NON-INVASIVE IMAGING

Cardiac imaging in the patient with chest pain: echocardiography

Frank A Flachskampf, Werner G Daniel

▶ Supplementary videos are available online only. To view these files please visit the journal online (http://heart.bmj.com).

Med.Klinik 2, University of Erlangen, Erlangen, Germany

Correspondence to
Professor Frank A Flachskampf, Med.Klinik 2, Ulmenweg 18, Erlangen 91054, Germany; frank.flachskampf@uk-erlangen.de

Echocardiography is the first line imaging modality in cardiovascular diseases. Its predominant role in clinical care is mainly based on the following factors:

- Universal availability. While it has always been a strength of echocardiography that it could be performed at the bedside with mobile machines, portability has reached a new level with the advent of laptop or even palmtop type devices. These small machines do sacrifice some degree of image quality and a few echo modalities, but an experienced examiner can obtain almost immediately relevant clinical data with such a portable echo machine. Even state-of-the-art machines have been coming down in size and weight, and all are fully mobile and able to function in an emergency ward or intensive care environment.
- Low cost. Typically, state-of-the-art echocardiography machines are available for about 10–20% of the price of competitor techniques such as a gamma camera, magnetic resonance imaging (MRI), or computed tomography (CT). There are only minimal additional material costs per examination. No contrast agent is routinely necessary. The exam can be performed by a sonographer or a physician. Cost effectiveness of stress echocardiography compared to conventional exercise ECG or nuclear imaging in patients with low to intermediate pre-test likelihood has been shown.[1 2]
- No radiation. Ultrasound for practical purposes can be regarded as biologically safe. Unlike with MRI, the presence of metal implants such as pacemakers poses no hazard.
- Echocardiography is the original 'one-stop shop', evaluating global and regional left and right ventricular morphology and function, valvular function, pericardial abnormalities, aortic disease, and other data in real time within minutes. Furthermore, a three dimensional echocardiogram or deformation imaging are done with the same machine during the same examination, adding at most a few minutes to an examination whose typical duration does not exceed about 20 min.

ECHOCARDIOGRAPHIC SIGNS OF CORONARY ARTERY DISEASE

The hallmark of coronary artery disease (CAD) in echo is the wall motion abnormality. 'Wall motion' refers to the visual, qualitative evaluation of regional systolic endocardial inward motion and, as the most important element, systolic wall thickening (figure 1). In a broader sense, it also encompasses parameters of myocardial deformation which can be measured quantitatively, such as regional myocardial velocity and deformation ('strain'), including radial, longitudinal, and circumferential deformation. Qualitative assessment of wall motion, due to the necessity of visually identifying endocardial and epicardial borders in each region and due to the broad limits of normalcy, constitutes one of the most difficult tasks in echocardiography and depends critically on image quality as well as operator skill and experience. It is usually reported in a 16 segment or 17 segment model[3] of the left ventricle (figure 2). Wall motion traditionally is qualitatively labelled and scored per segment as:

- normokinesia (normal wall motion/thickening, score 1)
- hypokinesia (reduced, but not absent wall motion/thickening, score 2)
- akinesia (absent wall motion/thickening, score 3)
- dyskinesia (systolic thinning and outward endocardial border motion, score 4).

The segmental scores are summed up and divided by the number of segments, yielding the wall motion score index. This index is 1 in a normal ventricle; the higher its value, the more segmental wall motion abnormalities are present. Wall motion abnormalities at rest indicate acute myocardial ischaemia or scar. If they develop during a stress test, they indicate inducible ischaemia (figure 3). A positive stress echo provides much important information beyond the presence or absence of inducible ischaemia: level of exercise/stress at which the myocardium becomes ischaemic, extent (number of segments) and degree (severity of wall motion abnormality) of ischaemia, coronary perfusion territory, and more. Not all wall motion abnormalities are due to CAD; frequent other causes include bundle branch block, ventricular pacing, myocarditis, or cardiomyopathy.

In patients with suboptimal image quality, diagnostic benefit is obtained by using left heart contrast to delineate the endocardial border more clearly, which is recommended if more than two segments are unevaluable. Left heart contrast agents have also been successfully employed as perfusion tracers to assess directly myocardial perfusion by echo, both at rest[4] and with pharmacologic stress,[5 6] but the method is not yet sufficiently standardised to recommend broad use.

Many attempts to quantify wall motion abnormalities objectively have been made, but largely

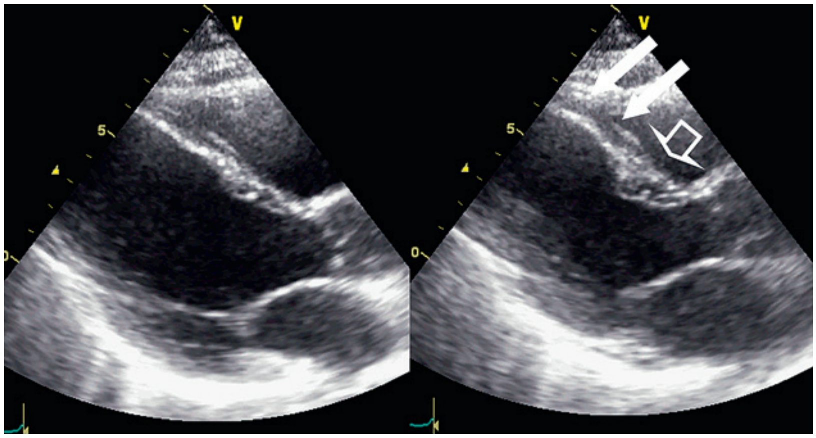

Figure 1 Typical wall motion abnormality in the left anterior descending artery perfusion territory due to an anterior myocardial infarction. Left: diastole; right: systole. Long arrows point at dyskinetic mid anteroseptal wall, while shorter arrow points to basal anteroseptal wall with preserved contractility.

abandoned due to the difficulty to match—let alone beat—the experienced observer's eye in this regard. Myocardial deformation measured by Doppler or speckle tracking methods currently offers the best approach,[7–9] but is not superior to expert visual assessment.

Direct visualisation of the complete course of the coronary arteries by echocardiography at the present time is prohibitively difficult. Left main and a short section of the left anterior descending artery are visible clearly in transoesophageal views, and the distal left anterior descending artery may be imaged from the apical echo window, allowing

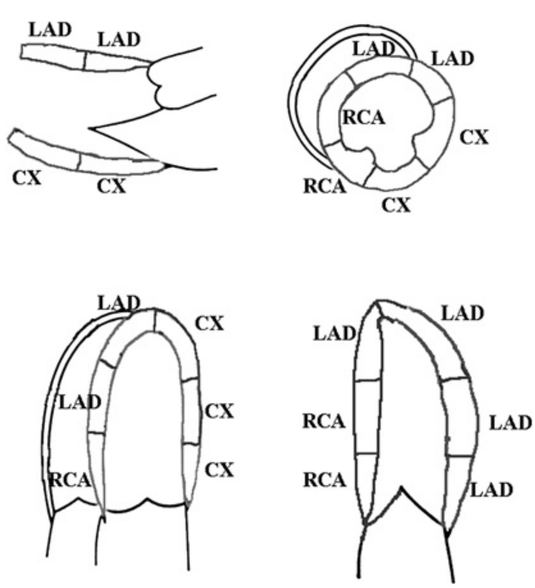

Figure 2 Sixteen segment model of the left ventricle for the assessment of segmental wall motion abnormalities; clockwise, parasternal long axis, parasternal short axis, apical four chamber view, apical two chamber view. The segments are assigned to typical perfusion territories (CX, circumflex; LAD, left anterior descending; RCA, right coronary artery), which vary individually.

Doppler assessment of coronary flow reserve in this vessel.[10] Other great coronary vessels and bypass grafts, in particular left internal mammary grafts, have also been imaged with varying success. This technique so far has not been extensively evaluated and should be considered experimental.

The role of echocardiography in the management of the patient with chest pain will be presented according to three typical clinical scenarios: (1) the patient with acute chest pain at rest; (2) the stable patient with a history of chest pain; (3) the patient with chronic congestive heart failure due to CAD (ischaemic cardiomyopathy).

The patient with acute chest pain at rest

Echocardiography provides important information at the bedside and within minutes in the patient with acute chest pain. The following information should be systematically sought by echo:

- Is there a wall motion abnormality? If so, severity, extent in the 16 segment model of the left ventricle, coronary perfusion territory, global left ventricular function, and the presence of complications (eg, mitral regurgitation, right ventricular impairment, thrombus formation, etc) are important for risk stratification and management. The question of whether a wall motion abnormality is new or old is difficult to answer. Dysfunctional myocardium which is thin (<5 mm end-diastolic thickness) and bright most likely represents a scar, but not all scars are thin and bright, and not all thin wall segments are non-viable. Small wall motion abnormalities may go unnoticed, especially in the perfusion territory of the circumflex artery, which is where echocardiography has its lowest sensitivity for abnormalities. Detection of a new wall motion abnormality is also very difficult in diffusely impaired left ventricular function. Nevertheless, the finding of a resting wall motion abnormality in a patient with acute chest pain has a high sensitivity and specificity for ongoing ischaemia.[11] In a study of 171 patients presenting to the emergency room with symptoms suggestive of heart disease, already the simple finding of any wall motion abnormality at rest predicted an eightfold short term (48 h) and a fourfold long term (48 h to 2 years) increase in cardiac events including death or myocardial infarction.[12]
- Are there signs indicative of other major cardiovascular diseases?
  - A dilated and impaired right ventricle with increased right ventricular systolic pressure suggests severe pulmonary embolism (figure 4). A pattern with right ventricular free wall hypokinesis and normokinesis of the right ventricular apex (McConnell sign[13]) is typical, although not uniformly present, in acute as opposed to chronic right ventricular pressure overload, where right ventricular impairment is more diffuse. In some cases, central thrombi may be directly visualised in a modified parasternal short axis view bringing out the main pulmonary

Heart 2010;96:1063–1072. doi:10.1136/hrt.2009.172114

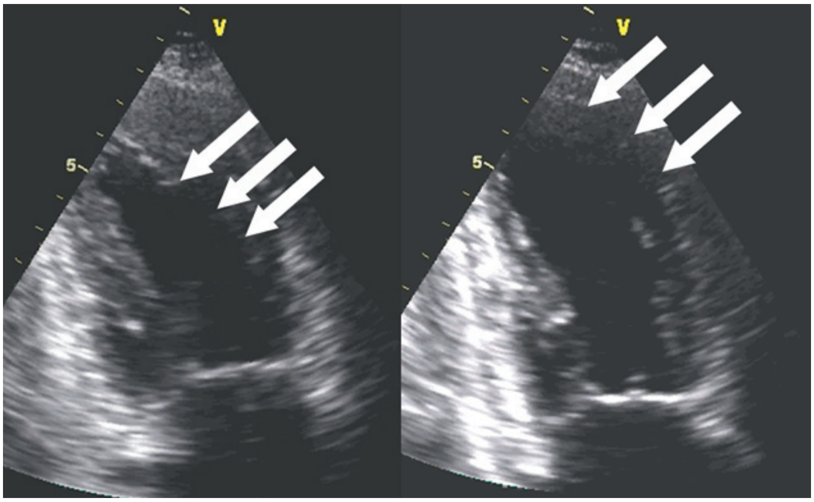

Figure 3 Inducible anterior ischaemia in a patient with multivessel disease including a severe stenosis of the left anterior descending. Left, baseline two chamber view at end-systole. Right, peak dobutamine stress two chamber view at end-systole. Note increase in apical left ventricular cavity due to severely reduced contraction of the anterior wall (arrows). Cine-loops are available as supplementary files (1 rest, 2 peak stress).

artery and bifurcation, and also by transoesophageal echocardiography, which is able to delineate not only the main pulmonary artery and bifurcation but also the proximal right pulmonary artery.

- Aortic regurgitation, pericardial effusion, and an enlarged ascending aorta raise the red flag of possible ascending aortic dissection (figure 5). Often, the dissection membrane is visible in the ascending aorta or the aortic arch visualised from the suprasternal notch. However, much higher diagnostic accuracy for transoesophageal echocardiography has been well documented and this technique, CT or MRI should be used to definitely exclude acute aortic dissection. Aortic dissection is very frequently misdiagnosed initially as myocardial ischaemia; both may coexist, together with ST elevation on the ECG, if the dissection obstructs a coronary ostium.
- Pericardial effusion in acute pericarditis (figure 6). Although typically pericarditic pain subsides once a circumferential pericardial effusion develops, both may coexist in early disease. Pericardial effusion in conjunction with chest pain, however, should also alert the examiner to the possibility of type A aortic dissection or myocardial rupture and perforation of the left ventricular free wall as a complication of previous myocardial infarction. These possibilities would strongly discourage use of thrombolytics or anticoagulation. Lastly, approximately 1 week or more after myocardial infarction, an inflammatory reaction—the Dressler syndrome—may produce a mild pericardial effusion. This syndrome seems to have decreased in incidence in the last decades and is now rare.[14]

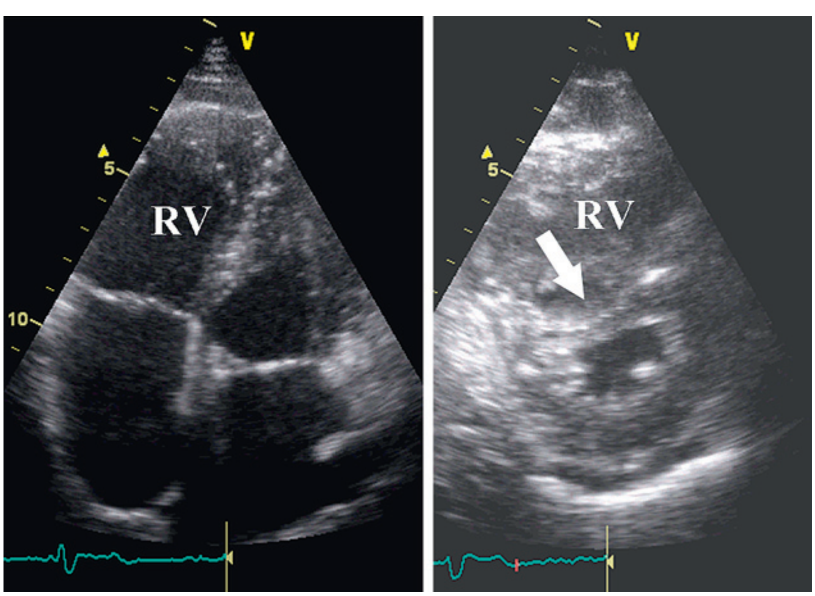

Figure 4 Pulmonary embolism. Left, modified apical four chamber view showing enlarged right ventricle in end-diastole (compare to the 'compressed' left ventricle). Right, parasternal short axis view showing flattened septum in systole (arrow; also called the 'D' sign because of the D shape of the left ventricular cross section) due to pulmonary hypertension. A supplementary video file (3) is available.

Thus, echocardiography can corroborate or refute the suspicion of myocardial ischaemia in a patient with acute chest pain, and detect, in the same examination, major and life threatening differential diagnoses. Therefore, all patients with acute chest pain should be examined by echocardiography as soon as possible, which corresponds to the current pertinent guideline recommendations.[15] Even in the patient with ST segment elevation, an immediate limited emergency echo is helpful and with proper logistics does not delay reperfusion treatment, including primary intervention. The key role of echocardiography in the detection of complications of myocardial infarction (eg, ischaemic mitral regurgitation, cardiogenic shock, left ventricular thrombus formation, ventricular septal rupture, aneurysm or pseudoaneurysm formation) is beyond the scope of this article.

The value of stress echocardiography in the assessment of emergency room patients in whom acute ischaemia has been excluded by ECG and myocardial necrosis markers (eg, troponins) has been studied. In these patients, stress echocardiography has a high predictive power for risk stratification, making it possible to distinguish patients who can be safely sent home and followed on an ambulatory basis from those who should be worked up further invasively. In an Italian multicentre study a negative pharmacologic stress echo had a very high negative predictive value: only 1.2% (6/502) of patients with a negative stress echo had a follow-up event over the next 13 months.[16] In another study of 351 patients with negative dobutamine stress echo there were 14 (4%) who had a follow-up event (including revascularisation, which is a relatively soft end point) during the next 6 months.[17]

Contrast echocardiography

If image quality is impaired, the application of left heart contrast improves endocardial border

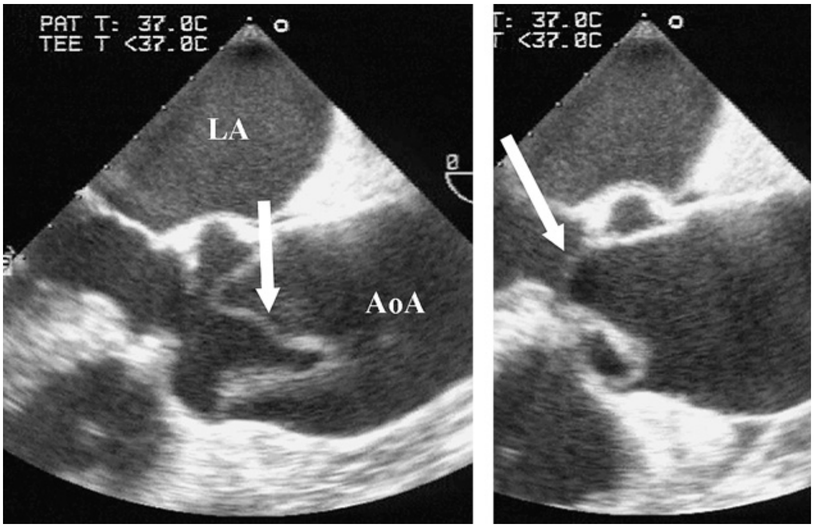

Figure 5 Aortic dissection of the ascending aorta (AoA). Left, the mobile dissection flap (arrow) is seen during systole in the proximal ascending aorta in a transoesophageal long axis view of the aorta. In this patient there was no pericardial effusion. Right, during diastole, the flap prolapses through the aortic valve into the left ventricular outflow tract (arrow), creating aortic regurgitation. A supplementary video file (4) is available.

delineation and thus facilitates recognition of wall motion abnormalities. This can be very useful, especially in the acute setting,[18 19] where both improved wall motion recognition and assessment of (especially subendocardial) regional perfusion can be accomplished by a left heart contrast examination (figure 7), with a demonstrable increase in diagnostic accuracy and prognostic power. Reduced transmit power settings ('low

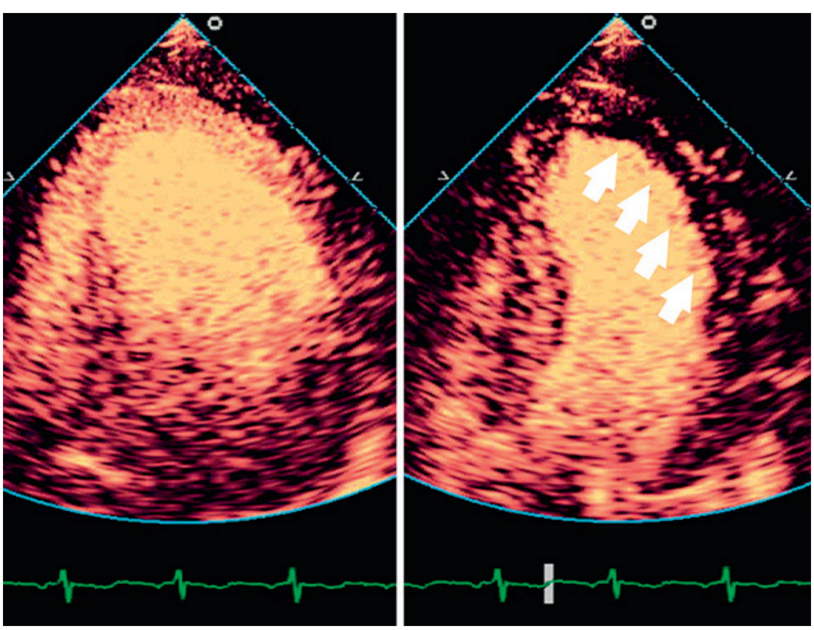

Figure 7 Myocardial contrast echocardiography with perflutren (Luminity). Low myocardial index (0.1) imaging of the apical four chamber view in end-systole in a patient with an apical hypokinesia, showing apical lateral hypoperfusion. Left, homogeneous perfusion of left ventricular myocardium before destructive ultrasound pulse. Right, one heart cycle after destructive pulse, replenishment image shows perfusion defect in the apical lateral and partially in the mid lateral segment (arrows), while septal perfusion is re-established. A supplementary video file (5) is available.

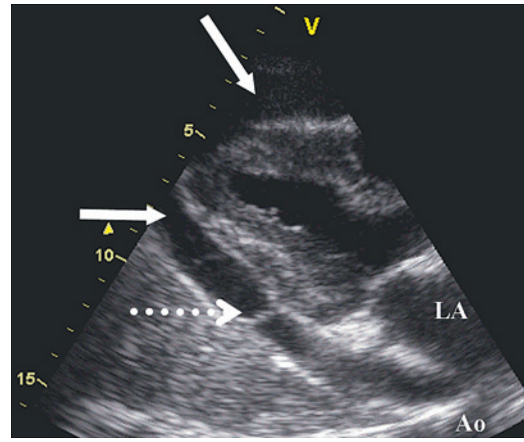

Figure 6 Circular pericardial effusion (arrows). Modified parasternal long axis view. Note that there is effusion between left atrium (LA) and descending aorta (Ao), distinguishing it from pleural effusion. There is a fibrin strand (dotted arrow) in the posterior pericardial space.

mechanical index') are advantageous to limit bubble destruction by the insonation, and several special modalities (eg, 'pulse inversion', 'power modulation' and others) are available on some echo machines to enhance the contrast effect.[20] Echo contrast examination in patients with acute ST elevation myocardial infarction after reperfusion therapy has furthermore provided insight into the efficacy of reperfusion therapy at the tissue level, as opposed to patency of the infarct artery as indicated by coronary angiography. 'No reflow' by myocardial contrast echocardiography predicts lack of recovery, infarct remodelling, and adverse prognosis in spite of angiographically successful (epicardial) coronary reperfusion (figure 8).[21–23] Myocardial contrast echocardiography, similar to other techniques, requires familiarity with the technique and remains fraught with limited specificity; however, regionally impaired wall motion and perfusion are closely associated and therefore simultaneous assessment may mutually reinforce the diagnosis of an abnormality. In 2008, the US Food and Drug Administration issued a warning against the use of left heart contrast agents in the setting of acute coronary syndrome,[24] based on a survey of adverse cardiovascular events, including deaths, in such patients shortly after use of left heart contrast. The warning was later revoked for the agents Optison and Definity, but currently, the only available left heart contrast agent in Europe, Sonovue, is not approved by the manufacturer for use in the acute coronary syndrome setting. However, a large retrospective analysis including acute settings found no excess mortality in patients receiving left heart contrast.[25]

New echocardiographic techniques

Motion and deformation of the left ventricular myocardium can be tracked and quantitated using several newer echo modalities based on tissue Doppler or speckle tracking, thereby offering quantitative tools to improve the highly subjective

Heart 2010;**96**:1063–1072. doi:10.1136/hrt.2009.172114

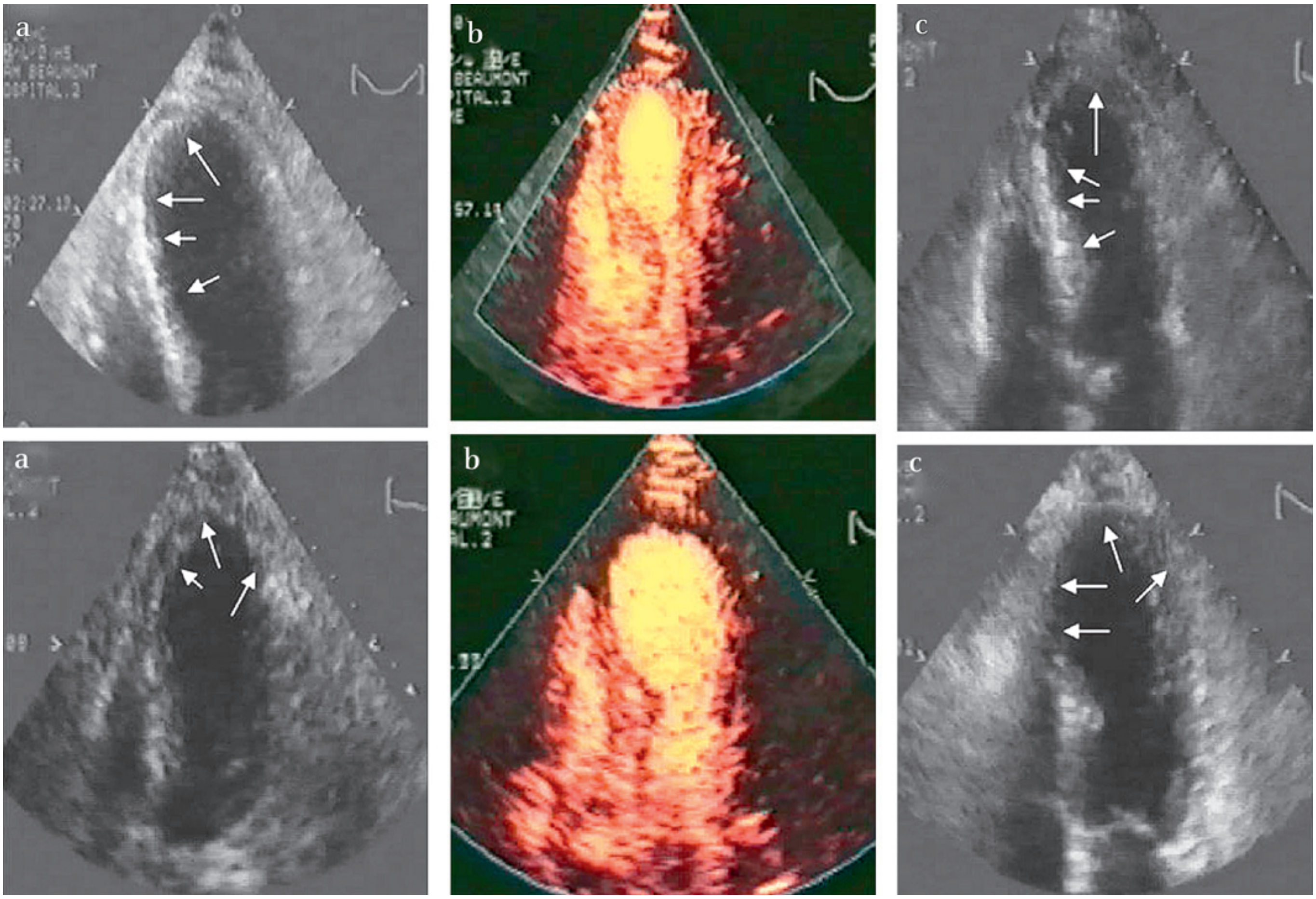

Figure 8 Myocardial contrast echocardiography for the assessment of microvascular perfusion. Two representative patients are shown 12 h after angiographically successful percutaneous intervention in acute ST elevation infarction. Top row: successful reperfusion at the microvascular level. (a) Apical four chamber view in systole showing akinetic septum and apex (arrows). (b) Homogeneous contrast opacification of the akinetic segments. (c) Follow-up echocardiography at 1 month, showing recovery of function of these segments (arrows) with reduction of left ventricular end-systolic volume. Bottom row: microvascular no-reflow in spite of angiographically successful recanalisation. (a) Apical four chamber view in systole showing akinetic mid septum and apex (arrows). (b) No contrast opacification seen in mid septum and apex. (c) Follow-up echocardiography at 1 month, showing lack of recovery of function of these segments (arrows) with no change in left ventricular end-systolic volume. Reproduced, with permission, from Hayat and Senior.[22]

traditional wall motion assessment, with the latest techniques working in a semi-automated fashion requiring only an approximate manual placement of the region of interest. These modalities measure regional myocardial strain (deformation, eg, thickening and thinning) and strain rate (rate of deformation). These parameters are highly sensitive to spontaneously occurring or stress induced regional ischaemia,[8] although their routine use to identify acute coronary syndrome is probably not warranted. In acute myocardial infarction, the amount of residual deformation (strain) is closely inversely related to the extent of tissue necrosis. Vartdal *et al* found that global longitudinal strain within 2 h after reperfusion therapy in ST elevation infarction correlated inversely and well with infarct size measured by late enhancement MRI 9 months later.[26]

The stable patient with a history of chest pain

The patient with a history of chest pain who is evaluated for the presence and severity of CAD poses a different diagnostic challenge. Age, presence of risk factors, and the presence or absence of typical characteristics of angina determine the 'pre-test likelihood' of CAD.[27 28] The diagnostic benefit of echocardiography (as of any test) is greatest in patients with an 'intermediate' pre-test likelihood of significant CAD. Such likelihoods should be construed as approximate; for intermediate likelihood, a rate of significant CAD between 10–90% or a yearly cardiovascular mortality of 1–2% are commonly cited. Echocardiography at rest may already provide evidence of old myocardial infarction by demonstrating areas of wall motion abnormality, but this does not prove that the patient has episodes of ischaemia. At the same time, other causes of anginal chest pain—for example, aortic stenosis or hypertrophic cardiomyopathy—can be excluded. Current guidelines for the management of patients with stable angina include echo at rest as a class I indication if there is a history of hypertension, diabetes, coronary artery disease, heart failure, or if there are resting ECG abnormalities.

In order to prove or exclude inducible ischaemia by echocardiography, a stress test is necessary. Stress echo is therefore indicated in stable patients

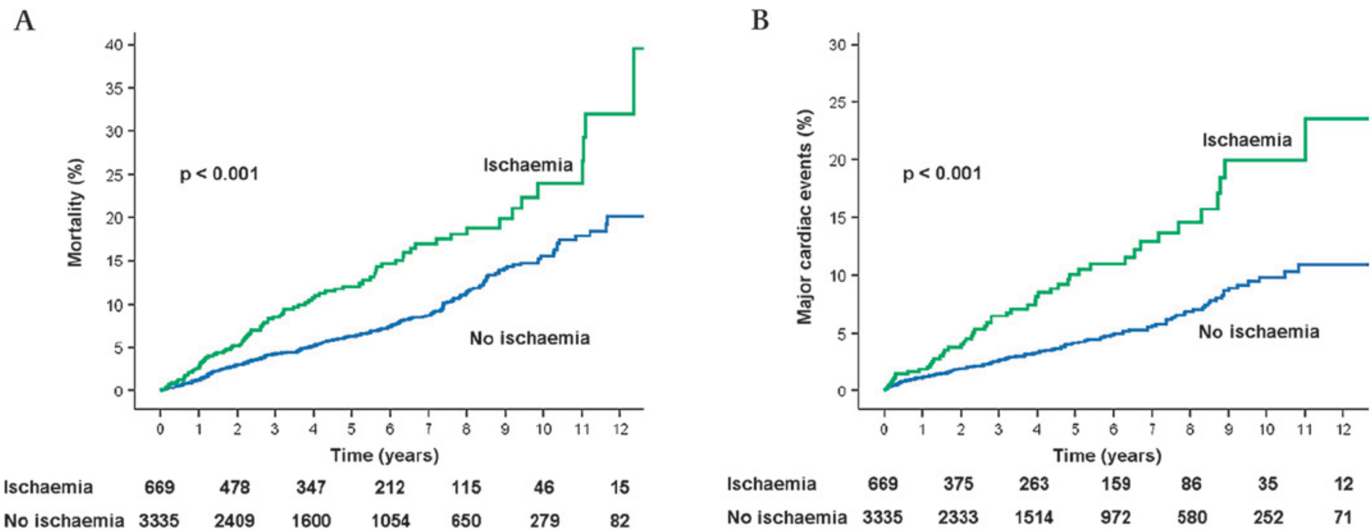

Figure 9 Incidence of all cause death (panel A) or major cardiac events (cardiac death or non-fatal myocardial infarction; panel B) during follow-up in 4004 patients who had a normal exercise (treadmill) ECG test and simultaneously an exercise stress echo, separated according to the results of the stress echo. The graphs show substantially and significantly higher risk of adverse events in patients with ischaemia on the stress echo, despite normal treadmill ECG test. Reproduced, with permission, from Bouzas-Mosquera *et al*.[30]

without acute chest pain who have an intermediate pre-test likelihood of CAD. Current guidelines recommend stress echo (or other imaging stress tests), due to limited resources, only if the patient is unable to exercise or if the ECG is uninterpretable (eg, due to left bundle branch block) or non-conclusive. However, there is little doubt that the diagnostic accuracy of stress echo far exceeds that of non-imaging exercise tests.[29 30] In patients unable to exercise, stress echo is a first line approach to detecting inducible ischaemia, competing with nuclear imaging and magnetic resonance stress tests.[31–33] Stress echocardiography detects ≥50% diameter stenoses of major coronary vessels with a reported sensitivity and specificity of 80–90%,[31] although under real world circumstances the numbers may be about 10% lower. In head-to-head comparisons, its sensitivity tends to be slightly lower and its specificity slightly higher than tomographic (SPECT) nuclear perfusion imaging.[32 33] It should be kept in mind, however, that comparisons between detection of ischaemia and angiographic degree of stenosis are problematic at best, and diagnostic errors may reflect shortcomings of both the stress test and the angiographic assessment.

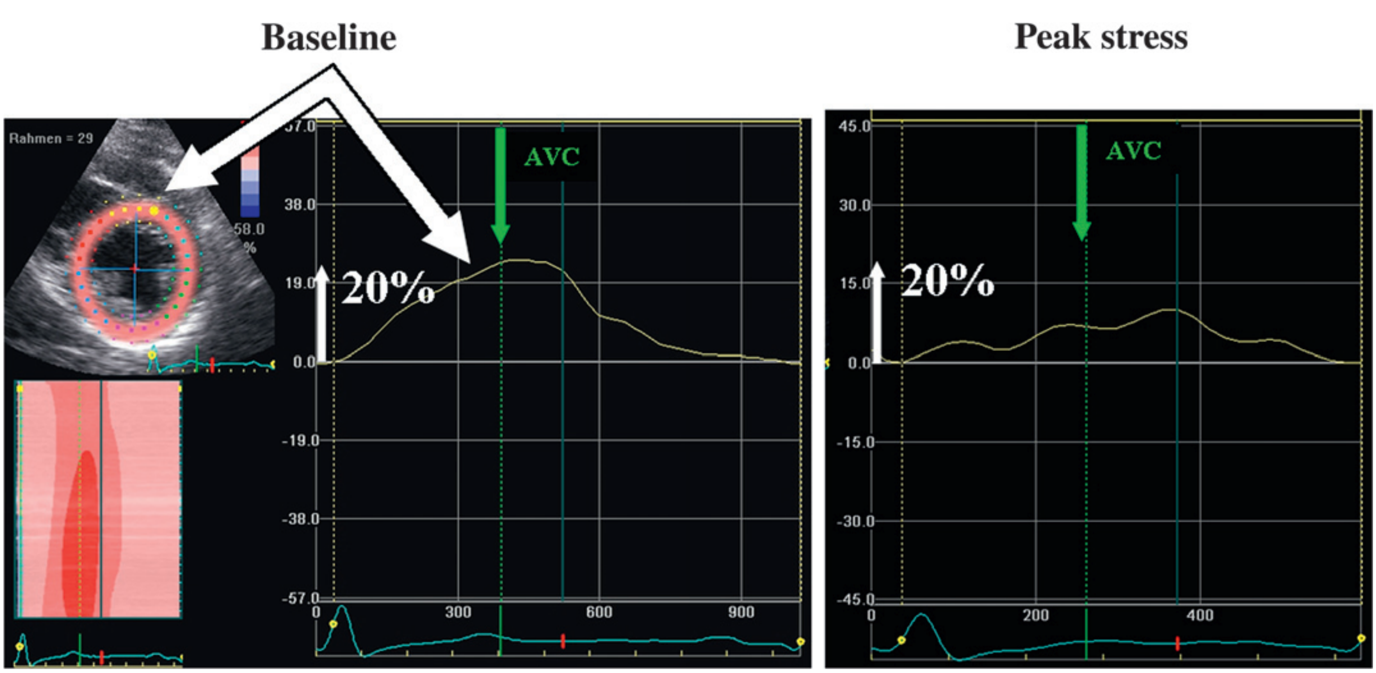

Figure 10 Deformation analysis by speckle tracking of the myocardium ('2D strain'). Short axis view of the left ventricle at baseline (left) and peak stress (right). Peak radial strain (local wall thickening in per cent) in the anterior segment (yellow dot indicated by arrow) at rest is 25%, decreasing to 11% during peak stress. Note that peak strain almost coincides with aortic valve closure (green arrow, AVC) at rest, but is notably delayed during peak stress.

 Heart 2010;96:1063–1072. doi:10.1136/hrt.2009.172114

More importantly, stress echocardiography has excellent predictive power to risk stratify patients with chest pain. This has been shown for large groups of patients as well as for women, patients after revascularisation, and other subsets of patients (figure 9).[34 35] A negative exercise stress echo predicted a yearly rate of 'hard events' (cardiac death and non-fatal myocardial infarction) of 0.54% in a meta-analysis comprising over 3000 patients.[36] Because of preferential selection of sicker patients, event rates after dobutamine stress echo are somewhat higher, but exercise (bicycle or treadmill) as well as pharmacologic stress tests (with dobutamine or dipyridamole) are well validated for the detection of provokable ischaemia and risk stratification. For a more detailed review of stressors, protocols, complications, and other issues see Sicari *et al*[31] and Pellikka *et al*.[37] Current guidelines for the management of patients with stable angina list stress echo, preferentially by exercise if possible, as a class I indication in patients with resting ECG changes preventing meaningful interpretation of changes during exercise or inconclusive exercise ECG.[28]

New echocardiographic techniques

Detection of inducible ischaemia may be aided by detecting stress inducible reduction and delay in systolic regional deformation (strain; figure 10). The retardation of systolic deformation leads to a shift in the maximum of deformation to late systole or even after aortic valve closure (post-systolic deformation or thickening). This phenomenon is not specific, but typical for ischaemia[8 38] and can aid in the interpretation of stress echocardiography. Semi-automatic algorithms based on image analysis ('speckle pattern') are replacing Doppler based techniques to measure tissue deformation and provide less subjective information.

Contrast echocardiography

As outlined in the section on the patient with acute chest pain, left heart contrast can aid echocardiographic diagnosis, especially the detection of inducible ischaemia by stress echocardiography, in two ways:

- By improving endocardial border definition where this is necessary due to suboptimal image quality; the proposed threshold to use contrast in this situation is the presence of two or more contiguous left ventricular wall segments where the endocardial border delineation is not seen or deemed non-diagnostic. Reduction of uninterpretable echos and of inter-observer variability has been shown both for resting studies (eg, when measuring left ventricular volumes and ejection fraction) and for stress echo to detect inducible ischaemia.
- By imaging myocardial perfusion directly with reduced mechanical index, as outlined in the section on the patient with acute chest pain. In experienced hands, this technique, when used with vasodilator stress (dipyridamole or

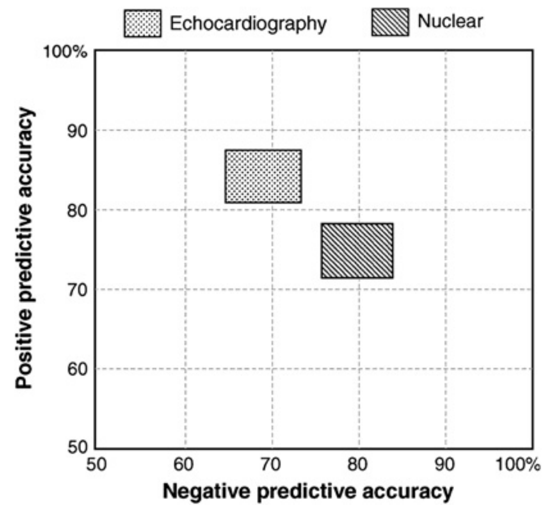

Figure 11 Positive and negative predictive accuracies for predicting recovery of segmental function after revascularisation in patients with ischaemic left ventricular dysfunction. The averaged 11 studies (n=325 patients) compared nuclear and echocardiographic techniques directly. The rectangles are centred on the weighted means and the size of the rectangles indicates 95% confidence intervals. Note truncated axes. Reproduced, with permission, from Underwood *et al*.[42]

The patient with acute chest pain: key echocardiographic findings

- (New) wall motion abnormality at rest suggests acute coronary syndrome.
- Pericardial effusion suggests pericarditis, aortic dissection type A, or myocardial rupture/perforation.
- Aortic regurgitation suggests aortic dissection type A.
- Right ventricular pressure overload suggests pulmonary embolism (dilated, impaired right ventricle, tricuspid regurgitation, elevated right ventricular systolic pressure).

The stable patient with chronic chest pain: key echocardiographic findings

- New wall motion abnormalities and deterioration of global systolic left ventricular function during stress (suggest CAD with flow limiting lesion).
- Wall motion abnormalities at rest and impaired systolic left ventricular function suggest past myocardial infarction, especially if wall motion abnormalities follow typical coronary perfusion territories.
- Abnormalities of transmitral flow and signs of increased left ventricular filling pressure often accompany chronic CAD, but are unspecific.

adenosine), was not inferior to nuclear perfusion studies in the detection of ischaemia.[39]

It must be emphasised, though, that assessment of myocardial perfusion by contrast echocardiography requires special training and appropriate machine settings and modalities, and presently cannot be considered a routine clinical technique.

The patient with chronic congestive heart failure due to CAD (ischaemic cardiomyopathy)

Systolic heart failure (impaired left ventricular ejection fraction) due to CAD is an increasingly frequent condition. Echocardiography is essential and mandatory[40] in these patients for several reasons:

- Assessment of systolic and diastolic dysfunction[3 41] and of left ventricular remodelling. Important steps are quantification of left ventricular volumes and ejection fraction, presence of a restrictive transmitral profile, and estimation of elevated left ventricular filling pressures. These findings contribute to guiding medical and device therapy (eg, implantable cardioverter-defibrillator).
- Determination of contractile reserve by stress echo due to viable, but dysfunctional, myocardial regions indicating a possible benefit of revascularisation, together with the detection of remaining inducible ischaemia. This is typically accomplished by low dose dobutamine stress echocardiography, where dysfunctional wall segments show contractile reserve under dobutamine stimulation. The accuracy of this method in comparison to nuclear perfusion methods has been well validated (figure 11).[42] The diagnosis can be aided by:
  - showing residual systolic (particularly radial) strain at rest,[43] with the amount of residual strain predicting likelihood of recovery, or
  - an increase in systolic strain rate under low dose dobutamine.[44]
- Visual or quantitative determination of interventricular and intraventricular asynchronous contraction in patients with left bundle branch block who may be candidates for cardiac resynchronisation therapy. Recent studies, however, have cast doubt on the accuracy with which echocardiography can identify prospective responders to such therapy.[45]
- Identification of substantial functional ('ischaemic') mitral regurgitation, which may be 'dynamic' (increasing with exercise) and is a marker of impaired prognosis.[46 47]
- Identification of left ventricular thrombi, which may be aided by the use of left heart contrast.

A more detailed description of the role of echo in heart failure can be found elsewhere.[48]

Limitations of echocardiography

Echocardiography, and indeed stress echo, is highly operator dependent. This is true not only in the sense that it takes a fairly long period of training to perform and interpret a good (stress) echo, but also because individual habits and preferences influence image interpretation (eg, 'over-readers' and 'under-readers', with similar overall diagnostic accuracy, but differing sensitivity and specificity).[49] This notorious shortcoming of echocardiography has somewhat decreased with better overall image quality, routine use of harmonic imaging and digital image management,[50] and availability of left heart contrast in difficult cases. Modalities like deformation imaging are likely to reduce operator dependency further, but will not abolish it.

Wall motion assessment by echocardiography does not allow inferences about the presence of 'subclinical' coronary stenoses and plaques which are not flow limiting even at maximal stress levels, but which may lead to adverse events in the future. Presence and extent of inducible ischaemia, however, which echo does detect reliably, are well validated determinants of prognosis and determine management of patients with chest pain in such important circumstances as indications for coronary angiography and for revascularisation.

Competing interests In compliance with EBAC/EACCME guidelines, all authors participating in Education in *Heart* have disclosed potential conflicts of interest that might cause a bias in the article. The authors have no competing interests.

Provenance and peer review Commissioned; not externally peer reviewed.

You can get CPD/CME credits for Education in Heart

Education in Heart articles are accredited by both the UK Royal College of Physicians (London) and the European Board for Accreditation in Cardiology—you need to answer the accompanying multiple choice questions (MCQs). To access the questions, click on **BMJ Learning: Take this module on BMJ Learning** from the content box at the top right and bottom left of the online article. For more information please go to: http://heart.bmj.com/misc/education.dtl

- **RCP credits:** Log your activity in your CPD diary online (http://www.rcplondon.ac.uk/members/CPDdiary/index.asp)—pass mark is 80%.
- **EBAC credits:** Print out and retain the BMJ Learning certificate once you have completed the MCQs—pass mark is 60%. EBAC/ EACCME Credits can now be converted to AMA PRA Category 1 CME Credits and are recognised by all National Accreditation Authorities in Europe (http://www.ebac-cme.org/newsite/?hit=men02).

Please note: The MCQs are hosted on BMJ Learning—the best available learning website for medical professionals from the BMJ Group. If prompted, subscribers must sign into *Heart* with their journal's username and password. All users must also complete a one-time registration on BMJ Learning and subsequently log in (with a BMJ Learning username and password) on every visit.

REFERENCES

1. **Marwick TH,** Shaw L, Case C, *et al*. Clinical and economic impact of exercise electrocardiography and exercise echocardiography in clinical practice. *Eur Heart J* 2003;**24**:1153—63.
2. **Shaw LJ,** Marwick TH, Berman DS, *et al*. Incremental cost-effectiveness of exercise echocardiography vs. SPECT imaging for the evaluation of stable chest pain. *Eur Heart J* 2006;**27**:2448—58.
3. **Lang R,** Bierig M, Devereux R, *et al*. Recommendations for Chamber Quantification. A report from the American Society of Echocardiography's Nomenclature and Standards Committee, the Task Force on Chamber Quantification, and the European Association of Echocardiography. *Eur J Echocardiogr* 2006;**7**:79—108.

- ► **These are the current technical recommendations from the European and American echo societies in regard to which quantitative morphologic parameters should be measured and how in a standard echocardiogram. Emphasis is put on two dimensional rather than M mode and linear measurements, eg, for the left ventricle and atrium.**

4. **Tong KL,** Kaul S, Wang XQ, *et al*. Myocardial contrast echocardiography versus Thrombolysis In Myocardial Infarction score in patients presenting to the emergency department with chest pain and a nondiagnostic electrocardiogram. *J Am Coll Cardiol* 2005;**46**:920–7.
5. **Elhendy A,** O'Leary EL, Xie F, *et al*. Comparative accuracy of real-time myocardial contrast perfusion imaging and wall motion analysis during dobutamine stress echocardiography for the diagnosis of coronary artery disease. *J Am Coll Cardiol* 2004;**44**:2185–91.
   - ► **In this study of patients with a high (75%) incidence of significant coronary disease, myocardial perfusion abnormalities detected by contrast echo were more sensitive and accurate than wall motion abnormalities during dobutamine stress echo for the detection of critical coronary stenosis.**
6. **Tsutsui JM,** Elhendy A, Anderson JR, *et al*. Prognostic value of dobutamine stress myocardial contrast perfusion echocardiography. *Circulation* 2005;**112**:1444–50.
   - ► **Myocardial perfusion abnormalities detected by contrast echo during dobutamine stress were better prognosticators of clinical events than inducible wall motion abnormalities in this large retrospective study.**
7. **Madler CF,** Payne N, Wilkenshoff U, *et al*; Myocardial Doppler in Stress Echocardiography (MYDISE) Study Investigators. Non-invasive diagnosis of coronary artery disease by quantitative stress echocardiography: optimal diagnostic models using off-line tissue Doppler in the MYDISE study. *Eur Heart J* 2003;**24**:1584–94.
8. **Voigt JU,** Exner B, Schmiedehausen K, *et al*. Strain rate imaging during dobutamine stress echocardiography provides objective evidence of inducible ischemia. *Circulation* 2003;**107**:2120–6.
   - ► **This study, which used nuclear perfusion imaging for comparison, showed that deformation (strain) imaging is able to help detect stress inducible ischaemia, especially in cases where visual interpretation is inconclusive.**
9. **Ingul CB,** Stoylen A, Slordahl SA, *et al*. Automated analysis of myocardial deformation at dobutamine stress echocardiography: an angiographic validation. *J Am Coll Cardiol* 2007;**49**:1651–9.
10. **Caiati C,** Montaldo C, Zedda N, *et al*. New noninvasive method for coronary flow reserve assessment: contrast-enhanced transthoracic second harmonic echo Doppler. *Circulation* 1999;**99**:771–8.
11. **Zabalgoitia M,** Ismaeil M. Diagnostic and prognostic use of stress echo in acute coronary syndromes including emergency department imaging. *Echocardiography* 2000;**17**:479–93.
12. **Sabia P,** Abbott RD, Afrookteh A, *et al*. Importance of two-dimensional echocardiographic assessment of left ventricular systolic function in patients presenting to the emergency room with cardiac-related symptoms. *Circulation* 1991;**84**:1615–24.
13. **McConnell MV,** Solomon SD, Rayan ME, *et al*. Regional right ventricular dysfunction detected by echocardiography in acute pulmonary embolism. *Am J Cardiol* 1996;**78**:469–73.
14. **Spodick DH.** Decreased recognition of the post-myocardial infarction (Dressler) syndrome in the postinfarct setting. *Chest* 2004;**126**;1410–11.
15. **Bassand JP,** Hamm CW, Ardissino D, *et al*. Task Force for Diagnosis and Treatment of Non-ST-Segment Elevation Acute Coronary Syndromes of European Society of Cardiology, Guidelines for the diagnosis and treatment of non-ST-segment elevation acute coronary syndromes. *Eur Heart J* 2007;**28**:1598–660.
16. **Bedetti G,** Pasanisi EM, Tintori G, *et al*. Stress echo in chest pain unit: the SPEED trial. *Int J Cardiol* 2005;**102**:461–7.
17. **Bholasingh R,** Cornel JH, Kamp O, *et al*. Prognostic value of predischarge dobutamine stress echocardiography in chest pain patients with a negative cardiac troponin T. *J Am Coll Cardiol* 2003;**41**:596–602.
   - ► **One of the few studies of the prognostic value of stress echo (in this case, with pharmacologic stress) in patients (n=377) who were admitted to the emergency unit with chest pain.**
18. **Kontos MC,** Hinchman D, Cunningham M, *et al*. Comparison of contrast echocardiography with single-photon emission computed tomographic myocardial perfusion imaging in the evaluation of patients with possible acute coronary syndromes in the emergency department. *Am J Cardiol* 2003;**91**:1099–102.
19. **Kaul S,** Senior R, Firschke C, *et al*. Incremental value of cardiac imaging in patients presenting to the emergency department with chest pain and without ST-segment elevation: a multicenter study. *Am Heart J* 2004;**148**:129–36.
20. **Senior R,** Becher H, Monaghan M, *et al*. Contrast echocardiography: evidence-based recommendations by European Association of Echocardiography. *Eur J Echocardiogr* 2009;**10**:194–212.
21. **Ito H,** Okamura A, Iwakura K, *et al*. Myocardial perfusion patterns related to thrombolysis in myocardial infarction perfusion grades after coronary angioplasty in patients with acute anterior wall myocardial infarction. *Circulation* 1996;**93**:1993–9.
22. **Hayat SA,** Senior R. Myocardial contrast echocardiography in ST elevation myocardial infarction: ready for prime time? *Eur Heart J* 2008;**29**:299–314.
23. **Galiuto L,** Garramone B, Scarà A, *et al*; AMICI Investigators. The extent of microvascular damage during myocardial contrast echocardiography is superior to other known indexes of post-infarct reperfusion in predicting left ventricular remodeling: results of the multicenter AMICI study. *J Am Coll Cardiol* 2008;**51**:552–9.
24. **Becher H.** Contrast agents for echocardiographic studies within 24 h after myocardial infarction. *Eur J Echocardiogr* 2008;**9**:719–20.
25. **Kusnetzky LL,** Khalid A, Khumri TM, *et al*. Acute mortality in hospitalized patients undergoing echocardiography with and without an ultrasound contrast agent: results in 18,671 consecutive studies. *J Am Coll Cardiol* 2008;**51**:1704–6.
26. **Vartdal T,** Brunvand H, Pettersen E, *et al*. Early prediction of infarct size by strain Doppler echocardiography after coronary reperfusion. *J Am Coll Cardiol* 2007;**49**:1715–21.
27. **Gibbons RJ,** Abrams J, Chatterjee K, *et al*. ACC/AHA 2002 guideline update for the management of patients with chronic stable angina: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1999 Guidelines for the Management of Patients with Chronic Stable Angina). 2002. www.acc.org/clinical/guidelines/stable/stable.pdf.
28. **Fox K,** Garcia MA, Ardissino D, *et al*; Task Force on the Management of Stable Angina Pectoris of the European Society of Cardiology; ESC Committee for Practice Guidelines (CPG). Guidelines on the management of stable angina pectoris: executive summary: the Task Force on the Management of Stable Angina Pectoris of the European Society of Cardiology. *Eur Heart J* 2006;**27**:1341–81.
29. **Marwick TH,** Case C, Vasey C, *et al*. Prediction of mortality by exercise echocardiography: a strategy for combination with the Duke treadmill score. *Circulation* 2001;**103**:2566–71.
   - ► **Landmark paper showing the incremental, independent prognostic value of stress echo over treadmill testing alone in 3156 patients with an average follow-up of 4 years.**
30. **Bouzas-Mosquera A,** Peteiro J, Alvarez-García N, *et al*. Prediction of mortality and major cardiac events by exercise echocardiography in patients with normal exercise electrocardiographic testing. *J Am Coll Cardiol* 2009;**53**:1981–90.
   - ► **This study analysed patients undergoing treadmill exercise stress. Patients with a pathologic exercise ECG or angina during exercise were excluded from analysis. Peak exercise stress echo in the remaining 'negative' patients provided a clear separation of high and low risk groups during subsequent follow-up, emphasising the incremental value of exercise stress echo over classic treadmill stress testing.**
31. **Sicari R,** Nihoyannopoulos P, Evangelista A, *et al*. European Association of Echocardiography. Stress echocardiography expert consensus statement: European Association of Echocardiography (EAE) (a registered branch of the ESC). *Eur J Echocardiogr* 2008;**9**:415–37.
32. **Marwick T,** D'Hondt AM, Baudhuin T, *et al*. Optimal use of dobutamine stress for the detection and evaluation of coronary artery disease: Combination with echocardiography or scintigraphy, or both? *J Am Coll Cardiol* 1993;**22**:159–167.
33. **Geleijnse ML,** Elhendy A, van Domburg RT, *et al*. Cardiac imaging for risk stratification with dobutamine-atropine stress testing in patients with chest pain. Echocardiography, perfusion scintigraphy, or both? *Circulation* 1997;**96**:137–47.
   - ► **Study involving 220 patients showing the prognostic impact of finding ischaemia, scar, a combination of both, or none on stress echo. Nuclear perfusion imaging was done in parallel and yielded remarkably similar results.**
34. **Marwick T,** Anderson T, Williams M, *et al*. Exercise echocardiography is an accurate and cost-efficient technique for

detection of coronary artery disease in women. *J Am Coll Cardiol* 1995;**26**:335—41.

35. **Bountioukos M,** Elhendy A, van Domburg RT, *et al*. Prognostic value of dobutamine stress echocardiography in patients with previous coronary revascularisation. *Heart* 2004;**90**:1031—5
36. **Metz LD,** Beattie M, Hom R, *et al*. The prognostic value of normal exercise myocardial perfusion imaging and exercise echocardiography: a meta-analysis. *J Am Coll Cardiol* 2007;**49**:227—37
37. **Pellikka PA,** Nagueh SF, Elhendy AA, *et al*; American Society of Echocardiography. American Society of Echocardiography recommendations for performance, interpretation, and application of stress echocardiography. *J Am Soc Echocardiogr* 2007;**20**:1021—41
38. **Skulstad H,** Edvardsen T, Urheim S, *et al*. Postsystolic shortening in ischemic myocardium: active contraction or passive recoil? *Circulation* 2002;**106**:718—24
39. **Senior R,** Monaghan M, Main ML, *et al*. Detection of coronary artery disease with perfusion stress echocardiography using a novel ultrasound imaging agent: two phase 3 international trials in comparison with radionuclide perfusion imaging. *Eur J Echocardiogr* 2009;**10**:26—35.
40. **Dickstein K,** Cohen-Solal A, Filippatos G, *et al*; Task Force for Diagnosis and Treatment of Acute and Chronic Heart Failure 2008 of European Society of Cardiology. ESC guidelines for the diagnosis and treatment of acute and chronic heart failure 2008: the Task Force for the Diagnosis and Treatment of Acute and Chronic Heart Failure 2008 of the European Society of Cardiology. Developed in collaboration with the Heart Failure Association of the ESC (HFA) and endorsed by the European Society of Intensive Care Medicine (ESICM). *Eur Heart J* 2008;**29**:2388—442.
41. **Nagueh S,** Appleton C, Evangelista A, *et al*. Recommendations for the echocardiographic diagnosis of diastolic dysfunction. *Eur J Echocardiogr* 2009;**10**:165—93.
42. **Underwood SR,** Bax JJ, vom Dahl J, *et al*; Study Group of the European Society of Cardiology. Imaging techniques for the assessment of myocardial hibernation. Report of a study group of the European Society of Cardiology. *Eur Heart J* 2004;**25**:815—36.
43. **Becker M,** Lenzen A, Ocklenburg C, *et al*. Myocardial deformation imaging based on ultrasonic pixel tracking to identify reversible myocardial dysfunction. *J Am Coll Cardiol* 2008;**51**:1473—81.
44. **Hanekom L,** Jenkins C, Jeffries L, *et al*. Incremental value of strain rate analysis as an adjunct to wall-motion scoring for assessment of myocardial viability by dobutamine echocardiography. A follow-up study after revascularization. *Circulation* 2005;**112**:3892—900.
45. **Chung ES,** Leon AR, Tavazzi L, *et al*. Results of the predictors of response to CRT (PROSPECT) trial. *Circulation* 2008;**117**:2608—16.
46. **Piérard LA,** Lancellotti P. The role of ischemic mitral regurgitation in the pathogenesis of acute pulmonary edema. *N Engl J Med* 2004;**351**:1627—34.
   - ► **Landmark paper showing that functional mitral regurgitation in patients with CAD is 'dynamic', ie, its severity can increase notably with exercise even in the absence of acute ischaemia.**
47. **Lancellotti P,** Gérard PL, Piérard LA. Long-term outcome of patients with heart failure and dynamic functional mitral regurgitation. *Eur Heart J* 2005;**26**:1528—32.
   - ► **Follow-up paper to the former study showing the negative prognostic impact of a stress inducible increase in functional mitral regurgitation in patients with CAD.**
48. **Kirkpatrick JN,** Vannan MA, Narula J, *et al*. Echocardiography in heart failure: applications, utility, and new horizons. *J Am Coll Cardiol* 2007;**50**:381—96.
49. **Hoffmann R,** Lethen H, Marwick T, *et al*. Analysis of interinstitutional observer agreement in the interpretation of dobutamine stress echocardiography. *J Am Coll Cardiol* 1996;**27**:330—6.
   - ► **Landmark paper revealing surprisingly high inter-centre variability in the interpretation of stress echos. All centres participating were experienced in stress echo.**
50. **Hoffmann R,** Marwick TH, Poldermans D, *et al*. Refinements in stress echocardiographic techniques improve inter-institutional agreement in interpretation of dobutamine stress echocardiograms. *Eur Heart J* 2002;**23**,821—9.
   - ► **This follow-up paper to the former study demonstrates that improvements in technique (eg, digital loops, harmonic imaging, and others), as well as a small set of interpretation rules agreed upon by all participants, significantly enhance reading uniformity.**

Heart 2010;**96**:1063—1072. doi:10.1136/hrt.2009.172114

Heart

Cardiac imaging in the patient with chest pain: echocardiography

Frank A Flachskampf and Werner G Daniel

Heart 2010 96: 1063-1072
doi: 10.1136/hrt.2009.172114