Echocardiographic Assessment of Chronic Ischemic Mitral Regurgitation (CIMR)

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Abstract
The concept of ischemic mitral regurgitation must be clarified according to mechanisms as well as by acuity. In acute coronary syndromes and early in the course of myocardial infarction, MR may occur due to PM ischemia or rupture due to infarction, ischemic LV dilation, and/or increased LV diastolic pressures. Chronic ischemic mitral regurgitation (CIMR), also known as "ischemic chronic secondary MR" by new guidelines, is the most frequent clinical scenario for MR arising post infarct. CIMR is MR caused by geometric changes of the LV and distortion of normal spatial relationships of the mitral apparatus, all secondary to remodelling from ischemic heart disease. The main concerns when evaluating MR by echocardiography include severity, defining the pathology in the mitral valve apparatus's components, the overall mechanism of MR, and, depending on it, considering treatment options of MR.
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Introduction:

Chronic ischemic mitral regurgitation (CIMR), also known as "ischemic chronic secondary MR" by new guidelines, is the most frequent clinical scenario for MR arising post infarct. CIMR is MR caused by geometric changes of the LV and distortion of normal spatial relationships of the mitral apparatus, all secondary to remodelling from ischemic heart disease.**(1).**

Inadequate mitral leaflet closure, or the displacement of the leaflet coaptation apically inside the LV cavity, is the mechanical hallmark of CIMR. Although there is a wide range of anatomic anomalies in both LV and PMs, research suggests that "tethering" plays the primary function as the last common mechanism in causing CIMR. After an infarct, the outward displacement of PMs causes the chordae tendinae to expand and the tethering forces on the mitral leaflets to rise, which results in apical coaptation and constrained closure. Incomplete closure brought on by the stretching of the leaflets caused by annular dilatation may also be a factor. In light of this, CIMR is categorised as functional MR, or type IIIb according to the Carpentier classification. **(2).**

	Primary ("Organic")	Secondary ("Functional")
Acute	Papillary muscle ischemia	Acute ischemic LV dilatation
	Ruptured papillary muscle (trauma, infarction)	
	Flail mitral valve leaflet	
	Ruptured chordae tendinae	
	Endocarditis (leaflet perforation)	
Chronic	Flail mitral valve leaflet	**Chronic ischemic mitral regurgitation (CIMR)**
	Mitral valve prolapse	Non-ischemic LV dilatation (failure of leaflets to coapt)
	Ruptured chordae tendinae	Non-ischemic LV systolic dysfunction
	Degeneration (myxomatous, endocarditis, calcification)	Hypertrophic cardiomyopathy
	Rheumatic	Right ventricular pacing
	Congenital	Aortic insufficiency [1]

Figure1: Etiology of mitral regurge

Previous studies suggested that shorter onset-to-reperfusion time and non-total occlusion were found to be independent predictors of early improvement of IMR, whereas higher cardiac biomarker levels, older age, global longitudinal strain and global LV infarct extent were found to have a negative impact in the chronic phase. In some studies, IMR was more frequent in patients with an inferior infarction compared with an anterior infarction.

Overview of echocardiographic assessment of CIMR:

The main concerns when evaluating MR by echocardiography include severity, defining the pathology in the mitral valve apparatus's components, the overall mechanism of MR, and, depending on it, considering treatment options of MR. As applied to CIMR, the echocardiographer should **(3)**:

- confirm underlying chronic ischemic heart disease.
- asses the severity of MR.
- exclude intrinsic pathology in mitral apparatus.
- confirm CIMR as the most likely etiology by assessing LV and PM displacement
- know the phenotype of CIMR as either symmetric or asymmetric.
- assessment of global and regional LV function, LV ejection fraction, LV dimensions, LV wall motion abnormalities.

severity of MR:

MR should be graded using an integrative approach, incorporating multiple Doppler techniques for direct quantification as well as supportive data (left atrial size, LV chamber size, pattern of pulmonary vein flow) in the overall assessment.

Color Doppler Technique include:

- Distal jet area:
  measures the high turbulent mosaic color Doppler pattern produced by the MR flow as it enters the left atrium, distal to the mitral valve leaflets. This color Doppler display is a measure of MR volume. It can be quantified as a ratio to the left atrial area or as an absolute area **(4).**
- Vena contracta (VC): measures the linear dimension of the neck of the MR jet as it enters the regurgitant orifice at the level of the leaflets.
- Proximal isovelocity surface area (PISA) or proximal flow convergence method calculates the effective regurgitant orifice area (EROA) and MR regurgitant volume (RVol) as follows: EROA ¼ 2πR2 Aliasing Velocity Peak Velocity of MR where R is the radius of the hemispheric PISA zone MR RVol ¼ EROA TVI of MR continuous wave Doppler profile **(5).**

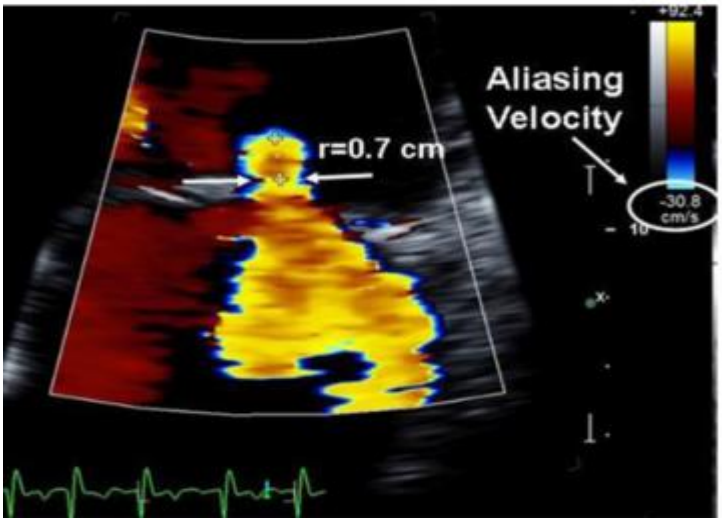

Figure 2: PISA measurements

Intrinsic pathology of mitral valve:

In general the pathologic processes underlying CIMR reflect ventricular and not leaflet pathology: adverse local and global remodelling of the LV changes the geometry of the PMs and the resultant dynamic vector forces exerted on the chordaeleaflet system **(2).**

During systole, Tethering forces, which prevent leaflet motion in systole by pushing apically away from the mitral annular coaptation plane, interact with closing forces generated by LV intracavitary systolic pressure on the ventricular surface of the mitral leaflets to mediate mitral leaflet closure. Incomplete systolic mitral leaflet closure is brought on by tethering forces applied by the LV, PMs, and annulus along apical, posterior, and lateral vectors **(6).**

Global LV dilatation will increase the distance from PM to the leaflet and cause tethering; similarly, a local area of infarction that distorts and outwardly displaces the myocardium underlying PM produces similar malposition.

Tethering and the ensuing CIMR are more common with inferior infarcts than with anterior infarcts, in part due to the more frequent single vascular supply of the posteromedial PM. Additionally, because of the structural support provided by the interventricular septum and the

fact that infarcts in the territory of the left coronary artery will frequently result in apical dilatation rather than dilatation of territory occupied by the anterolateral PM, displacement of the anterolateral PM is more constrained.**(7)**.

The vector sum of forces applied to the mitral leaflet in CIMR generates an abnormal, ventricularly displaced coaptation shape of the mitral leaflets referred to as "tenting"**(8).**

Asymmetric and symmetric tenting in CIMR are two echocardiographic phenotypes that depend on whether the posterior or both leaflets are damaged, which in turn depends on the underlying LV and PM derangements. **(2).**

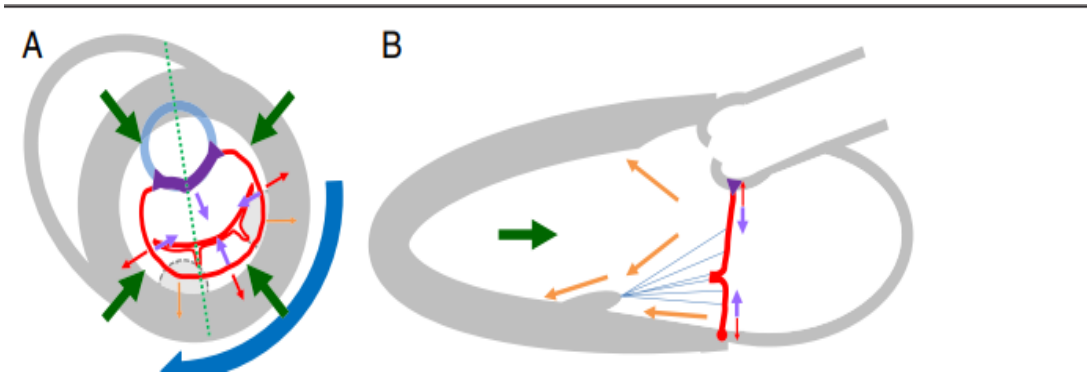

Figure 3: Model of closing and tethering forces acting on the mitral valve

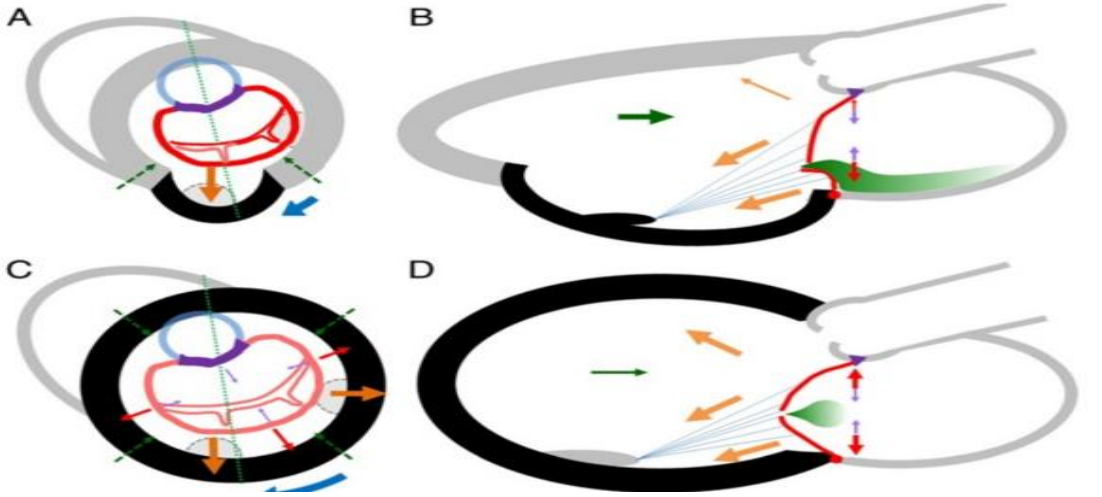

Figure 4: models of symmetric and assymetric phenotypes of CMIR

Echocardiographic assessment of global LV enlargement and dysfunction:

The LV end-systolic and end-diastolic volumes and the sphericity index are correlated with the severity of MR in CIMR with symmetric tethering. This is due to the direct correlation between PM apical displacement and LV dilatation degree **(9).**

Because a minor infarct can affect PM geometry and create severe MR, measurements of overall LV remodelling do not correlate with MR severity as strongly in asymmetric tethering phenotypes; instead, real measures of mitral valve deformation are superior predictors **(10).**

Local LV remodelling and PM displacement:

The long axis of the PMs should be parallel to the LV and perpendicular to the plane of the mitral annulus in normal alignment. A local infarct that damages the myocardium supporting a PM can significantly alter the relationship of that PM relative to the other PM and to the valve apparatus.

This asymmetric effect of the infarct on the posteromedial PM creating asymmetry in mitral valve apparatus anatomy and function – by rotating the posteromedial PM, tethering the posterior leaflet, and deforming the posterior portion of the mitral annulus – which creates a substrate for eccentric CIMR **(11).**

In real life, intracardiac landmarks are needed for echocardiographic determination of PM displacement. The aortomitral fibrous curtain, where the anterior mitral annulus is anchored, can serve as a reference point in the parasternal long axis or apical four chamber views for measuring the apical displacement of both PM heads.**(12).**

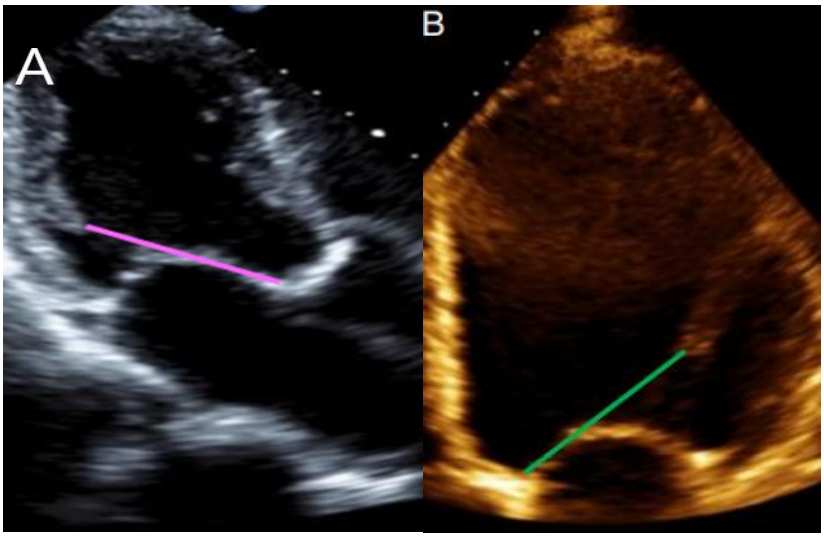

Figure 5: (A) Apical displacement of the posteromedial PM in the apical three chamber view (B) the apical displacement of the anterolateral PM in the apical 4 chamber view.

Papillary muscle dysfunction:

Beyond the effect of PM displacement, ischemic and/or systolic PM dysfunction does not appear to contribute to CIMR.

According to certain data, PM dysfunction, as determined by longitudinal systolic strain, actually lowers the MR seen following inferior myocardial infarction. When PM contraction is impaired, it is likely that the stress on the chordae is reduced, which paradoxically counteracts the tethering forces produced by PM misalignment and/or LV dilatation **(13).**

Tethering and tenting of the mitral leaflets is the final common pathway mediating leaflet malcoaptation and incomplete closure in CIMR

The aggregate of the abnormal vector forces on the mitral leaflets manifest echocardiographically as incomplete mitral leaflet closure or tenting; as such it represents the common pathway of LV remodelling and PM displacement in CIMR **(14)**.

By using standard 2D TTE procedures, different metrics for assessing tethering and tenting are accessible. Because the mitral annular plane is delineated in the apical four chamber view, it is frequently easiest to understand the partial mitral leaflet closure pattern. The maximum mid-systolic distance between the mitral leaflet tips and the annular plane, also known as "tenting height," is a single linear measurement that captures the aberrant apical shift of the coaptation zone.**(15)**.

Because height alone does not take into account the angle of tethering relative to the annular plane, tenting height will understandably vary when the tethering forces are oriented posterolaterally versus apically, for instance **(15)**.

The tethering angles define the relationship of the base of the leaflets to the annulus: α represents the angle between annular plane and anterior mitral leaflet and β the angle between annular plane and posterior mitral leaflet.

3D TTE and TEE allows selection of particular imaging slices to calculate tethering angle. Though the exact values depend on methodology and imaging plane selected, higher ratios of posterior angle to anterior angle characterize the asymmetric tenting phenotypes, and also predicts increased MR severity.

The measurement of tenting area is more comprehensive, less reliant on a certain angle, and takes into consideration the geometry of the entire leaflet, not only that at the annular connection. The tenting area is measured at mid-systole, when it would be at its greatest, and is defined as the region enclosed by the anterior and posterior leaflets and the mitral annular plane**(16)**.

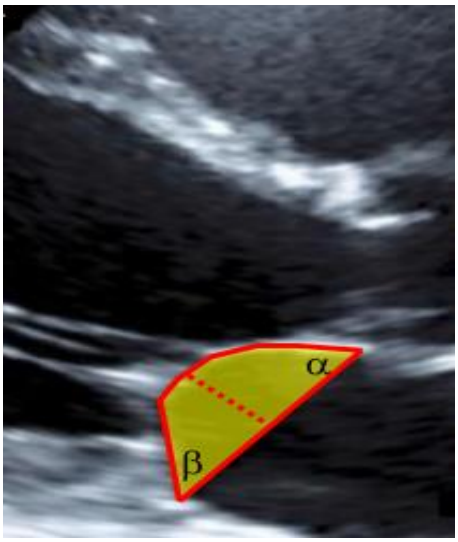

Figure 6: Measurement of tenting height, tenting area, tenting angles in mid systolic parasternal long axis.

Mitral annular dilatation:

The mitral annulus has a specialized 3D geometry likened to an ovoid saddle shape that reduces stresses on the leaflets and supports valvular competence.

By altering the leaflet motion, distortion of the natural 3D annular geometry to a "flattened" annulus may also cause CIMR. Significant MR, however, was not seen in a study of patients with isolated atrial fibrillation who had annular dilatation but normal LV chamber size. This is because, despite the study's finding that there was a slight link between the severity of functional MR and annular area, LV remodelling and dilatation are necessary to produce tethering forces.**(17).**

Annular dilatation can be measured by anterior and posterior dimensions, annulus area (apical four chamber mitral annulus dimension multiplied by apical two chamber mitral annulus dimension multiplied by $\pi/4$) **(18).**

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