Papillary Muscle Infarction by Delayed-enhancement Magnetic Resonance Imaging: Reproducibility and Potential as an Independent Predictor of Ischemic Mitral Regurgitation

T. Boonyasirinant[1], R. Curtin[2], R. M. Setser[1], M. L. Lieber[3], and S. D. Flamm[1]

[1]Radiology, Cleveland Clinic, Cleveland, Ohio, United States, [2]Cardiology, Cleveland Clinic, Cleveland, Ohio, United States, [3]Quantitative Health Sciences, Cleveland Clinic, Cleveland, Ohio, United States

Purpose

Ischemic mitral regurgitation (IMR) portends worsened prognosis and increased mortality in patients with ischemic cardiomyopathy. Various mechanisms of IMR have been proposed, resulting in a spectrum of surgical strategies with varying success rates. Delayed-enhancement MRI (DE-MRI) has been accepted as the high resolution, non-invasive infarction specific imaging for evaluation of myocardial viability.

Papillary muscle infarction may contribute to IMR, however the relationship between IMR severity and papillary muscle viability has not been established. We sought to: 1) assess the feasibility and reproducibility of DE-MRI in the assessment of papillary muscle infarction, 2) establish the association between IMR severity and papillary muscle infarction, and 3) determine the ability of left ventricular volumetric and DE-MRI parameters to predict the presence and severity of IMR.

Methods and Materials

Cardiac MRI was performed in 100 patients with ischemic cardiomyopathy (67 male, mean age 65 years), using a 1.5-tesla MRI scanner (Avanto; Siemens Medical Solutions, Erlangen, Germany). Cine MRI was acquired using a retrospectively-gated steady-state free-precession (SSFP) sequence (TE = 1.6 ms, TR = 3.2 ms, flip angle = 60°, slice thickness = 8 mm thick for short axis images and 6 mm for long axis images, FOVx = 263-360 mm, FOVy = 300-360 mm; typical matrix size = 152 x 176, and typical acquired spatial resolution = 2.0 x 2.0 mm; temporal resolution = 30-50 ms). DE-MRI images were acquired in identical short and long axis orientations with a breathhold inversion recovery spoiled gradient echo sequence: TE = 4 ms, TR = 8 ms, flip angle = 30°, bandwidth = 140 Hz/pixel, 23 k-space lines acquired every other R-R interval, FOVx = 260-360 mm, FOVy = 300-360 mm; typical matrix size = 152 x 256, and typical acquired spatial resolution = 2.0 x 1.3 mm. Images were acquired 15-20 minutes after intravenous injection of 0.2 mmol/kg Gadolinium dimeglumine (Magnevist, Berlex Imaging, Wayne, NJ). Both cine and DE-MRI were acquired during successive 8-10-second breath holds. For each individual patient, the TI (range, 225–275 ms) for DE-MRI was optimized to null viable myocardium.

Using dedicated cardiovascular image analysis software (Argus; Siemens Medical Solutions), LV endocardial contours were manually traced at end-diastole and end-systole in contiguous short-axis cine images using the disc summation technique for determination of end-diastolic volume (EDV), end-systolic volume (ESV), and ejection fraction (EF). In addition, mitral annular diameter was measured in the 3-chamber view at end-systole. Employing the AHA standardized 17-myocardial segmentation model, the extent of hyperenhanced tissue within each segment was graded based on a 5-point scale (score of 0 = no hyperenhancement, 1 = 1 to 25 % hyperenhancement, 2 = 26 to 50 % hyperenhancement, 3 = 51 to 75 % hyperenhancement, and 4 = 76 to 100 % hyperenhancement). Total scarring was represented as average infarct score, derived from the average of the scar grade over the 17 segments. Further, myocardial scarring in the vicinity of anterior and posterior papillary muscles was assessed in mid anterior-anterolateral and inferior-inferolateral segments (segments 7 and 12, and 10 and 11, respectively), and myocardial scarring in each coronary artery territory was identified. Both anterior and posterior papillary muscle infarction was determined from contiguous short axis, 2, 3, and 4-chamber views. To determine reproducibility of papillary muscle infarction identification, intra-observer and inter-observer variability was performed in a subset of 40 patients randomly selected.

Results

The prevalence of MR was 67%: 30% with mild MR, 27% moderate MR, and 10% severe MR. Papillary muscle infarction was found in 42% (anterior papillary muscle infarction in 19%, and posterior papillary muscle infarction in 38%). Using univariate analysis, EF, EDV, ESV, mitral valve annulus, and posterior papillary muscle infarction were associated with the severity of MR. In contrast, other DE-MRI variables were not associated with MR severity. Using multiple logistic regression analysis, only posterior papillary muscle infarction and LVEF remained independent determinants of MR severity ($p = 0.016$, odds ratio = 3.02, and $p = 0.021$, odds ratio = 0.92, respectively). Intra-observer and inter-observer variability for papillary muscle infarction identification were excellent: Kappa = 0.97 and 0.98, and 0.95 and 0.96 for anterior and posterior papillary muscle, respectively.

Conclusion

This study demonstrated the feasibility of papillary muscle infarction identification using DE-MRI with excellent intra-observer and inter-observer reproducibility. The presence of posterior papillary muscle infarction and impaired EF are independent predictors of MR severity in ICM patients. The identification of papillary muscle infarction may provide novel insights into improved surgical strategies for IMR.

Table Relationship between left ventricular and delayed-enhancement parameters and the severity of mitral regurgitation

	ICM with no MR (n = 33)	ICM with mild MR (n = 30)	ICM with moderate MR (n = 27)	ICM with severe MR (n = 10)	Univariate analysis	Multiple logistic regression
LVEF (%)	29.1	26.0	24.3	20.3	0.047	0.021
LVESV (ml)	182.0	209.1	215.9	297.4	0.236	na
LVEDV (ml)	252.0	274.2	284.1	378.1	0.268	na
Mitral annular diameter (cm)	3.27	3.45	3.48	3.81	0.034	0.058
Average infarct score	0.91	1.02	0.83	0.65	0.90	na
MI in LAD	25 (75.8%)	25 (83.3%)	18 (66.7%)	7 (70.0%)	0.787	na
MI in LCX	24 (72.7%)	21 (70.0%)	16 (59.3%)	8 (80.0%)	0.245	na
MI in RCA	21 (63.6%)	24 (80.0%)	20 (74.1%)	7 (72.0%)	0.850	na
MI in vicinity of APM (%)	17 (51.5%)	19 (63.3%)	10 (37.0%)	7 (70.0%)	0.910	na
MI in vicinity of PPM (%)	12 (36.4%)	15 (50.0%)	8 (29.6%)	7 (70.0%)	0.299	na
APM infarct	3 (9.1%)	8 (26.7%)	6 (22.2%)	2 (20.0%)	0.415	na
PPM infarct	5 (15.2%)	12 (40.0%)	14 (51.9%)	7 (70.0%)	0.003	0.016

ICM = Ischemic cardiomyopathy, MR = Mitral regurgitation, LVEF = Left ventricular ejection fraction, LVESV = Left ventricular end-systolic volume, LVEDV = Left ventricular end-diastolic volume, MI = Myocardial infarction, LAD = Left anterior descending artery, LCX = Left circumflex artery, RCA = Right coronary artery, APM = Anterior papillary muscle, PPM = Posterior papillary muscle, na = not analysis