ADVANCED IMAGING (MR and CT) IN MITRAL VALVE DISEASE: WHICH ROLE?

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The myth of David and Goliath
Management of severe chronic primary mitral regurgitation

Symptoms

No

LVEF ≤60% or LVESD ≥45 mm

No

New onset of AF or SPAP >50 mmHg

No

High likelihood of durable repair, low surgical risk, and presence of risk factors

No

Follow-up

Yes

Surgery (repair whenever possible)

Yes

Extended HF treatment/platform percutaneous edge-to-edge repair

Yes

Medical therapy

No

Refractory to medical therapy

Yes

LVEF >30%

No

Follow-up

Yes

Extended HF treatment/platform percutaneous edge-to-edge repair

Figure 4 Management of severe chronic primary mitral regurgitation. AF = atrial fibrillation; BSA = body surface area; CRT = cardiac resynchronization therapy; HF = heart failure; LA = left atrial; LVEF = left ventricular ejection fraction; LVESD = left ventricular end-systolic diameter; SPAP = systolic pulmonary arterial pressure.

*When there is a high likelihood of durable valve repair at low-risk, valve repair should be considered (III C) in patients with LVESD ≥40 mm and one of the following is present: flail leaflet or LA volume ≥60 mL/m² BSA at sinus rhythm.

*Extended HF management includes the following: CRT; ventricular assist devices; cardiac restraint devices; heart transplantation.
PIVOTAL ROLE OF II LEVEL CARDIAC IMAGING

Any imaging modality must address particular aspects of the valvular disease process to be clinically useful. It must be able to:

- Defined the valve morphology
- Precisely and reproducibly quantify the severity of the valvular abnormality
- Assess the impact of the valvular abnormality on the surrounding cardiac structure and on cardiac function
- To rule out the presence of concomitant CAD in case of surgical indication
16 patients referred to Cedars Sinai Medical Center for MR surgical correction evaluated by TTE with images referred to 18 expert cardiologist expert in echocardiography.

Substantial (raw agreement 80%), fair (raw agreement 60% to 79%), and poor (raw agreement 60% to 39%) interobserver agreements are shown for 3 study parameters for 18 observers.

Out of 16 patients, substantial agreement was achieved in 44% of cases for mitral regurgitation (MR) jet area, 44% of patients for vena contracta method, and only 38% for effective regurgitant orifice area (EROA) based on proximal isovelocity surface radius.

MR, support the concept of Gaasch and Meyer (19), namely “to question the diagnosis of severe chronic MR when little or no left ventricular or left atrial enlargement is found.”
MITRAL REGURGITATION
Cardiac magnetic resonance – grading VHD

METHOD 3: indirect method

STEP 1: Measurement of left stroke volume (LSV) and right stroke volume (RSV)

STEP 2: Measurement of Qs, Qp and Backflow

STEP 3: Semilunare Valve regurgitation = backflow
Atrio-ventricular regurgitation = SV – Qx - Backflow

... internal check analysis ...
MITRAL REGURGITATION
Cardiac magnetic resonance – grading VHD

Hamada S, AJC 2012
MITRAL REGURGITATION
Cardiac magnetic resonance – grading VHD

Discordance Between Echocardiography and MRI in the Assessment of Mitral Regurgitation Severity
A Prospective Multicenter Trial

Seth Uretsky, MD,* Linda Gillam, MD, MPH,* Roberto Lang, MD,|| Farooq A. Chaudhry, MD,* Edgar Argulian, MD, MPH,* Azhar Supariwala, MD,§ Srinivasa Gurram, MD,§ Kavya Jain, MD,§ Marjorie Subero, MD,§ James J. Jang, MD,|| Randy Cohen, MD,§ Steven D. Wolff, MD, PhD§

91%
61%

TABLE 2 Interobserver Variability for MRI and Echo

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Echo – echocardiography; MRI – magnetic resonance imaging.
MITRAL REGURGITATION
Cardiac magnetic resonance – grading VHD

Figure 2: Quantitative Comparison of Regurgitant Volume as Determined by MRI and Echo

(A) Quantification of MR severity: echocardiography versus MRI. (B) Bland-Altman plot. Echo = echocardiography; other abbreviations as in Figure 1.
MITRAL REGURGITATION
Cardiac magnetic resonance – grading VHD

FIGURE 4 Post-Surgical Decrease in LV EDV Versus Pre-Surgical Regurgitant Volume

(A) MRI (B) Echocardiography. LV EDV = left ventricular end-diastolic volume; other abbreviations as in Figures 1 and 2.

GENERAL INFORMATION
Protocol # (if assigned):
Version Number: 1.0  Version Date: 27JUL2016
Principal Investigator: Seth Uretsky, MD, FACC
Protocol Title: Prospective Evaluation of MRI as a Predictor of Outcomes in Patients Undergoing Mitral Valve Surgery: MRI-MVS Study

Funding Agency: Atlantic Health Systems  Sponsor (if applicable):
Target Enrollment: 100 subjects  Overall Target Enrollment (for multi-centered studies): 100 subjects

Uretsky S, JACC 2015
CMR interrogation of the mitral valve. Using a cross-sectional view of the mitral valve as a reference point (a), serial long-axis views are prescribed through the A1-P1 scallops (b), the A2-P2 scallops (c), or the A3-P3 scallops (d) to produce long-axis cine views interrogating the individual scallops and coaptation points of the mitral valve. In this example, there is adequate coaptation of the A1-P1 scallops (b) and the A3-P3 scallops (d) but impaired coaptation of the A2-P2 scallops, demonstrating a flail P2 scallop.
Representative Examples of Complete and Partial PMI Typical examples of (A) complete papillary muscle infarction (PMI) and (B) partial PMI detected by delayed-enhancement cardiac magnetic resonance. Each example is composed of 2 short-axis images within the affected papillary muscle. As shown, complete PMI was often associated with transmural infarction of the adjacent left ventricular wall, whereas partial PMI was associated with subendocardial infarction. Upper right shows bilateral, complete PMI with transmural infarction of the inferior and lateral walls.
Arrhythmic Mitral Valve Prolapse and Sudden Cardiac Death

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Background—Mitral valve prolapse (MVP) may present with ventricular arrhythmias and sudden cardiac death (SCD) even in the absence of hemodynamic impairment. The structural basis of ventricular electric instability remains elusive.

Methods and Results—The cardiac pathology registry of 650 young adults (≤40 years of age) with SCD was reviewed, and cases with MVP as the only cause of SCD were re-examined. Forty-three patients with MVP (26 females; age range, 19–40 years; median, 32 years) were identified (7% of all SCD, 13% of women). Among 12 cases with available ECG, 10 (83%) had inverted T waves on inferior leads, and all had right bundle-branch block ventricular arrhythmias. A bileaflet involvement was found in 70%. Left ventricular fibrosis was detected at histology at the level of papillary muscles in all patients, and inferobasal wall in 88%. Living patients with MVP with (n=30) and without (control subjects; n=14) complex ventricular arrhythmias underwent a study protocol including contrast-enhanced cardiac magnetic resonance. Patients with either right bundle-branch block type or polymorphic complex ventricular arrhythmias (22 females; age range, 28–43 years; median, 41 years), showed a bileaflet involvement in 70% of cases. Left ventricular late enhancement was identified by contrast-enhanced cardiac magnetic resonance in 93% of patients versus 14% of control subjects (P<0.001), with a regional distribution overlapping the histopathology findings in SCD cases.

Conclusions—MVP is an underestimated cause of arrhythmic SCD, mostly in young adult women. Fibrosis of the papillary muscles and inferobasal left ventricular wall, suggesting a myocardial stretch by the prolapsing leaflet, is the structural hallmark and correlates with ventricular arrhythmias origin. Contrast-enhanced cardiac magnetic resonance may help to identify in vivo this concealed substrate for risk stratification. (Circulation. 2015;132:556-566. DOI: 10.1161/CIRCULATIONAHA.115.016291.)
MITRAL REGURGITATION
Cardiac magnetic resonance – to stratify arrhythmic risk
MITRAL REGURGITATION
Cardiac magnetic resonance – to stratify arrhythmic risk

Contrast-enhanced cardiac magnetic resonance findings in patients with mitral valve prolapse with complex ventricular arrhythmias and aborted sudden cardiac death. A and B, A 30-year old woman with mitral valve prolapse and complex ventricular arrhythmias. LGE of the papillary muscle is visible on mid short-axis view (A). The 12-lead ECG (B) shows the presence of nonsustained ventricular tachycardia with right bundle-branch block (RBBB) morphology originating from the posterior papillary muscle (superior axis). C and D, A 33-year-old woman with mitral valve prolapse and complex ventricular arrhythmias. LGE of the left ventricular inferobasal region under the posterior valve leaflet with endocardial-midmural extension is visible on the 3-chamber long-axis view (C). The 12-lead ECG demonstrates nonsustained ventricular tachycardia with RBBB morphology originating from the left ventricular inferobasal wall near the mitral annulus (inferior axis; D).
MITRAL REGURGITATION
Cardiac magnetic resonance – to stratify arrhythmic risk

MVP

Basal LV

No- MVP
MITRAL REGURGITATION
Cardiac magnetic resonance – to stratify arrhythmic risk

**CENTRAL ILLUSTRATION** Mitral Annulus Disjunction (MAD) Arrhythmic Syndrome

116 Patients with Mitral Annulus Disjunction (MAD)

14 with aborted cardiac arrest or sustained ventricular tachycardia

90 MAD with Mitral Valve Prolapse

26 MAD without Mitral Valve Prolapse

One hundred and sixteen patients with mitral annulus disjunction (MAD) were enrolled in the study, of which 14 had experienced aborted cardiac arrest (ACA) or sustained ventricular tachycardia (VT) (top). (Top left) An echocardiogram with pronounced MAD. (Top right) An original electrocardiogram (ECG) from an implantable loop recorder from one of the study participants. A total of 90 patients with MAD had concomitant mitral valve prolapse (MVP) (bottom left), while 26 patients with MAD did not have MVP (bottom right). Severe ventricular arrhythmias (ACA or VT) were frequent in the study participants, and were more prevalent in MAD without MVP, chi-square test, p = 0.003.
PIVOTAL ROLE OF II LEVEL CARDIAC IMAGING

Any imaging modality must address particular aspects of the valvular disease process to be clinically useful. It must be able to:

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- Precisely and reproducibly quantify the severity of the valvular abnormality
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- To rule out the presence of concomitant CAD in case of surgical indication
MITRAL REGURGITATION
Cardiac magnetic resonance – grading LV remodelling (mass)

\[ \text{Volume} = \frac{4}{3} \pi \left( \frac{l}{2} \right)^3 = 1.05 l^3 \]

\[ \text{Volume}_\gamma = 1.05 (\text{IVST} + \text{LVID} + \text{PWT})^3 \]
\[ \text{Volume}_c = 1.05 (\text{LVID})^3 \]
\[ \text{Volume}_m = \text{Volume}_\gamma - \text{Volume}_c \]

\[ \text{LVM} + 0.8 \times \left[ 1.05 (\text{IVST} + \text{LVID} + \text{PWT})^3 - (\text{LVID})^3 \right] + 0.8 \text{ g} \]
Case 1 has preserved cardiac geometry, but case 2 shows left ventricular remodeling. The usual assessment of LVM by cardiac magnetic resonance (CMR) does not require cardiac geometry assumptions, as opposed to linear measurements used in echocardiography. (Courtesy of Dr. Gustavo Volpe.) (A and C) CMR-derived images representing usual echocardiography views for linear measurements assessing LVM. The anterior septal wall (ASW) corresponds to the interventricular septal thickness; the end-diastolic dimension (EDD) corresponds to the left ventricular internal dimension; and the posterior lateral wall (PLW) corresponds to the posterior wall thickness. At the bottom, the ASE-recommended formula was used to calculate LVM (see Fig. 1 for a full description). (B and D) Usual CMR assessment for LVM, using contiguous short-axis slices covering the entire left ventricle from the atrioventricular ring to the apex (1 to 9). The estimated LVM is displayed at the bottom.
Receiver-operating characteristic curve is depicted for postoperative normal RV-EF in relation to preoperative RV-EDVI determined by cardiac magnetic resonance imaging. With a cut-off value of 164 mL/m², sensitivity and specificity of postoperative normal RV-EF were 77 and 72%, respectively.

**Conclusions**

CMR imaging demonstrated that remarkable reduction in RV volumes as well as preservation of RV-EF within a normal range can be achieved after successful corrective TR surgery. Preoperative RV-EDVI assessed by CMR has a potential for determining optimal timing of TR surgery, although requiring confirmation in a large-scale study. In addition, successful TR surgery led to a significant rise in LV preload and CI, which may significantly
MITRAL REGURGITATION
Cardiac magnetic resonance – grading LV remodelling (volume)

**CENTRAL ILLUSTRATION**
Proposed Clinical Pathway and Rationale for the Use of Cardiac MRI in the Assessment of Patients With Severe Mitral Regurgitation

1. Severe mitral regurgitation (MR) on echocardiography
   - A need for greater diagnostic certainty

2. MRI without contrast to quantify regurgitant volume
   - Reliable parameter of MR severity
   - Low variability, excellent reproducibility
   - Gold standard for left atrium and left ventricle size and function
   - Does not rely upon the characteristics of the regurgitant jet

3. Severe MR confirmed on MRI
   - Consider mitral valve surgery; watchful waiting

4. Non severe MR confirmed on MRI
   - Routine follow up

**Recommended future directions:** Prospective randomized trials to review the outcomes of MR assessment by MRI


MRI = magnetic resonance imaging.
Frequent surveillance echocardiography is considered appropriate in asymptomatic patients with moderate to severe AR and MR. However, the evidence to support this practice and to define the appropriate frequency is limited.

Regurgitant Volume < 30 ml/m²

Clinical symptoms. Accordingly, previous guidelines (4) recommended “...repeat echocardiography at yearly intervals in patients with moderate MR,” and recent guidelines also recommend that patients with moderate severity should be followed up every 1 to 2 years (5). However, our data suggest that moderate regurgitation, at least in this population, remained stable during 3 years of follow-up. Although a major-
PIVOTAL ROLE OF II LEVEL CARDIAC IMAGING

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The two types of diagnostic work-up for the diagnosis of CAD in patients with mitral valve prolapse and severe mitral regurgitation referred for cardiac surgery. Work-up A includes MDCT as gatekeeper to ICA that is performed only in patients with CAD>50% in a patient-based model at MDCT. Work-up B includes ICA to rule out CAD before cardiac valve surgery. CAD: coronary artery disease; ICA: invasive coronary angiography; MDCT: multidetector computed tomography coronary angiography.
Comparison of ED and cost of the two types of diagnostic work-up as described. The overall ED and cost based on Italian and medicare reimbursements in work-up A versus work-up B were 4.25 3.6 mSv versus 6.79 5.57 mSv, (pb0.01), 747.42 1022.21 euro versus 2331 euro (pb0.01) and 1047.50 767.42 versus 1750$ (pb0.01), respectively. ED: effective radiation dose.
Percutaneous treatment of mitral valve disease
PATHOLOGIC MITRAL VALVE Calcification

Diagram depicting calcium extending into the base of the LV as well as beneath the ventricular surface of the PML. The latter elevates the leaflet and stretches the chordae tendineae. With permission from Cammack et al.  

Jeffrey J. Silbiger AHJ 2012
The presence of MAC affected surgical outcomes in both groups (8% patients with MAC underwent replacement after a first attempt of repair vs 3% without MAC).
CT IMAGING OF MAC_For procedural planning

Step 1: Circumferential annular calcification definition

The presence of circumferential annular calcification, needed for optimal device anchoring of balloon-expandable prostheses, can be confirmed with reformatted CT images.

Short-axis parasternal transthoracic echocardiography images (left) and CT angiography images (right) in corresponding patients are shown. (Top) **Grade 1 (mild)** MAC is characterized by scattered noncontiguous calcification limited to <180 total annular circumference (arrows). (Middle) **Grade 2 (moderate)** MAC is composed of dense continuous calcification limited to <270 total annular circumference (arrows). (Bottom) **Grade 3 (severe)** MAC is defined as dense continuous calcification extending past the commissures into anterior annulus or complete circumferential MAC (>270 calcification arc [arrows]).
CT IMAGING OF MAC_For procedural planning

Step 2: Measuring mitral annular area (Blanke method)

Annulus segmentation. The saddle-shaped mitral annulus is segmented by placing 16 seeding points along the insertion of the posterior mitral leaflet and along the contour of the fibrous continuity while the long axis view is rotated in an automated fashion every 22.5° aligned to the long axis of the left ventricle (yellow line denotes the orientation of the left ventricular long axis). Upper left, 4-chamber view; upper right, 2-chamber view; lower left, 3-chamber view. The short-axis view (lower right) indicates the position of the 16 seeding points projected on 1 imaging plane.
CT IMAGING OF MAC_For procedural planning

Step 2: Measuring mitral annular area (Blanke method)

Saddle-shaped and D-shaped mitral annulus: geometric assessment. After generating the 3-dimensional (3D) mitral annulus contour, the annular height and 3D perimeter are assessed. Area, 2D perimeter, and trigone-to-trigone (TT) and septal-lateral (SL) distances are assessed based on projected dimensions by means of the least squares method. The orange dots indicate the position of the fibrous trigones which define the TT distance and thus the anterior border of the D-shaped annulus. 2D-PPosterior, projected circumference of the posterior peak; 2D-PS-Anterior, projected circumference of the anterior peak; 3D-PPosterior, 3D circumference of the posterior peak; AD, projected annulus area of D-shaped mitral annulus; AS, projected annulus area of saddle-shaped mitral annulus; SLD, projected septal-to-lateral distance from the aortic peak to the posterior peak perpendicular to TT of the D-shaped annulus; SLS, projected septal-to-lateral distance from the aortic peak to the posterior peak perpendicular to TT of the saddle-shaped annulus.

Blanke P JCCT 2014
CT IMAGING OF MAC_For procedural planning

Step 3: To predict neo-LVOT obstruction

3D reformatted cardiac CT angiogram demonstrating (left) apical long axis view of a patient with severe MAC and 29 mm SAPIEN 3 (third generation balloon expandable valve) valve implanted in the 20% atrial 80% ventricular mitral position. (Right) Surgeon’s transaortic view demonstrating the ventricular aspect of the transcatheter valve protruding into the left ventricular outflow tract.

A lower aortomitral angle (arrows) is associated with greater risk of left ventricular outflow tract obstruction.
Predicting neo–left ventricular outflow tract (LVOT) area in a native mitral valve on postcontrast cardiac computerized tomography (CT). A, Left ventricle short-axis multiplanar reformat (MPR) at the level of the mitral annulus demonstrates mitral annulus measurements. Note the mild mitral annular calcification. B, A 3-dimensional (3D) circular volume-rendered segmentation (red circle) is performed at the corresponding level of the mitral annulus with the dimensions of the proposed prosthetic valve (in this case a 29-mm Edwards SAPIEN XT valve). C, This creates a 3D segmented cylindrical volume (green cylinder), viewed here in profile. D, Once segmented, the segmented 3D volume can be projected onto the CT image data, as demonstrated on this 4-chamber MPR (red volume). E, The proposed prosthetic valve height is then measured (line) and segmented (F) as demonstrated on these 2-chamber MPRs. G, A 3-chamber MPR can determine the level of the minimal neo-LVOT (blue line), and planimetry of the neo-LVOT can be performed in an orthogonal plane (H).
CT IMAGING OF MAC For procedural planning

Step 3: To predict neo-LVOT obstruction

Predicting neo–left ventricular outflow tract (LVOT) area in a prosthetic mitral valve on postcontrast cardiac computerized tomography (CT) using 30 mL iodinated contrast. A, Left ventricle short-axis multiplanar reformat (MPR) at the level of the mechanical mitral valve demonstrates mitral valve prosthetic measurements. B, A 3-dimensional (3D) volume segmentation (red circle) is performed of the internal surface of the prosthetic valve at the corresponding level of the mitral annulus with the dimensions of the proposed prosthetic valve (in this case a 23-mm Edwards SAPIEN XT valve). C, Four-chamber MPR demonstrates the resulting segmented volume (red volume). D, The valve height (line) is then segmented (E), and 4-chamber MPR shows the proposed valve prosthesis. F, A 3D segmented volume-rendered image demonstrates the prosthetic valve volume (green cylinder) in profile inside the existing prosthesis. G, Three-chamber MPR demonstrates the level of the neo-LVOT (blue line), with planimetry of the neo-LVOT performed in an orthogonal plane (H).
CT IMAGING OF MAC_For procedural planning

Step 3: To predict neo-LVOT obstruction

CT angiogram reformatted to show the LVOT without and with (“Neo-LVOT”) (arrows) a simulated 29-mm valve placed in the mitral position. The LVOT area without the valve is 335 mm² (top) and with the valve is 53 mm² (bottom). Predicted percentage of obstruction is 84%.
New tools
**ViosWorks** to have 3D cardiac anatomy in 1 free-breathing in less than 10 min scan

**What is it?**
- 3D Cine (EFGRE)
- Capture data in 7 dimensions
  - 3 in space, 1 in time, and 3 in velocity direction

**Benefits**
- Free-breathing, non-invasive
- Unsupervised cardiac imaging – no expertise or clinician guidance needed
- Faster cardiac exams help to shorten backlog scheduling times
- Cloud-based visualization and reporting attracts new referrals

- 60-90 min exam
- 20-50+ breath-holds
- Many imaging slices and sequences
- Dedicated, cardiac technologist and Clinician needed to perform exam and post-processing

- 8-30 min exam (clinical indication dependent)
- Free breathing
- 1, 3D volume placed over chest
- No dedicated, cardiac technologist or clinician needed to perform exam.
Quantification of mitral regurgitant volume by 4D flow (top) and planar MRI (bottom). Methods of measurement include direct interrogation of the regurgitant jet (left, yellow lines) or indirect quantification by subtracting aortic flow (right, red lines) from stroke volume.
MRI-MVS study

**POST SURGICAL DECREASE IN LVEDV VS PRE SURGICAL REGURGITANT VOLUME**

(Correlation)

- R=0.7762
- P=0.0083

- R=0.8066
- P=0.0048
TAKE HOME MESSAGE

① TTE/TEE remains the primary noninvasive imaging modality in patients with VHD

② CMR is a robust alternative to echo in pts with mitral valve disease in the following settings: poor acoustic window and/or eccentric origin and/or not olosystolic regurgitation or equivocal case

③ CMR is highly suggested as additional test in all pts with severe left/right side regurgitant disease at TTE and normal LV/RV volumes and/or LV/RV ejection fraction

④ CMR is always suggested in case of VHD with right side involvement to estimate tricuspid regurgitant volume, RV volumes and RF ejection fraction

⑤ CMR is a pivotal tool for arrhytmic stratification in valve disease

⑦ CCT is the first line test to rule out CAD before surgery

⑦ CCT is emerging as robust tool to plan percutaneous mitral valve implantation
«David, you killed Goliath ... now it's your turn to bury him»
NEXT MEETING

EuroCMR 2019
EXTENDING THE CLINICAL VALUE OF CMR THROUGH QUALITY AND EVIDENCE

2-4 May
Venice
ITALY

17th Annual Meeting
on Cardiovascular Magnetic Resonance (CMR)
of the European Association of Cardiovascular Imaging (EACVI)
www.escardio.org/EACVI

12th – 14th May (Lisbon)

12th – 14th May (Lisbon)

ICNC 2019
INTERNATIONAL CONFERENCE ON
NUCLEAR CARDIOLOGY AND CARDIAC CT

ESC
European Society of Cardiology
Training in cardiac computed tomography: EACVI certification process

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Cardiac Computed Tomography Certification at Euroecho Imaging 2018

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Figure 1 Cardiac computed tomography certification session during Euroecho Imaging Congress 2018 in Milan.

Next exam at ESC 2019 (Paris)
THANKS

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Edoardo Conte, MD

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Alberto Formenti, MD
Elisabetta Mancini, MD
Giuseppe Muscogiuri, MD

**Fellow**
Francesca Baessato
Gloria Cicala, MD
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