Ischemia and Viability Testing
With Stress Echocardiography

Theodora A Zaglavara, MD, PhD
Director of Echocardiography
EUROMEDICA KYANOUS STAVROS HOSPITAL
Thessaloniki GREECE
Goals of Cardiac Imaging in Coronary Artery Disease

➢ Direct imaging of coronary arteries

➢ Coronary Flow Reserve -question mark

➢ Myocardial Perfusion  ✓  -question mark

➢ Detection of inducible ischaemia  ✓

➢ Prognosis / risk stratification in patients with known or suspected CAD  ✓

➢ Ventricular dimensions and overall function  ✓

➢ Coexisting significant valve disease  ✓

➢ Detection of myocardial viability/myocardial scar  ✓
Development of Ischemic Cardiomyopathy as a Time-Dependent Phenomenon
Pathophysiological Targets of Different Imaging Modalities

- fibroblast
- $^{13}\text{NH}_3$ ammonia
- Gadolinium
- FDG
- dobutamine
- Tc MIBI/TF
- $^{201}\text{Thallium}$
- $^{82}\text{Rubidium}$
- $\text{H}_2^{15}\text{O}$ water

**Subepicardium: “viable black rim”**

Glucose → FDG → Glucolysis

$^{13}\text{NH}_3$ → Cardiomyocyte

$\text{H}_2^{15}\text{O}$ water

Krebs Cycle

β-Oxidation

Mitochondrion

$[\text{Ca}^{2+}]$ inotropy

β-AR

dobutamine

Blood Vessel Delivery of Imaging tracers
Myocardial Response to Dobutamine Infusion

RESPONSE TO DOBUTAMINE

- Baseline
- Low Dose
- Peak
- Recovery

- Biphasic
- Viable
- Monophasic
- Scar
- Non Phasic
Normal Response to Stress:

Increase in EF and Decrease in End-Systolic Volume

REST- HR 78/min  STRESS- HR 142/min
Abnormal Response

Inducible Ischaemia at a Low Ischaemic Threshold

REST
HR 70/min

LOW DOSE

PEAK STRESS
HR 100/min
A High Risk Coronary Lesion Detected in a 46 year old Man with Multiple Risk Factors including Diabetes

**Ischaemic threshold:**

<table>
<thead>
<tr>
<th>HR</th>
<th>100</th>
<th>57%</th>
</tr>
</thead>
<tbody>
<tr>
<td>220-age</td>
<td>220-46</td>
<td></td>
</tr>
</tbody>
</table>

Heart rate (dobutamine dose) at which ischaemia develops.

Correlates both with number of stenosed vessels and EF response to exercise (Panza, Circ 1995)
Cumulative effect of ischemic extent and maximal severity (jeopardized myocardium) of wall motion abnormalities on event rate/year

Yao SS et al. Am J Cardiol 2004
Cardiac Mortality Based on Dobutamine Stress Echocardiography (3156 patients)

Independent and incremental value of stress echocardiography over clinical and stress ECG parameters for the prediction of hard cardiac events in new-onset suspected angina with no history of CAD

Chelliah R et al. Eur J Echocardiography 2010
Risk Stratification after Myocardial Infarction

Risk Stratification after Myocardial Infarction

Low dose  Peak Stress
LV EF, infarct-zone WMSI, EDVI, and ESVI in patients with a 1st AMI treated with primary PTCA separated on the basis of presence or absence of infarct-zone viability at DSE.

3- D EF and LV volumes

Circulation 1997
Eur Heart Journal 2011
Stress Echocardiography: Effective Risk Stratification in Women

Bangalore S et al. ASE 2007
Stress Echocardiography: A Powerful Prognostic Tool in High Risk Populations

DIABETES MELITUS

Cortigianni L et al. JACC 2006
Stress echocardiography for detection of CAD/Risk assessment: Symptomatic or ischaemic equivalent

Journal of the American Society of Echocardiography, March 2011
Stress echocardiography following prior treadmill ECG, coronary calcium scoring, or carotid intimal medial thickness test results
Stress echocardiography following prior stress imaging or coronary angiogram test results.
Stress Echocardiography for risk assessment

Perioperative evaluation for noncardiac surgery without active cardiac conditions

Journal of the American Society of Echocardiography, March 2011
Stress echocardiography for risk assessment

Postrevascularization (PCI or CABG)

Journal of the American Society of Echocardiography, March 2011
Stress – Contrast Echo
ASE strongly supports the use of contrast agents in clinical practice.

These agents assist physicians in maximizing the accuracy of information obtained from echocardiograms and thus optimizing patient care.

ASE also believes that these agents are generally safe and well tolerated.
EDITOR'S PAGE

Contrast Echocardiography: Over-Achievement in Research, Under-Achievement in Practice?

Thomas H. Marwick, MD, PhD,* Jagat Narula, MD, PhD†
3D Stress Echo: Dynamic Slices
EDITORIAL COMMENT

Contractility: Still Searching After All These Years*

Michael Feneley, AM, MD
Darlinghurst, Australia
Normal Response to Stress: Enhanced Radial Strain
Viability and Prognosis

Analysis of pooled data using different viability techniques. Allman et al, JACC 2002
Impact of Improvement in Medical Therapy during the Past Decade on Prognosis

Circulation 2008

J Am Coll Cardiol 2002
Comparison of Imaging Techniques for Detection of Myocardial Viability

Marwick et al. Heart 2003
Viable Myocardium Responds with Increased Contractility at Low-dose Dobutamine Infusion
No Viability: Stress Echo and 2-D Radial Strain
Prediction of Viable Myocardium in Akinetic Segments: Incremental Value of Diastolic Wall Thickness Measurement

Zaglavara et al. Heart 2005
Algorithm of Management of Patients with Ischaemic LV dysfunction

LV Dysfunction

LV Wall Thickness In Area of Dysfunction

- Echo
- CMR if echo not satisfactory

Wall Thickness ≤5-6 mm (Probability of improvement of LV function ≤5%)

LDDE and SPECT

- Viable
  - Revascularization
    - HE ≤50% or Mismatch
      - Revascularization
  - Not viable
    - CMR or PET
      - HE >50% or Matched Defect
        - No Revascularization
      - HE ≤50% or Mismatch
        - Revascularization

Wall Thickness >5-6 mm (Probability of improvement of LV function ≥50%)

- Not viable
  - Revascularization

†Evaluate remote areas for CAD, ischemia if appropriate

*All patients need intensive medical therapy by standards of current era

Rahimtoola SH, et al. JACC Cardiovascular Imaging 2008
PARR-2 TRIAL
PET and Recovery following Revascularization Trial, JACC 2007

HEART TRIAL
The Heart Failure Revascularization Trial, Eur J Heart Fail 2011

Original Article

Myocardial Viability and Survival in Ischemic Left Ventricular Dysfunction

The STICH Trial!!!
April 2011 - cited in 111 papers so far!!
1,212 patients enrolled in the STICH Revascularization Hypothesis Trial

601 patients included in the STICH Myocardial Viability Substudy

303 patients randomized to medical therapy alone
- 243 patients with myocardial viability
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P = 0.53 for the interaction between viability status and treatment assignment with regard to mortality
Is viability still viable after the STICH trial?

Lauro Cortigiani¹, Riccardo Bigi², and Rosa Sicari³*

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There is no convincing evidence that the assessment of myocardial viability should not be included in the work-up of the chronic dysfunctioning patient, at least not on the basis of the STICH trial.⁶⁹
2013 ACCF/ACR/ASE/ASNC/SCCT/SCMR Appropriate Utilization of Cardiovascular Imaging in Heart Failure

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# Appropriate Use Criteria

## 2013 ACCF/ACR/ASE/ASNC/SCCT/SCMR Appropriate Utilization of Cardiovascular Imaging in Heart Failure

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## Table 3. Viability Evaluation (After Ischemic Etiology Determined) Known to Be Amenable to Revascularization With or Without Clinical Angina

<table>
<thead>
<tr>
<th>INDICATION</th>
<th>Echo</th>
<th>RNV</th>
<th>SPECT Rest/Redistribution</th>
<th>PET</th>
<th>CMR</th>
<th>Rest Only</th>
<th>Echo</th>
<th>SPECT</th>
<th>PET</th>
<th>CMR</th>
<th>CCT</th>
<th>Cath</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Severely reduced ventricular function (EF &lt;30)</td>
<td>M</td>
<td>R</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>9. Moderately reduced ventricular function (EF 30%-39%)</td>
<td>M</td>
<td>R</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
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<tr>
<td>10. Mild ventricular function (EF 40%-49%)</td>
<td>M</td>
<td>R</td>
<td>M</td>
<td>M</td>
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</table>
CABG Guidelines 2011

• **Class IIa**

-- CABG to improve survival is reasonable in patients with significant (≥70% diameter) stenoses in 2 major coronary arteries with severe or extensive myocardial ischemia or target vessels supplying a large area of viable myocardium. (Level of Evidence: B)

-- CABG to improve survival is reasonable in patients with mild–moderate LV systolic dysfunction (ejection fraction 35% to 50%) and significant (≥70% diameter stenosis) multivessel CAD or proximal LAD coronary artery stenosis, when viable myocardium is present in the region of intended revascularization. (Level of Evidence: B)

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-- CABG might be considered with the primary or sole intent of improving survival in patients with SIHD with severe LV systolic dysfunction (ejection fraction <35%) whether or not viable myocardium is present. (Level of Evidence: B)
Ionizing Radiation in Cardiac Imaging.

American Heart Association Recommendations:

Cardiac imaging studies that expose patients to ionizing radiation should be ordered only after thoughtful consideration of the potential benefit to the patient and in keeping with established appropriateness criteria (Class I).

Considerations should include options for answering the clinical question at hand by means that do not use ionizing radiation or choosing the type of study that exposes the patient to the lowest amount of radiation (Class I).

Routine surveillance radionuclide stress tests or cardiac CTs in asymptomatic patients at low risk for ischaemic heart disease are not recommended (Class I).

Healthcare providers should discuss the risks and benefits of planned imaging procedures with patients whenever practical or appropriate (Class I).
Cardiac Imaging: does radiation matter?

✓ Doses of 5-100 mSv corresponds to an excess relative cancer risk of 2%

✓ There is no dose below there is no cancer risk

✓ The higher the patients age the lower the cancer risk

✓ For women, radiation risk is greater while cardiovascular risk is less

Eur Heart Journal 2012
The right test for the right patient at the right time!

✓ Use imaging tests only in patients with accepted indications

✓ None of the imaging tests is recommended in asymptomatic patients and in patients with stable symptoms and low pre-test likelihood of CAD (ESC guidelines 2010)

✓ Guidelines still leave the clinician a lot of responsibility in terms of what is the best test for an individual patient
First Do Not Harm!
“Ωφελέειν, ἢ Μη Βλάπτειν”

The art (medicine) consists in three things: the disease, the patient and the physician.

Hippocrates, Epidemics, 5th century B.C
Assessment of Myocardial Viability with Dobutamine Stress Echocardiography

Cusick et al. J Heart Lung Transplant 1997
Meluzin et al. J Am Coll Cardiol 1997
Patient with Heart Failure Referred for Viability Testing

LVEDV: 338 ml
LVESV: 260 ml
LVDD: 7.7 cm
LVSD: 6.8 cm
EF: 23%
Low Dose Dobutamine Echo:
No viability in the interventricular septum area
Significant viability in anterior, lateral and inferior areas
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Michael Feneley, AM, MD
Darlinghurst, Australia
Απεικόνιση της Μυοκαρδιακής Παραμόρφωσης με το 2-D strain για την Κατάδειξη Βιώσιμου Μυοκαρδίου

Cutoff of 17.2% for peak radial strain

Becker et al. JACC 2008
No Viability: Stress Echo and 2-D Radial Strain
Comparison of Imaging Techniques for Detection of Myocardial Viability

Marwick et al. Heart 2003
Diagnostic Accuracy of Different Techniques to Assess Hibernating Myocardium

![Graph showing sensitivity and specificity of diagnostic techniques](image-url)
CMR Imaging Assessing Viability in Patients With Chronic Ventricular Dysfunction Due to Coronary Artery Disease

A Meta-Analysis of Prospective Trials
Πρόβλεψη Βιώσιμου Μυοκαρδίου με Βάση το Διαστολικό Πάχος Τοιχωμάτων και το Σπινθηρογράφημα TI -201

Prediction of Viable Myocardium in Akinetic Segments: Incremental Value of Diastolic Wall Thickness Measurement

Zaglavara et al. Heart 2005
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Rahimtoola SH, et al. JACC Cardiovascular Imaging 2008
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Robert O. Bonow, M.D., Gerald Maurer, M.D., Kerry L. Lee, Ph.D., Thomas A. Holly, M.D., Philip F. Binkley, M.D., Patrice Desvigne-Nickens, M.D., Jaroslaw Drozdz, M.D., Ph.D., Pedro S. Farsky, M.D., Arthur M. Feldman, M.D., Torsten Doenst, M.D., Ph.D., Robert E. Michler, M.D., Daniel S. Berman, M.D., Jose C. Nicolau, M.D., Ph.D., Patricia A. Pellikka, M.D., Krzysztof Wrobel, M.D., Nasri Alotti, M.D., Ph.D., Federico M. Asch, M.D., Liliana E. Favaloro, M.D.

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P = 0.53 for the interaction between viability status and treatment assignment with regard to mortality
Myocardial Viability and Mortality

Without Viability

- MED (33 deaths)
- CABG (25 deaths)

With Viability

- MED (95 deaths)
- CABG (83 deaths)

Subgroup

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>N</th>
<th>Deaths</th>
<th>HR</th>
<th>95% CI</th>
<th>Interaction P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without viability</td>
<td>114</td>
<td>58</td>
<td>0.70</td>
<td>0.41, 1.18</td>
<td>0.528</td>
</tr>
<tr>
<td>With viability</td>
<td>487</td>
<td>178</td>
<td>0.86</td>
<td>0.64, 1.16</td>
<td></td>
</tr>
</tbody>
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Is viability still viable after the STICH trial?

Lauro Cortigiani¹, Riccardo Bigi², and Rosa Sicari³*

¹Cardiovascular Unit, Campo di Marte Hospital, Lucca, Italy; ²Department of Cardiovascular Sciences, University School of Medicine, Milan, Italy; and ³Institute of Clinical Physiology, CNR, Via G. Moruzzi 1, 56124 Pisa, Italy

There is no convincing evidence that the assessment of myocardial viability should not be included in the work-up of the chronic dysfunctioning patient, at least not on the basis of the STICH trial.
The STICH Trial or How Statisticians Can Defy Nature from a Flawed Database!!!!

Blood is better than drugs for ischemic myocardium

Rahimtoola
ACC/AHA CABG Guidelines 2011

- **Class IIa**
  - CABG to improve survival is reasonable in patients with significant ($\geq 70\%$ diameter) stenoses in 2 major coronary arteries with severe or extensive myocardial ischemia or target vessels supplying a large area of viable myocardium. (Level of Evidence: B)
  - CABG to improve survival is reasonable in patients with mild–moderate LV systolic dysfunction (ejection fraction 35% to 50%) and significant ($\geq 70\%$ diameter stenosis) multivessel CAD or proximal LAD coronary artery stenosis, when viable myocardium is present in the region of intended revascularization. (Level of Evidence: B)

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2013 ACCF/ACR/ASE/ASNC/SCCT/SCMR Appropriate Utilization of Cardiovascular Imaging in Heart Failure

A Joint Report of the American College of Radiology Appropriateness Criteria Committee and the American College of Cardiology Foundation
### Table 10. Recommendations for Noninvasive Cardiac Imaging

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>COR</th>
<th>LOE</th>
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<tr>
<td>Patients with suspected, acute, or new-onset HF should undergo a chest x-ray</td>
<td>I</td>
<td>C</td>
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<td>A 2-dimensional echocardiogram with Doppler should be performed for initial evaluation of HF</td>
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<td>Repeat measurement of EF is useful in patients with HF who have had a significant change in clinical status or received treatment that might affect cardiac function or for consideration of device therapy</td>
<td>I</td>
<td>C</td>
</tr>
<tr>
<td>Noninvasive imaging to detect myocardial ischemia and viability is reasonable in HF and CAD</td>
<td>IIa</td>
<td>C</td>
</tr>
<tr>
<td>Viability assessment is reasonable before revascularization in HF patients with CAD</td>
<td>IIa</td>
<td>B (281–285)</td>
</tr>
<tr>
<td>Radionuclide ventriculography or MRI can be useful to assess LVEF and volume</td>
<td>IIa</td>
<td>C</td>
</tr>
<tr>
<td>MRI is reasonable when assessing myocardial infiltration or scar</td>
<td>IIa</td>
<td>B (286–288)</td>
</tr>
<tr>
<td>Routine repeat measurement of LV function assessment should not be performed</td>
<td>III: No Benefit</td>
<td>B (289,290)</td>
</tr>
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<th>Rest Only</th>
<th>Rest + Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Echo</td>
<td>RNV</td>
</tr>
<tr>
<td>8. Severe reduced ventricular function (EF &lt;30)</td>
<td>M</td>
<td>R</td>
</tr>
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<td>M</td>
<td>R</td>
</tr>
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<td>10. Mild ventricular function (EF 40%-49%)</td>
<td>M</td>
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</table>
ACCF/AHA UA/NSTEMI (97a)

CLASS I
1. Percutaneous coronary intervention or CABG for patients with 1- or 2-vessel CAD without significant proximal LAD CAD, but with a large area of viable myocardium and high-risk criteria on noninvasive testing. * (Level of Evidence: B)  

CLASS IIa
1. Use of PCI or CABG for patients with 1-or 2-vessel CAD without significant proximal LAD disease, but with a moderate area of viable myocardium and demonstrable ischemia on noninvasive testing. * (Level of Evidence: B)  

CLASS III
1. Use of PCI or CABG for patients with 1-or 2-vessel CAD without significant proximal LAD disease who have mild symptoms that are unlikely to be due to myocardial ischemia, or who have not received an adequate trial of medical therapy and have only:
   a. A small area of viable myocardium; or
   b. Have no demonstrable ischemia on noninvasive testing. * (Level of Evidence: C)
Recommendations on revascularizations in patients with chronic heart failure and systolic LV dysfunction (ejection fraction ≤ 35%)

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>Class</th>
<th>Level</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>CABG is recommended for patients with significant LM stenosis and LM equivalent with proximal stenosis of both LAD and LCx arteries.</td>
<td>I</td>
<td>C</td>
<td>-</td>
</tr>
<tr>
<td>CABG is recommended for patients with significant LAD artery stenosis and multivessel disease to reduce death and hospitalization for cardiovascular causes.</td>
<td>I</td>
<td>B</td>
<td>112,288</td>
</tr>
<tr>
<td>LV aneurysmectomy during CABG should be considered in patients with a large LV aneurysm, if there is a risk of rupture, large thrombus formation or the aneurysm is the origin of arrhythmias.</td>
<td>IIa</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Myocardial revascularization should be considered in the presence of viable myocardium.</td>
<td>IIa</td>
<td>B</td>
<td>55</td>
</tr>
<tr>
<td>CABG with surgical ventricular restoration may be considered in patients with scarred LAD territory, especially if a post-operative LVESV index &lt; 70 mL/m² can be predictably achieved.</td>
<td>IIb</td>
<td>B</td>
<td>291–295</td>
</tr>
<tr>
<td>PCI may be considered if anatomy is suitable, in the presence of viable myocardium, and surgery is not indicated.</td>
<td>IIb</td>
<td>C</td>
<td></td>
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Cardiac Imaging: does radiation matter?

✓ Doses of 5-100 mSv corresponds to an excess relative cancer risk of 2%

✓ There is no dose below there is no cancer risk

✓ The higher the patients age the lower the cancer risk

✓ For women, radiation risk is greater while cardiovascular risk is less

Eur Heart Journal 2012
Approaches to Enhancing Radiation Safety in Cardiovascular Imaging: A Scientific Statement From the American Heart Association

Patient referred for cardiac imaging for CAD evaluation

Is study appropriate?

Yes

Consider imaging without radiation, especially in younger patients

No

Contact referring clinician

Is imaging without radiation available and comparable? (includes consideration of nonradiogenic risks, diagnostic accuracy, cost, patient convenience and local expertise)

Can patient exercise?

Yes

Consider coronary CTA or PET, if available

No

No

Consider SPECT (using lowest dose, ≥2 heads and high-sensitivity camera, if available)

Can patient exercise?

Yes

Candidate for stress-only?

Yes

Tc99m stress with attenuation correction, if available

No

Tc99m stress with attenuation correction, if available

Circulation. published online September 29, 2014;
The right test for the right patient at the right time!

✓ Use imaging tests only in patients with accepted indications

✓ Guidelines still leave the clinician a lot of responsibility in terms of what is the best test for an individual patient
The art (medicine) consists in three things: the disease, the patient and the physician.

Hippocrates, Epidemics, 5th century B.C
Clinicians’ Referrals for Stress Echocardiography: Are we Compliant with Nice Guidelines?
Stepwise Approach to Perioperative Cardiac Assessment for CAD
2.8. **Stress echocardiography.**
- Stress echocardiography may be helpful in the evaluation of patients with intermediate or high pretest probability for CAD, (echocardiogram uninterpretable or unable to exercise) who will receive regimens that may cause ischemia (fluorouracil, bevacizumab, sorafenib, and sunitinib).
- Stress echocardiography may be of help in the determination of contractile reserve of patients with evidence of CTRCD.
# 2013 ACCF/AHA Guideline for the Management of Heart Failure

## Table 10. Recommendations for Noninvasive Cardiac Imaging

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CAD indicates coronary artery disease; COR, Class of Recommendation; EF, ejection fraction; HF, heart failure; LOE, Level of Evidence; LV, left ventricular; LVEF, left ventricular ejection fraction; and MRI, magnetic resonance imaging.
### Indications for diagnostic testing in patients with suspected CAD and stable symptoms

<table>
<thead>
<tr>
<th>Anatomical detection of CAD</th>
<th>Symptomatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive angiography</td>
<td>III A</td>
</tr>
<tr>
<td>CT angiography(^f_g)</td>
<td>III B</td>
</tr>
<tr>
<td>Stress echo</td>
<td>III A</td>
</tr>
<tr>
<td>Nuclear imaging</td>
<td>III A</td>
</tr>
<tr>
<td>Stress MRI</td>
<td>III C</td>
</tr>
<tr>
<td>PET perfusion</td>
<td>III C</td>
</tr>
<tr>
<td>Combined or hybrid imaging test</td>
<td>III C</td>
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</table>

<table>
<thead>
<tr>
<th>Functional test</th>
<th>Symptomatic</th>
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<tbody>
<tr>
<td>Ref</td>
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<tr>
<td>50–52,54</td>
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<tr>
<td>57–62</td>
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<td>63–65</td>
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<td>60,66–70</td>
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<td>71–75</td>
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<tr>
<td>67,69,70,76,77</td>
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<td>78–83</td>
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</table>
### APPROPRIATE USE CRITERIA

ACCF/AHA/ASE/ASNC/HFSA/HRS/SCAI/SCCT/SCMR/STS
2013 Multimodality Appropriate Use Criteria for the Detection and Risk Assessment of Stable Ischemic Heart Disease

Table 1.1. Symptomatic

Refer to pages 16 and 17 for relevant definitions, in particular Table A and text for age, sex, symptom presentation, and risk factors relevant to each pre-test probability category.

<table>
<thead>
<tr>
<th>Indication Text</th>
<th>Exercise ECG</th>
<th>Stress RNI</th>
<th>Stress Echo</th>
<th>Stress CMR</th>
<th>Calcium Scoring</th>
<th>CCTA</th>
<th>Invasive Coronary Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Low pre-test probability of CAD</td>
<td>A</td>
<td>R</td>
<td>M</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
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<tr>
<td>ECG interpretable AND able to exercise</td>
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<td>2. Low pre-test probability of CAD</td>
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<td>R</td>
<td>M</td>
<td>R</td>
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<tr>
<td>ECG uninterpretable OR unable to exercise</td>
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<tr>
<td>3. Intermediate pre-test probability of CAD</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
<td>R</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>ECG interpretable AND able to exercise</td>
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<tr>
<td>4. Intermediate pre-test probability of CAD</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>A</td>
<td>A</td>
<td>M</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>5. High pre-test probability of CAD</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>ECG interpretable AND able to exercise</td>
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</tr>
<tr>
<td>6. High pre-test probability of CAD</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>R</td>
<td>M</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>ECG uninterpretable OR unable to exercise</td>
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</tr>
</tbody>
</table>

Appropriate Use Key: A = Appropriate; M = May Be Appropriate; R = Rarely Appropriate.

A = Appropriate; CAD = coronary artery disease; CCTA = coronary computed tomography angiography; CMR = cardiac magnetic resonance; ECG = electrocardiogram; Echo = echocardiography; M = May Be Appropriate; R = Rarely Appropriate; RNI = radionuclide imaging.
### Section 3. Pre-Operative Evaluation for Noncardiac Surgery

#### Table 3.3. Poor or Unknown Functional Capacity (<4 METs)

<table>
<thead>
<tr>
<th>Indication Text</th>
<th>Exercise ECG</th>
<th>Stress RNI</th>
<th>Stress Echo</th>
<th>Stress CMR</th>
<th>Calcium Scoring</th>
<th>CCTA</th>
<th>Invasive Coronary Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>73. Low-risk surgery</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>74. Intermediate-risk surgery</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>75. Vascular surgery</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>76. Kidney transplant</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
<td>R</td>
<td>M</td>
</tr>
<tr>
<td>77. Liver transplant</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td>M</td>
<td>R</td>
<td>R</td>
<td>M</td>
</tr>
</tbody>
</table>

Refer to pages 12 and 13 for relevant definitions.

Appropriate Use Key: A = Appropriate; M = May Be Appropriate; R = Rarely Appropriate.

A = Appropriate; CCTA = coronary computed tomography angiography; CMR = cardiac magnetic resonance; ECG = electrocardiogram; Echo = echocardiography; M = May Be Appropriate; R = Rarely Appropriate; RNI = radionuclide imaging.