Introduction

The prevalence of chronic total occlusions (CTOs) has been reported up to 15% to 30% among patients with suspected or known coronary artery disease[1].

Decision of revascularization mode (percutaneous coronary intervention (PCI) or coronary artery bypass grafting surgery) mainly depends on concomitant significant left main and/or multivessel coronary artery disease[2].

The main treatment targets are relief of symptoms, improvement in left ventricular (LV) functions and survival[3,4].

Some studies showed that opening of CTO is associated with significantly lower mortality than leaving CTO, though other reports did not confirm these observations[5-9].

However, no data exist on regarding possible improvement will occur in right ventricular (RV) functions after successful recanalization of right coronary artery (RCA) CTOs. Novel echocardiographic approaches like tissue Doppler imaging (TDI) improved the assessment of myocardial functions in both LV and RV, and may identify subtle changes in response to revascularization procedures[10-12].

Aim of the Work

The aim of this study is to assess right ventricular functions in patients with right coronary artery chronic total occlusion according to Rentrop class of collaterals in addition according to presence of ECG evidence of INF MI.

The Echocardiographic Assessment of the Right Ventricle

Introduction

For decades, the right ventricle (RV) has been considered 'dispensable' for cardiac function and consequently ignored. Only in the second half of the past century, after recognizing its key role in various physiological and pathological conditions the RV regained attention[13–17].

The RV performance defines prognosis in patients with congenital heart disease. In this population group, the RV may be subjected to either volume (atrial septal defect, pulmonary, and/or tricuspid regurgitation) or pressure overload (pulmonary stenosis, atrial switch operations, congenitally corrected transpositions). Assessing RV morphology and function is of paramount importance in acquired diseases as well. The RV has a great impact on the prognosis of patients with pulmonary hypertension, myocardial infarction involving the RV, and left ventricular (LV) dysfunction[17,18].

Echocardiography, being non-invasive, widely available, relatively inexpensive, and having no side effects, is the modality of choice for the assessment of morphology and function of the RV in clinical practice. Recent developments have provided several new methods

for analysing the RV, each having advantages and disadvantages. Doppler myocardial imaging (DMI), speckle tracking, or3D echocardiography (3D Echo) are some of the techniques that may now add to a better understanding of RV function.

Anatomy and physiology of the right ventricle:

The RV is positioned directly behind the sternum, anterior to the left ventricle (LV). It has a complex geometry, appearing triangular when viewed from the front, and crescentic when viewed in a transverse section of the heart, with the septum being the most important determinant of shape. Under normal loading conditions, the septum arches in to the RV both in systole and diastole. This complex geometry cannot be fitted to simple geometric models, which presents important limitations for the estimation of RV volume and function based on two-dimensional (2D) tomographic views. In a normally developed RV with atrioventricular and ventriculoarterial concordance and normal tricuspid and pulmonary valves, three anatomical parts of the RV can be distinguished: the inlet part which accommodates the tricuspid valve, the trabeculated apical part, and the outlet[19,20].

The myocyte arrangement in the RV wall differs from that of the three-layered LV. Myocytes are predominantly oriented in the longitudinal direction in the subendocardial layer. Circumferentially oriented myocytes

are found in the thinner sub epicardium. Consequently, the RV contraction pattern is predominantly longitudinal [21-23].

The thickness of the RV free wall is in the range of only 3–5 mm, and the RV mass is approximately one-fourth of that of the LV. Still, owing to the lower impedance and greater distensibility of the pulmonary artery bed, the RV can pump blood at the same rate and volume as the LV[24-28].

Pathophysiology of the right ventricle:

Right ventricular myocardial ischaemia or infarction is the major primary cause of RV contractile dysfunction. The RV is affected in 50% of inferior infarctions[29].

Other primary RV myocardial diseases such as arrhythmogenic RV cardiomyopathy (ARVC) can be associated with globally or regionally decreased RV performance[30].

An acute change in afterload of sufficient magnitude, as produced by pulmonary embolism (PE), can quickly result in RV failure as the RV has little ability to cope with this condition. A chronic exposure to an increased afterload results in RV hypertrophy and altered geometry, which temporarily reduces wall stress but ultimately results in RV failure. In addition, the flattening or displacement of the IVS seen in chronic RV pressure overload impairs LV compliance and filling[31-33].

Echocardiographic evaluation of the right ventricle:

Echocardiographic assessment of the RV is complicated by the complex geometry of this chamber, the pronounced trabeculation that compromises accurate endocardial delineation, and the anterior position that often limits echo image quality. Owing to the incomplete visualization of the RV in a single 2D echocardiographic view, more than one projection is needed for a comprehensive evaluation of RV structure and function[34-36] (Fig. 1).

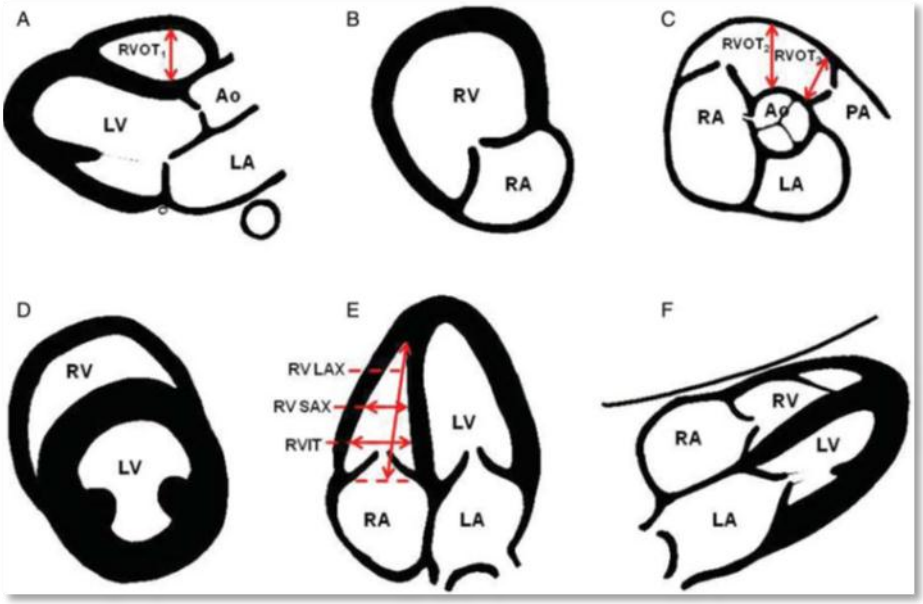

Fig. (1): Graphic representation of the echocardiographic views used for evaluating the right ventricle. **(A)** Parasternal long-axis view; **(B)** long-axis view of the inflow tract; **(C)** Parasternal short-axis view at the base of the heart; **(D)** Parasternal short-axis view at the level of the papillary muscles; **(E)** Apical four-chamber view; **(F)** subcostal view. Legend: Ao, aorta; LA, left atrium; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RV, right ventricle; RVIT, RV inflow tract; RV LAX, RV long axis; RV SAX, RV short axis; RVOT, RV outflow tract.

Assessment of right ventricular function:

Right ventricular fractional area change (RVFAC) expresses the percentage change in RV area between end-diastole and endsystole. It is obtained from a four-chamber view where the RV enddiastolic (RVEDA) and end-systolic areas (RVESA) are measured, and the RVFAC is calculated as follows: RVFAC (%)=(RVEDA - RVESA)/RVEDA (Fig. 2). It has a good correlation with MRI-derived RVEF and was shown to have prognostic significance in patients with myocardial infarction and pulmonary hypertension. Its main limitation is related to the need of good endocardial border delineation, which can be difficult to achieve in the highly trabeculated RV[37-39].

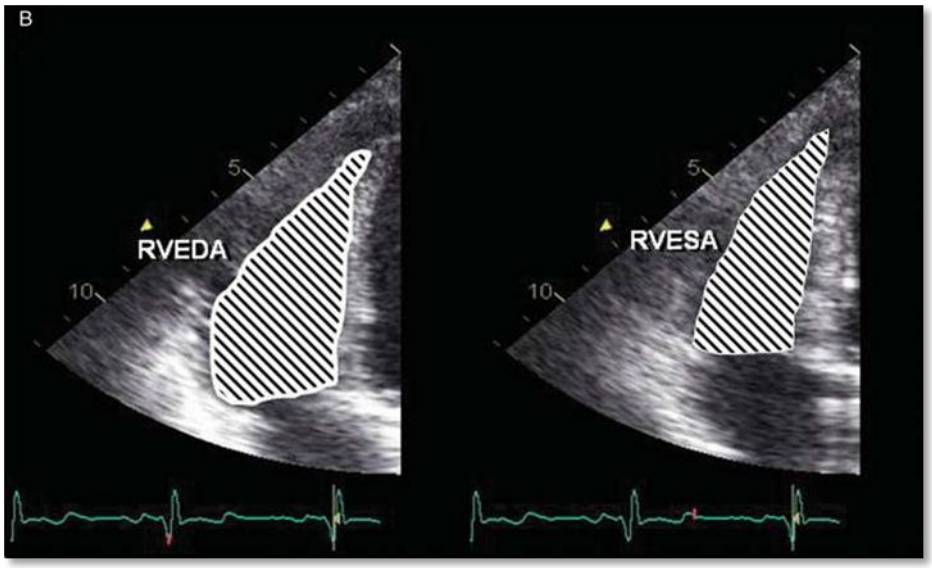

Fig. (2): Measurements of right ventricular end-diastolic area (RVEDA) and right ventricular end-systolic area (RVESA), from which right ventricular fractional area change is derived as 100*(RVEDA 2 RVESA)/RVEDA (%).

Tricuspid annular plane systolic excursion (TAPSE) has proved a useful index for evaluating RV longitudinal function. It is especially attractive in clinical practice given the ease with which it is measured using an M-mode cursor passed through the tricuspid lateral annulus in a four-chamber view (Fig. 3). This parameter measures the extent of systolic motion of the lateral portion of the tricuspid ring towards the apex. It has been shown to have a good correlation with isotopic derived RVEF, normal values for TAPSE are 15–20 mm. The prognostic value of TAPSE was emphasized in cardiac failure and myocardial infarction. Although simple to use, TAPSE has some inherent limitations mostly because assessment is restricted to the longitudinal function of the RV free wall, disregarding the contribution of the interventricular septum and the RVOT. As TAPSE is measured relative to transducer position and was shown to be influenced by the functional status of the LV, care must be taken when interpreting this parameter in longitudinal studies of patients undergoing procedures that affect the overall heart motion (cardiac surgery)[40-46].

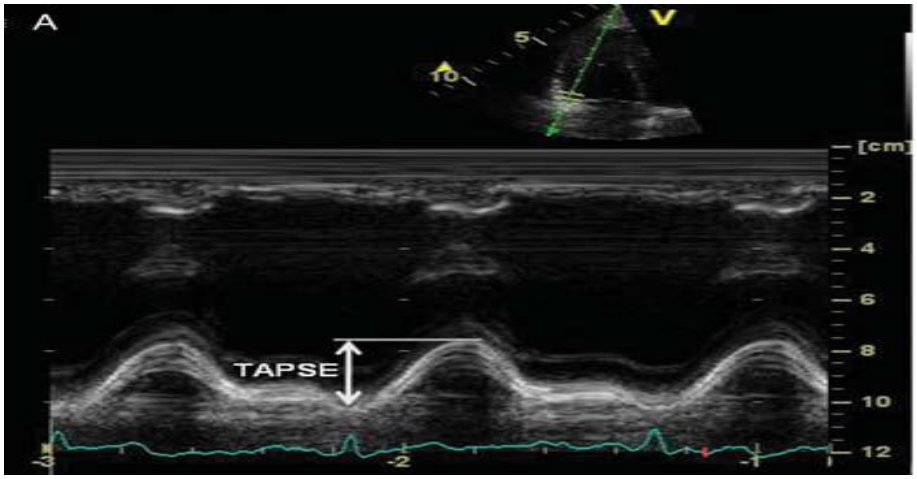

Fig. (3): Measurements of tricuspid annular plane systolic excursion (TAPSE) in a normal individual 24 mm.

The myocardial performance index (MPI) differs from the previously described parameters in that it is derived from physiological rather than structural features. It is calculated as the ratio between the sum of the times of the isovolumic periods and the ejection time for the RV. The MPI is a parameter of global function, combining information on both systole and diastole. Unlike the left heart, where these time intervals can be determined during the same cardiac cycle (owing to the possibility of aligning the mitral and the aortic valves in the same view), measuring MPI for the right heart using conventional Doppler techniques is less accurate, as it needs at least two different cardiac beats for determining the time periods. The ejection time can be determined from the parasternal short-axis view at the pulmonary valve, while isovolumic intervals are derived based on the tricuspid flow. Myocardial performance index was shown to correlate with

radionuclide-derived RVEF. Normal values for MPI are 0.28+0.04, and it usually increases in diseases associated with RV dysfunction. Furthermore, it was shown to be useful in the longitudinal follow-up of patients with chronic thrombo-embolic pulmonary hypertension who undergo pulmonary thrombendarterectomy, in whom RV MPI decreases after treatment. However, the use of this index is limited by the absence of the isovolumic periods in the normal RV as well as the pseudonormalization of the index when RA pressure is increased .The increased RA pressure determines a shortening of the IVRT that will result in a decreased value of the MPI index[47-51] (Fig. 4).

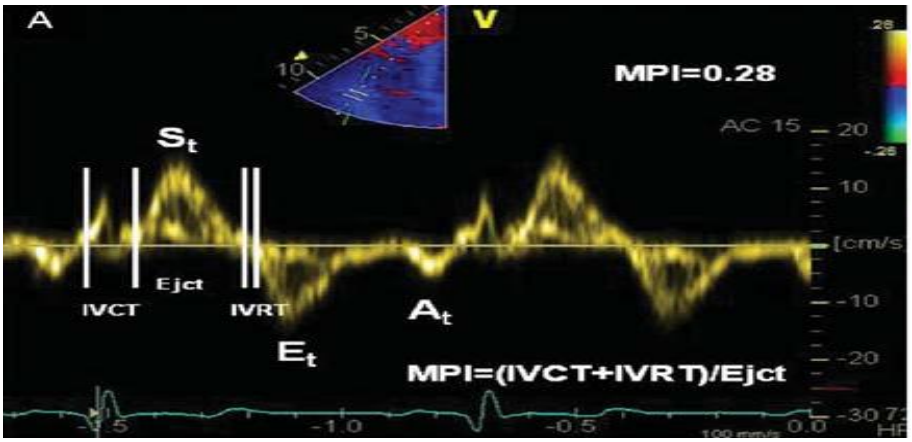

Fig. (4): Pulsed-wave Doppler at the tricuspid level of the right ventricular free wall in a normal individual MPI, myocardial performance index; IVRT, isovolumic relaxation time; IVCT, isovolumic contraction time; Ejct, ejection time; St, peak systolic velocity at the tricuspid valve; Et, peak early filling velocity at the tricuspid ring; At, peak late filling (atrial) velocity at the tricuspidring.

Pulsed Doppler myocardial imaging (DMI) is simple to use online and has a very good temporal resolution. It was found that a cut-off value of 11.5 cm/s for tricuspid ring systolic velocities is able to accurately predict global RV dysfunction (defined as RVEF, 45%). Apart from angle dependency, the main disadvantage is that the sample volume is fixed and does not enable tracking of the region of interest as it translates with the cardiac cycle and respiration[52] (fig. 4).

*Right ventricular diastolic function:*Several echocardiographic parameters can be determined for evaluating RV diastolic function, but less data exist regarding their accuracy. The tricuspid inflow pattern is obtained in a four-chamber view by placing a cursor at the tips of the tricuspid valve. It is similar to the mitral pattern, although velocities are smaller and there are marked inspiratory variations[53].

Coronary Artery Choronic TotalOcclusion

Chronic total occlusion (CTO) of coronary arteries is one of the most challenging PCI, usually defined as more than three-month-old obstruction of a native coronary artery. This coronary lesion subset is a frequent finding in patients with coronary artery disease (CAD) as CTOs have been reported in approximately one-third of patients undergoing diagnostic coronary angiography. However only 7-15% of CTOs were treated with percutaneous coronary intervention (PCI)[54] (Fig. 5).

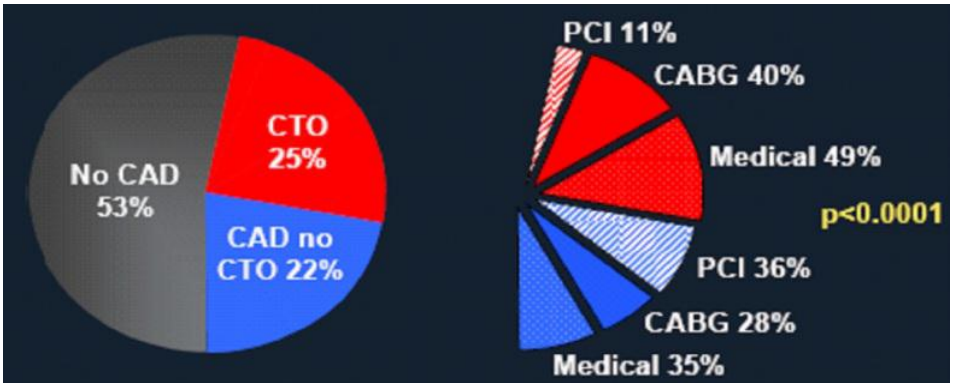

Fig. (5): Diagnostic catheterization results stratified by treatment strategy.

Perhaps for the fact that procedural success is hampered by the difficulties associated with crossing and/or dilating the occluded segment with guide- wires and recanalization devices and by a high incidence of restenosis and reocclusion. Despite these obstacles, several studies have documented that successful PCI of CTOs leads to an improvement in anginal status, normalization of functional

tests, improvement of left ventricular function and avoidance of coronary artery bypass graft surgery (CABG)[55-59].

Patients with untreated CTOs face a threefold increase in cardiac mortality or complications in case of future acute events[60-62].

Historically, a procedural success rate of 60-70% was achieved using anterograde approach[63].

Nowadays, specifically trained operators are able to improve the rate of CTO recanalization thanks to several new techniques and dedicated device developments. In particular, the retrograde CTO PCI approach, that was first mastered by Japanese operators, has evolved rapidly, resulting in higher success rates, shortened procedural time and reduced exposure to radiation.

CTO anatomy and definitions

A deeper understanding of CTO histopathology might offer insights into the development of new techniques and procedural strategies. The occluded part of the lumen in CTOs consists of two types of tissue: atheromatous plaque and old thrombus. The respective amount of these items are largely dependent on CTO formation which may be grossly classified as the two following phenomena:

1. The late organization and development of an acute occlusion due to a plaque rupture, generally apart from the maximal narrowing area.
2. The progressive occlusion of a long term and high-degree stenosis (with a large amount of plaque and sometimes several layers of additional thrombi).

The two mechanisms of CTO formation:

a) Late evolution of an acute occlusion of an eccentric stenosis

b) Progressive occlusion of a long standing concentric stenosis.

The histopathology of CTOs was comprehensively described by Srivatsa and coll. in 1997[64] (fig. 6).

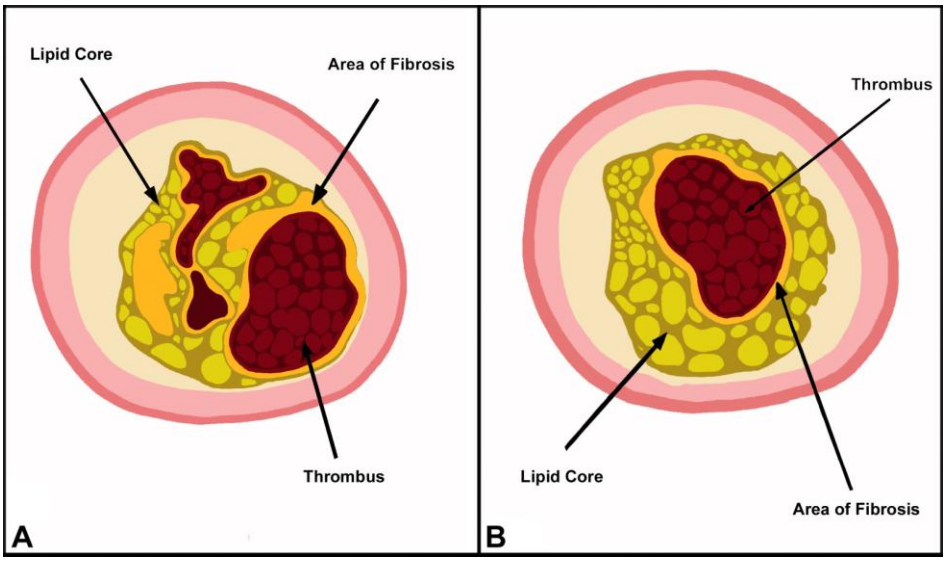

Fig. (6): The two mechanisms of CTO formation: **A)** late evolution of an acute occlusion of an eccentric stenosis **B)** progressive occlusion of a long standing concentric stenosis.

These lesions are characterized by a mix of luminal plaque, thrombin, fibrin, inflammatory cells and neovascular channels. The occlusive thrombus is mainly composed of collagen-rich extracellular matrix, intra and extracellular lipids, smooth muscle cells and mixed components, including a small quantity of cholesterol, dense collagen and calcium deposits. The core composition correlates with the CTO age. Older occlusions have higher concentration of fibrocalcific material (defined as "hard plaques"), while CTOs visible for less than one year have more cholesterol clefts and foam cells among less fibrous materials (defined as "soft plaque"). Typically CTOs may be classified as soft, hard or a mixture of both. Hard plaques are more prevalent with an increasing CTO age (> 1 year old)[65] (fig. 7).