progressive adaptation of the left atrium, which tends to expand. Over time, the left ventricle may develop a loss of contractile efficiency due to prolonged volume overload with an increase in end-diastolic pressure. Moreover, left ventricular dilation may lead to dilation of the mitral annulus, which further increases MR severity in a potential downward spiral towards chronic heart failure [4,5,9].

## 3. Transcatheter mitral valve procedures: when and how?

In the past years, several transcatheter mitral valve procedures have been developed building on existing surgical techniques as a conceptual framework.

The MitraClip NT® system (Abbott Vascular, Santa Clara, CA) is a mitral valve repair system that mimics the 'edge-to-edge' repair described by Maisano et al. [10]. As its name suggests, it consists of a clip that allows capturing both the anterior and posterior mitral leaflets with its two arms, resulting in shrinking of the regurgitant mitral valve orifice. TMVRep with Mitraclip® is performed using a trans-septal approach with 3D-transesophageal echocardiography as the gold standard for preprocedural planning and intraoperative guidance, although MDCT can provide incremental anatomical data such as for the severity assessment of mitral valve calcifications (which may interfere with or contraindicate device implantation) [6,11,12]. Among current percutaneous treatment options, Mitraclip®-based edge-to-edge TMVRep is the most commonly performed transcatheter mitral valve procedure, has gained both CE and FDA approval, and although the rate of residual MR up to 5 years is higher than with surgical repair, it is generally safe and can improve symptoms while inducing reverse left ventricular remodelling [13].

Alternative devices for percutaneous treatment of functional MR are available such as the Cardioband System® (Valtech Cardio, Or Yehuda, Israel) and the CARILLON Mitral Contour System® (Cardiac Dimensions, Inc., Kirkland, WA), which have been developed for direct and indirect transcatheter mitral annuloplasty procedures, respectively. The Cardioband® system is a catheter-based device that functions as a percutaneous annuloplasty band. Using a transvenous and trans-septal approach, the Cardioband® device is deployed via multiple screw fixation on the posterior mitral annulus from the anterolateral to the posteromedial commissures, with intraprocedural adjustment to reduce the septolateral diameter of the mitral annulus and restore leaflet coaptation, resulting in a direct 'surgical-like' annuloplasty. On the other hand, the CARILLON Mitral Contour System® consists of a proximal anchor and a distal anchor connected by a shaping ribbon, and is positioned in the coronary sinus and great cardiac vein using standard cardiac catheterisation techniques. The CARILLON implant is a fixed length, double anchor device designed to plicate the tissue next to the mitral annulus during the deployment process.

While the Mitraclip NT® system can be used for percutaneous repair of both primary (type II of Carpentier's classification) and functional (type I-IIIb) MR, direct and indirect percutaneous mitral annuloplasty is confined to functional MR only (with mitral annulus dilation and apical displacement of papillary muscles).

The device armamentarium for percutaneous mitral valve interventions has significantly expanded over the last years with the introduction of new systems for transcatheter mitral valve replacement (TMVR), including the CardiAQ-Edwards® valve (Edwards Lifesciences; Irvine, CA), Tiara® valve (Neovasc Inc; Richmond, BC), Tendyne® valve (Abbott Vascular, Santa Clara, CA), Intrepid TMVR® system (Medtronic Inc, Redwood City, CA), Caisson TMVR® system (LivaNova PLC, Maple Grove, MN), MValve® (MValve Technologies Ltd, Herzliya, Israel), and HighLife valve® (HighLife Medical, Irvine, CA) as some examples. Such evolution has been driven by anatomical and pathophysiological factors related to the D-shape of the mitral annulus and the heterogeneous pathogenesis of MR, leading to prosthesis designs that differ mostly in the valve anchoring mechanisms (i.e. apical tether, native leaflet engagement, mitral annulus clamping, annular winglets, radial force, external anchor, subannular mitral ring or mitral annulus clamping). TMVR procedures may offer several advantages over TMVRep in primary (organic) forms of MR, but their role in treating secondary (functional) types of MR has not yet been established. Moreover, there is still uncertainty about the best implantation modality for mitral devices. In fact, the majority of percutaneous mitral valve prostheses are positioned via a transapical approach (i.e. through puncture of the left ventricular apex), whereas others are deployed through a trans-septal (venous) approach, which would be ideal in highest risk patients [11,12,14,15]. Encouraging data have recently been provided by a feasibility study (NCT02321514) about the effectiveness and safety of transapical TMVR using a self-expanding device in patients with native MR at high risk for cardiac surgery, resulting in NYHA functional class improvement with mild or no symptoms in 75% of patients and successful device implantation without cardiovascular mortality, stroke, and device malfunction in 86.6% of patients at 30-day follow-up [16].

## 4. MDCT image acquisition protocol

### 4.1. General considerations

While cardiac ultrasound is the gold standard for diagnosing, grading and monitoring mitral valve disease before and after treatment