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EAE RECOMMENDATIONS

European Association of Echocardiography recommendations for training, competence, and quality improvement in echocardiography

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The main mission statement of the European Association of Echocardiography (EAE) is 'to promote excellence in clinical diagnosis, research, technical development, and education in cardiovascular ultrasound in Europe'. As competence and quality control issues are increasingly recognized by patients, physicians, and payers, the EAE has established recommendations for training, competence, and quality improvement in echocardiography. The purpose of this document is to provide the requirements for training and competence in echocardiography, to outline the principles of quality measurement, and to recommend a set of measures for improvement, with the ultimate goal of raising the standards of echocardiographic practice in Europe.

Introduction

Echocardiography has changed the practice of cardiovascular medicine by improving prevention, diagnosis, and management of various cardiovascular disorders. It is the most commonly used imaging modality in clinical cardiology, since it allows a comprehensive, immediate assessment of cardiac and vascular anatomy and function. The availability, portability, non-invasive nature, and cost-effectiveness, together with the wealth of information it provides, render echocardiography the first-choice imaging technique for the diagnosis and follow-up of most heart diseases.[1,2]

During the last decades, echocardiography has enjoyed rapid technological developments, and at present, an impressive amount of information can be gathered from different modalities (M-mode, two- and three-dimensional, Doppler), approaches (transthoracic—TTE, transoesophageal—TEE, intravascular, epicardial), and applications (e.g. stress and contrast echocardiography) used to study the heart. However, echocardiography remains largely an operator-dependent technique. A thorough knowledge of cardiovascular anatomy and pathophysiology together with appropriate technical skills is required to perform a comprehensive and clinically useful echocardiography study. The required knowledge and skill can only be gained through supervised education and training in an appropriate environment. Previous

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publications, both from Europe[3–5] and from the USA,[6,7] have focused on training requirements for clinical competence in echocardiography.

Purpose

The purpose of this document is to provide criteria for training, competence, and quality improvement in modern clinical echocardiography.

Document format

The present document released by the European Association of Echocardiography (EAE) is developed in accordance with the principles outlined in the European Society of Cardiology (ESC) Core Curriculum and is intended to complement it by giving more details on specific, echocardiography-related issues.

The ESC Core Curriculum[8] defines the different levels of competence on several diagnostic techniques and states the level expected for a given area of subject matter.

Level I—experience on selecting the appropriate diagnostic modality and interpreting results; this level does not include performing the technique (e.g. advanced methods of imaging, such as cardiac magnetic resonance, CMR);
Level II—practical experience, but not as independent operator (the trainee has assisted in or performed the procedure under the guidance of a supervisor);
Level III—able to independently perform the procedure unaided (for the general cardiologist, this includes TTE).

Training

General aspects of training in echocardiography

Irrespective of the echocardiographic modality used, there is a body of knowledge required by any person involved in performing or reading echocardiograms. The basic knowledge required for competence in echocardiography is summarized in *Table 1* and presented in detail in the EAE Core Syllabus for echocardiographers.[9]

Table 1 Basic knowledge for competence in echocardiography

Ultrasound physics and biological effects
Principles of echocardiographic image formation and blood flow/tissue velocity measurements
Machine settings and instrumentation handling for an optimal image quality
Normal cardiovascular anatomy, including possible normal variants
Pathological changes in cardiovascular anatomy in different disease states
Normal cardiovascular physiology and fluid dynamics of normal blood flow
Pathological changes in blood flow in different disease states
Indications, contraindications, and appropriateness criteria
Alternative diagnostic techniques for any given situation
Potential complications (e.g. for TEE, stress echo, and contrast procedures)

Knowledge of ultrasound physics and principles is particularly important. Briefly, trainees should have knowledge of the properties of ultrasound waves, the elements of an echo machine, echo image formation, and post-processing.[8,9] The trainee should have knowledge of the settings and controls of the echo machine and be familiar with typical artefacts and biological effects of ultrasound. Finally, the trainee should understand the principles of Doppler echocardiography, being able to choose from the different modalities (pulsed wave, continuous wave, colour, and tissue Doppler) those which apply for adequate measurements with specific clinical use.

Training in echocardiography should also include the ability to communicate and report echocardiography results effectively to healthcare professionals and patients and to cooperate with interventional cardiologists, electrophysiologists, anaesthesiologists and other physicians involved in emergency medicine and intensive care, and cardiac surgeons.[8,10]

Over the last years, several echocardiography modalities have emerged, each one with specific applications requiring their own knowledge and skills and, therefore, training. This is the case for stress echocardiography, TEE, and intraoperative echocardiography, echocardiography in congenital heart diseases (CHDs), contrast echocardiography, three-dimensional (3D) echocardiography, intracardiac and intravascular ultrasound.

In recent years, other non-invasive imaging modalities such as nuclear imaging, CMR, and multi-slice computed tomography (MSCT) have witnessed a rapid development. Echocardiographers should be able to understand the strengths and weaknesses of each of these non-echo imaging modalities and to integrate them for better patient management.

Training duration

Recommendations for minimal training requirements (i.e. duration, number of cases) have been previously published.[3–7]

This writing committee of the EAE recommends two levels of expertise for training in echocardiography: basic and advanced. The basic level is meant to be achieved by every general cardiologist who uses echocardiography to take clinical decisions about patient management. The advanced level is addressed to cardiologists undertaking echocardiography as their main subspecialty, who should be able to perform comprehensive echo examinations and provide pertinent information, allowing other clinicians to address patient management.

For each level, minimal requirements for training duration and number of examinations performed are issued. As there is little evidence base for required duration and number of studies, the figures mentioned in *Table 2* represent a consensus view among the writing committee members, derived from practical experience.

Although recommendations for training duration are used to facilitate the organization of a focused training programme, the emphasis remains not on a specific duration of training, but on obtaining the required expertise. Although the number of echo studies in which a trainee participates is important, the case-mix of patients is equally important and should cover the full range of cardiovascular diseases (*Table 3*).

Table 2 Training requirements to achieve basic and advanced level of competence

Echocardiographic technique	Minimum number of examinations performed to become competent	Level of competence	Minimum number of examinations performed/year to maintain competence
TTE	350 (basic)	III	Reasonable exposure
	750 (advanced)	III	100[a]
TEE	75 (advanced)	III	50
Stress echocardiography	100 (advanced)	III	100

Level III, ability to independently perform the procedure (unsupervised).
[a]Details from reference 32.

Table 3 Case-mix for basic-level training in transthoracic echocardiography

Cardiac disease/clinical scenario	Knowledge and skills to be acquired
Valvular heart diseases	
Aortic stenosis	Display views for the diagnosis
Aortic regurgitation	Recognition of diagnostic features
Mitral stenosis	Evaluation/quantification of severity
Mitral regurgitation	Distinction between chronic and acute lesions (regurgitant lesions)
Tricuspid stenosis	Evaluation of the consequences on the size, geometry, and function of the cardiac chambers
Tricuspid regurgitation	Criteria and timing for intervention, amenability for surgical repair, and suitability for
Pulmonary stenosis	percutaneous intervention
Pulmonary regurgitation	Echocardiographic (2D and Doppler) findings of normal function and malfunction of biological and
Prosthetic valves	mechanical valves
	Judge the need for complementary diagnostic approaches
	Define the need for regular follow-up studies
Ischaemic heart disease	
Myocardial infarction	Recognition of the signs and consequences of myocardial ischaemia and infarction
Ischaemic cardiomyopathy	Localize segmental wall motion abnormalities in a standardized format
	Evaluation of infarct size and the amount of myocardium at risk
	Evaluation of global and regional LV systolic and diastolic function
	Diagnose mechanical complications of MI and their haemodynamic consequences
	Recognition of the prognostic implications of structural and functional parameters
Cardiomyopathies	
Dilated cardiomyopathy	Perform a complete M-mode, 2D, and Doppler examination which allows to establish the diagnosis,
Myocarditis	accurately quantify disease severity, and help to choose the proper therapeutical modality
Hypertrophic cardiomyopathy	Make the differential diagnosis of athlete's heart vs. hypertrophic cardiomyopathy
Restrictive and infiltrative	Identify patients who are appropriate candidates for cardiac resynchronization therapy
cardiomyopathies	
Heart failure	
	Outline echocardiographic features of cardiomyopathies, coronary heart disease, valvular heart disease, myocarditis, constrictive pericarditis, pulmonary hypertension, and other conditions associated with heart failure
	Identify causes of acute heart failure
	Recognize the prognostic implications of functional parameters
	Recognize typical complications in heart failure (spontaneous echo contrast and thrombus formation, pleural effusion, etc.)
Hypertension	
	Calculation of LV mass, relative wall thickness, evaluation of LV geometry
	Assessment of LV systolic function and diastolic function
	Estimation of LV filling pressures
Infective endocarditis	
Emergency echocardiography	
Simple CHDs	
Cardiac tumours and masses	
Sources of embolism	
Pulmonary embolism	
Pulmonary hypertension	
Diseases of the aorta	
Diseases of the pericardium	
Normal examinations	Not more than one-third of total studies

Level III competence in general adult TTE as recommended in the ESC Core Curriculum for general cardiologists.[8]

For this reason, it is recommended that fellows keep a log book documenting their direct involvement in echo studies, including specific diagnoses of patients they have examined.

Basic level

A trainee with a basic level of expertise should be able to independently perform a general TTE examination (level III in TTE) according to the recommendations for standardization of performance, digital storage, and reporting published by the EAE.[10]

The trainee should acquire sufficient knowledge and technical ability to be able to answer common clinical questions and to be helpful in urgent clinical situations.

A 6-month full-time training fellowship in echocardiography is the minimum recommended training period to achieve the basic level of expertise in TTE. Training time should be time-tabled and protected. If this period does not allow the trainee to achieve the required number of examinations or a well-balanced mix of pathology, the training period should be extended.

During training for the basic level, the number of TTE examinations performed by a trainee should be at least 350.[8] This portfolio must be completed within the 6-month period of continuous training. It should include an appropriate case-mix as described in *Table 3*.

It is expected that after successful completion of this training level, a trainee should be able to undertake and pass the EAE accreditation examination in TTE. Trainees will be exposed to TEE and stress echocardiography examinations, being able to understand the indications, contraindications, strengths, and weaknesses of these techniques (level I competence). However, they will not be required to perform these techniques by themselves.

Thus, the recommended basic-level training corresponds to level III competence in general adult TTE and to level I competence in TEE and stress echocardiography.

Advanced level

The advanced-level training in echocardiography is reserved for trainees who already have the basic level, but who want to engage in more complex TTE studies and to become fully competent (level III) in: special TTE procedures, such as 3D echo, contrast echo, or echocardiography during interventional procedures, and also to be able to perform TEE and stress echocardiography independently.

Examples of TTE examinations that require special expertise and would be outside the competence of a general cardiologist with only basic echo training are: the comprehensive haemodynamic evaluation of patients with complex valve disease (including full quantitation), the assessment of patients referred for cardiac resynchronization therapy, and the performance of more complex TTE procedures (e.g. deformation imaging, detection of subclinical disease including cardiomyopathies, eligibility for percutaneous valve implantation).

The advanced level of training is aimed at acquiring independence in performing and interpreting TEE studies—minimum 75 independently performed; stress echo studies—minimum 100 independently performed (*Table 2*).

Competence at an advanced level implies an additional training period in echocardiography of at least 6 months and performance of 750 TTE studies, beyond those reserved for the basic level (*Table 2*).

This higher level of dedicated training should be acquired in echocardiography laboratories fulfilling the EAE recommendations for advanced accreditation.[11]

The competence levels for echo practitioners are summarized in *Table 4*.

Table 4 Summary of competence levels for echocardiographic practitioners

Basic echocardiography (corresponds to ESC Core Curriculum requirements for general training for cardiologists)	Level III competence in general adult TTE Level I competence in TEE Level I competence in stress echocardiography
Advanced echocardiography (appropriate for cardiologists with subspecialty interest in echocardiography)	Level III competence in general adult TTE Level III competence in complex adult TTE Level III competence in TEE Level III competence in stress echocardiography

ESC, European Society of Cardiology; TTE, transthoracic echocardiography; TEE, transoesophageal echocardiography.

Training programme

The trainee in echocardiography should follow a structured training programme to address the learning objectives. The training programme should include practical training, theoretical educational activities, and ideally research activities. It has to be comprehensive and should include, apart from acquiring knowledge and skills, development of appropriate behaviours and attitudes.[8] For consistency, it is recommended that the programme is completed in a single accredited centre able to cover the training requirements.

During the training period, trainees should regularly attend departmental meetings reviewing topics, presenting, and discussing difficult cases, indications, results, procedure-related complications, and comparisons with other modalities (including cardiac catheterization and heart surgery). The trainee should attend at least once a year a national and/or international accredited echocardiography meeting. It is strongly recommended that the trainee is involved in the research projects of the laboratory.

Self-assessment needs to be emphasized, and web-based online educational programmes and products will play an important role in a fellow's overall learning experience during and after training. The trainee should have sufficient background knowledge for each level of training and must complete the required number of echo studies.

Training centres

The EAE has published standards for laboratory accreditation in TTE, TEE, and stress echocardiography.[11] These recommendations consider two levels of laboratory accreditation: standard and advanced, depending on the services provided, staffing, equipment resources, and other organizational and internal criteria judged as essential

to guarantee suitability for competitive training and research.

The echocardiography laboratories in which training is undertaken should fulfil the EAE recommendations, preferably those for an advanced level.[11] In particular, the commitment of training staff is vital for training quality. The trainer should be available to supervise, criticize, and correct the performance and interpretation of echo studies and to promote the active participation of trainees in research activities. Furthermore, the training centre should organize regular educational activities on a weekly basis.

A training echo laboratory may be autonomous or integrated in a cardiac imaging department or in a cardiology department. The presence of a coronary care unit, of other non-invasive imaging modalities (e.g. nuclear cardiology, CMR, MSCT), as well as different subspecialties (e.g. interventional cardiology, electrophysiology, cardiac surgery) in the same institution allows the trainee to be exposed to a full range of techniques and to relate and confront the echo findings with those provided by complementary techniques.

Ideally, there should be joint educational programmes that rotate fellows who are training in cardiovascular medicine, among echocardiography, nuclear cardiology, CMR, and CT, if these are available.[12] The echo laboratory should collaborate closely with both non-invasive and invasive services because these approaches are complementary rather than competitive.

Transthoracic echocardiography in adult patients

In order to use this powerful technique adequately, criteria for appropriateness have been published,[13] with recommended strengths of indication for specific clinical scenarios.

As operator dependence is an important issue for echocardiography, the trainee needs to understand, acquire, and document all the standard imaging planes as recommended.[10] However, limiting the examination to standard imaging planes may sometimes lead to overlooking important pathological findings and/or to reporting inaccurate data. It is therefore essential that the echocardiographer is able to adapt the examination on the basis of live interpretation of encountered findings. The trainer has a key role in teaching a trainee how to use the transducer appropriately and to understand what represents optimal data acquisition and technical quality for the individual patient.

Specific training and competence recommendations for special procedures

Transoesophageal echocardiography

TEE provides an excellent window to the heart and great vessels. The detailed indications, contraindications, risks, and potential complications of TEE have been published in dedicated documents[14,15] and are beyond the scope of this document.

In order to achieve the advanced level III of competence in TEE, a minimum number of 75 TEE studies performed unsupervised is recommended.

To be eligible for accreditation in TEE by the EAE, documentation within a year of 75 TEE cases for candidates holding TTE accreditation, and of 125 for those not holding TTE accreditation, is required. National accreditation or EAE accreditation is required for physicians independently performing and reporting TEE studies.

Table 5 Knowledge and skills required for competence in transoesophageal echocardiography

Knowledge
Basic general knowledge related to echocardiography (*Table 1*)
Strengths and weaknesses of TEE for a given indication
Differential benefit compared with other imaging techniques, in particular TTE and other tomographic techniques
Indications, contraindications, risks, and complications of the TEE procedure
Infection control measures and electrical safety issues related to the use of TEE
Techniques and risks of local anaesthesia and sedation; pharmacology of involved drugs
Anatomy of the upper gastrointestinal tract with special emphasis on potential problems and hazards during oesophageal intubation
Knowledge of normal and abnormal cardiovascular anatomy on TEE, and of the typical cross-sections used
Ability to communicate examination results to the patient and to other healthcare professionals
Skills
Ability to perform a complete TTE examination
Ability to obtain a focused history of upper gastrointestinal disorders
Operation of the TEE probe and biteguard, including manipulation of the probe tip and change in imaging plane orientation
Ability to operate the echo machine, including all controls affecting image quality
Techniques of oesophageal intubation (both in ventilated and non-ventilated patients) including sedation techniques, appropriate monitoring, readiness of supportive equipment
Proficiency in cardiopulmonary resuscitation
Manipulating the probe to generate the necessary imaging cross-sections for answering specific clinical questions
Familiarity with obtaining typical sets of imaging and other data (cross-sections, Doppler data, and others) to be obtained during TEE for specific indications (e.g. search for cardiac source of embolism, prosthetic valve dysfunction, etc.), including intravenous right heart contrast injection for shunt detection
Ability to recognize anomalies of cardiac structure and function as imaged by TEE, and to recognize artefacts
Ability to perform qualitative and quantitative analyses of the echocardiographic data
Ability to produce a logical and comprehensive written report of the echocardiographic findings, including the possible clinical implications
Competence in disinfecting the probe and detecting technical defects, in particular in electrical insulation

The specific knowledge and skills required to become competent in safely performing and reporting TEE studies are mentioned in *Table 5*.

Ideally, training in TEE should also include exposure to intra-operative TEE (see what follows) and to interventional TEE. Interventional TEE (e.g. closure of atrial septal defects, percutaneous mitral balloon valvuloplasty, and percutaneous valve implantation) requires a thorough knowledge of each particular procedure and its potential problems.

Intra-operative transoesophageal echocardiography

Intra-operative echocardiography refers to applications of echocardiography in patients undergoing surgery, whereas peri-operative echocardiography refers to applications of echocardiography performed during the early post-operative period. Nowadays, these examinations are performed mainly through the TEE approach, although epicardial techniques continue to have a role during surgery in specific cases.

Intra-operative echocardiography relies on most of the echo modalities used in the non-surgical setting, so previously mentioned requirements for training and competence in TEE apply here as well. In addition, intra-operative TEE requires understanding the particular challenges of the operating theatre environment, taking into account the variable haemodynamics of patients on and off cardiac bypass, discussing the findings with the surgeons in an adequate manner, and understanding the surgical procedures including their potential complications, which often require special knowledge of local techniques and vocabulary. The indications for intra(peri)-operative TEE have been previously published.[16] Results of surgery may be evaluated by echocardiography, and additional surgical therapy may be performed if deemed necessary on the basis of the echo results.

In many European countries, the intra-operative TEE studies are performed by anaesthesiologists with special training in TEE.

Stress echocardiography

The EAE has recently published an expert consensus statement on stress echocardiography.[17] The document presents in detail the different types of stressors and protocols to be used, the indications and contraindications for each type of stress, the diagnostic criteria and prognostic value of stress echo findings, and the possible complications and adverse events.[17]

It is not reasonable to begin using stress echocardiography without a complete training in TTE, and holding national or EAE accreditation in TTE is highly recommended. The basic skills required for imaging the heart under resting conditions do not differ substantially from those required for imaging the same heart from the same views during stress. However, it has been shown that the interpretation of stress echo tests by an echocardiographer without specific training in stress echo severely underestimates the diagnostic potential of the technique.[18] To build the learning curve and reach a plateau of diagnostic accuracy, examination of 100 stress echocardiography studies was found to be adequate.[18]

The EAE recommendation is to perform at least 100 examinations under the supervision of an expert reader in a high-volume laboratory, ideally with the possibility of angiographic verification, before starting stress echocardiography on a routine basis.[17]

To acquire intra-reader diagnostic power and to reduce inter-reader variability, there is no substitute for joint reading stress echo studies with an expert echocardiographer.[19] The use of digital images instead of videotapes may improve agreement,[20] although reproducibility is usually poor in patients with resting images of borderline quality. In patients with a difficult acoustic window, native second harmonic imaging[21] and the use of contrast agents help improve accuracy and reduce variability.[22,23] Trainees must also learn and understand the safety aspects of stress echo and the importance of appropriately trained staff.

Table 6 Staff requirements for stress echocardiography

- Training requirements for performance and interpretation of stress echocardiography
  - Understanding the basic principles, indications, applications, and technical limitations of echocardiography
  - Level III training in TTE
  - Specialized training in stress echocardiography with performance and interpretation of 100 or more stress studies under appropriate supervision by an echocardiographer with level III of competence in stress echocardiography
- Maintenance of competence in stress echocardiography
  - Performance and interpretation of 100 or more stress studies per year
  - Participation in continuing medical education in echocardiography
  - At least two persons are required to record and monitor stress echo studies. One should be qualified in advanced life support, the other in basic life support. A nurse should always be present to support the physician performing the test
  - If the study is performed by a sonographer/technician, a physician with expertise in both echocardiography and resuscitation should be always attending in case a life-threatening complication occurs

To achieve a versatile diagnostic approach enabling to address individual patient needs, it is important to become familiar with all types of stressors (pharmacological and exercise). However, since difficulty in performance, reading, and safety varies according to patients' characteristics, type of stress, and protocol used, it is recommended to begin with those easier and safer and then progress to the more technically demanding and with higher risk.[17]

Trainees must also understand that for a given diagnostic accuracy, every observer has his/her own 'sensitivity/specificity curve', depending on whether images are aggressively or conservatively interpreted as abnormal and so it is important to use optimal consensus criteria for reading stress echo studies.[17,24]

The training requirements for competence in stress echocardiography are mentioned in *Table 2*, and the staff requirements of the stress echo laboratory are presented in *Table 6*.[17,25,26]

Echocardiography for adults with congenital heart disease

Echocardiography has become the first-choice non-invasive tool in the diagnosis and serial evaluation of infants, children, and adults with CHD.

To perform TTE in patients with suspected or known CHD, practitioners must know the protocol of standardized analysis, crucial when acquiring sequential data.[27]

The appropriate views, measurements, and the awareness of possible co-existence of multiple pathologies are all part of training. In adults with poor-quality transthoracic images or in instances where better definition of anatomy or flow dynamics is needed, TEE or saline contrast may be helpful. The trainee should have appropriate knowledge of the indications for TEE and contrast studies.

In addition, the limitations of echocardiography and the complementary role of other imaging techniques (e.g.

assessment by CMR of right ventricular size and function) have to be known. Adult cardiologists with basic training in echo (level III in general TTE) should be able to recognize benign developmental variants and common congenital heart defects (e.g. isolated atrial and ventricular septal defects, patent ductus arteriosus, isolated congenital valve disease, subaortic membrane, coarctaction of the aorta, transposition of great arteries, tetralogy of Fallot, Ebstein's anomaly, persistent left superior vena cava), define the need and appropriate frequency of follow-up studies, and evaluate the need for surgical or percutaneous intervention.

Contrast echocardiography

Agitated saline has been used for a long time as an echo contrast agent (e.g. to assess for the presence, size, and functional relevance of an inter-atrial shunt in patients with suspected patent foramen ovale). The introduction of transpulmonary intravenous contrast agents has improved the assessment of LV structure and function.

The EAE has recently published recommendations for the clinical use of contrast echocardiography.[23] The document describes in detail the characteristics of currently available contrast agents, the contrast imaging modalities, the indications, clinical efficacy, and the safety of contrast agents used in echocardiography.

Before using contrast agents, physicians and sonographers must have acquired basic training and preferably also accreditation in TTE. Those planning to use contrast agents during stress echocardiography must be accredited or at least must have undergone appropriate training in stress echocardiography. Beyond training in resting and stress echo techniques, the use of contrast agents requires a level of experience acquired under appropriate supervision. Everyone involved in contrast echocardiography should be competent in the administration of contrast agents, should know the indications and contraindications, and should be able to manage adverse events.[23] Experience with contrast agents for LV opacification is a prerequisite for moving on to the assessment of myocardial perfusion.

Competence

Requirements for competence in different echocardiography techniques, together with the minimal training requirements, have been discussed in the previous section. This section presents the general principles of assessing competence, maintaining competence, and the current status of the EAE accreditation and re-accreditation for various echo modalities.

Proof of competence: accreditation

Although in theory completion of an appropriate training programme should ensure competence, all systems need to have additional checks. Furthermore, individual competence cannot be distinguished from the competence of the team and facilities around them. This link is illustrated both in the fact that laboratories applying for EAE accreditation must have evidence that their sonographers are accredited[11] and equally in the fact that the American system for accreditation of echo laboratories requires submitted samples of each individual's work as part of the assessment.[28] Therefore, the assessment of competence requires evaluation of the knowledge and skill of the individual, and the echo laboratory within which they work.

Proof of individual competence

Competence requires assessment that the candidate has appropriate knowledge, skills, and attitudes[6,8] and is measured in a combination of three ways:

(a) evidence (statements or testimonials) by trainers and supervisors;
(b) knowledge-based assessments (examinations);
(c) evidence of practical ability (log books and practical assessment).

(a) Letters of reference and simple verification of subspecialty training may not be adequate substitutes for independent evaluation of an echocardiographer's skill and expertise. The ideal way of assessing the competence of an individual is by direct observation while performing the examination, using the directly observed procedural skills assessment.[29]

Therefore, the importance of trainers and supervisors cannot be underestimated. The supervisor should hold national and/or EAE accreditation and would usually be the director of the laboratory in which training was undertaken.

At the end of the training, the supervisor will be asked to state (testify) that the candidate has

(i) undergone a programme of training;
(ii) achieved appropriate competence.

(b) As a method of assessment, examinations are much criticized and do indeed have many faults. They mainly test factual knowledge. However, they are widely accepted, validated, and very widely used in assessment processes.

In echocardiography, questions should test theoretical knowledge and also the interpretation of images shown to the candidates. Images can be collated within a case study (most useful for TTE) or shown as single independent images (method used for TEE).

Therefore, as part of the assessment of competency used to award EAE accreditation, candidates will undertake a multiple choice question examination:

(i) 100 items testing theoretical knowledge;
(ii) 50 items testing the ability to interpret images from echo studies.

Although the examination has a projected pass mark, it is appropriate that this can be adjusted by the examination committee after each examination on the basis of a combination of methods including benchmarking against a panel of experts and benchmarking against cohorts of candidates (who tend to have a consistent range of competence) derived from item response statistics.

The examination should be constantly revised and evaluated.[30,31]

(c) The very practical nature of echocardiography means that a practical element to assessment is necessary. Although this could be entirely provided by the supervisor's

statement/testimonial (American NBE/CCI/ARDMS system), there are strong arguments for including it in the assessment process (the EAE accreditation process).

A log book allows the assessors to review the range of work undertaken by the trainee and by analysis (grading) of reports achieve an assessment. An additional or alternative approach is to ask the candidate to submit samples of their work electronically on a disc or via the web. This must be done within local data-protection regulations. The studies can again be graded. In both cases, it is important that grading is objective and reproducible and this requires training and quality control processes to be in place.

The practical element for EAE accreditation consists of submission of a log book of cases (250 for TTE, 125 for TEE, unless candidate already has TTE accreditation where 75 suffice, 250 for CHD echocardiography) performed by the candidate within a 12-month period after passing the written examination. The case-mix is proscribed to cover the range of pathologies normally seen.

Previously, a random sample of 15 cases drawn from the log book were graded by two examiners. However, an electronic log book has been introduced for TTE in 2009 and is planned for TEE in 2010. This involves submission of six studies covering a range of key pathologies and a full range of echocardiographic views and modalities. The candidate uploads the studies into the web-based system at the Heart House (still frames and clips, properly anonymized) together with his reports for those studies. This electronic log book is then marked by independent EAE graders.[32]

In combination, the supervisor's statement, completion of the written examination, and practical log book provide evidence of competence and the award of accreditation by the EAE.

Maintenance of individual competence

Re-accreditation

Ongoing competence cannot be assumed in the practice of echocardiography. Its practical nature and the constant development of new techniques require ongoing practice and learning to maintain competence. This is an important aspect of quality control in echocardiography.

Numbers alone may be a poor guide, but there is no other practicable system short of asking practitioners to retake knowledge-based and practical assessments at regular intervals. Most systems for re-accreditation combine requirements for ongoing practice with the obtaining of credits for continuing education through attendance at relevant meetings or other continuing learning activities.[28,32] Further inclusion of a requirement to participate in a quality control (assurance) programme is included within some systems. Health systems where physicians largely report studies performed by sonographers may distinguish between the numbers of studies reported and studies performed for ongoing competence.

Although award of EAE accreditation is valid for 5 years, re-accreditation requires evidence of continuing practice (statement from laboratory head or assistant) and also evidence of CME activity (e.g. certificates of attendance).

The basic requirements for EAE re-accreditation in TTE are:

- 250 studies per year and 40 h of CME (high-volume applicants), or
- 100 studies per year and 50 h of CME (low-volume applicants).[32]

Laboratory accreditation

In determining the quality of an echocardiographic laboratory, criteria have been established. There are large programmes for laboratory accreditation in Europe[11,32] and the USA.[28] The main areas assessed are:

- facilities (environment and equipment);
- work flow;
- education and training;
- quality assurance.

Separate criteria exist for TTE, TEE, and stress echocardiography, and the EAE system has two levels, standard and advanced, the latter applicable to laboratories offering internationally recognized training and research.

In summary, the EAE requires candidates to undertake a supervised programme of training in a suitable echo laboratory and to demonstrate knowledge through a written examination and skill through submission of a log book of echo study reports.

Quality improvement

Despite the fact that ensuring a high level of quality has become an important issue for patients, physicians, and payers, relatively limited attention has been focused on measures of quality control and quality improvement in echocardiography.

Principles of quality measurement

At present, quality assessment of echocardiography services in Europe occurs almost exclusively through voluntary accreditation. Both the American Society of Echocardiography, through the Intersocietal Commission for the Accreditation of Echocardiographic Laboratories,[28] and the EAE have introduced accreditation both for individuals[30–32] and for echocardiographic laboratories.[11,32] However, it is clear that quality measurement and monitoring are needed beyond accreditation because accreditation typically reflects conditions during a snapshot in time and it would be desirable to implement continuous monitoring for quality control and improvement.[33]

Assessing quality in echocardiography

The first step is to create specific quality measures.[34] The EAE model consists of four distinct domains which may influence clinical outcome: patients' selection, study performance, interpretation, and reporting (*Figure 1*). Laboratory infrastructure (logistics, equipment, staffing) and organization (procedures and protocols) influence and support these four domains.

- The first step to a high-quality echocardiographic service is to ensure appropriate patient selection for a particular echo modality on the basis of evidence or consensus that

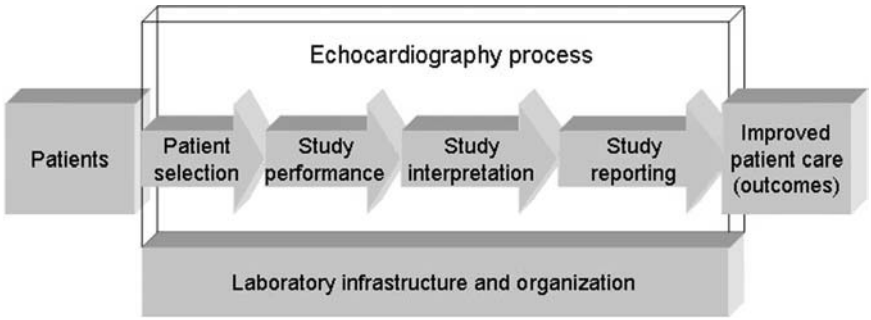

Figure 1 Framework for assessing quality in echocardiography and its influence on patient management. The proposed model consists of four main domains which may influence clinical outcome. Laboratory infrastructure and organization support the whole echocardiography process.

it is reasonable, cost-effective, will affect patient management, and will lead to clinical benefit.

- The second step is study performance using adequate equipment,[11] accredited sonographers and physicians,[11,31] to obtain complete and accurate information related to the clinical questions.[10] All the studies need to be recorded, ideally in digital format.[10]
- Images and tracings are assessed qualitatively and quantitatively in an accurate way.
- Finally, a report should be timely issued in a clear, concise, and clinically oriented manner in order to address further patient management and ultimately improve outcome. Study and previous report archiving and retrieval procedures are part of the latter step.

Quality measures are proposed for each step of the framework depicted in *Figure 1* (*Table 7*).

Patient selection

The continuous expansion of clinical applications of echocardiography together with continued technical improvements has led to an explosive increase in the number of echo studies performed. In order to identify patients who would benefit most from echocardiography, guidelines listing the indications for which echocardiography may be considered appropriate have been published.[13] Since most studies are performed solely in response to the referring physician's request without any previous discussion with the cardiologist who analyses and reports the study, educational efforts should be made to increase referring physician awareness about the existing guidelines. To help referring physicians to make appropriate requests and to collect data for monitoring study indications, it would be useful to develop specific order forms. Feedback to referring physicians about their study ordering behaviour should also be provided.

Although it requires some work and adequate data collection, optimizing and monitoring patient selection are important because of their impact on downstream testing, skill maintenance, procedures, and costs.

Study performance and patient's safety

High-quality image acquisition and study completeness depend on specific protocols which optimize the likelihood that an echo study is complete and accurate.[10] Adhering to such recommendations and monitoring accuracy, completeness, and overall quality of echo studies could be useful tools for evaluating the quality of echo services (*Table 7*). Factors such as the incidence of complications during TEE or stress echo studies or the percentage of unsuccessful intubation in attempted TEE studies are indicators to be used for assessing patient's safety. Training and accreditation of sonographers and/or cardiologists who perform echo studies are also important quality indicators. However, accreditation of individual echocardiographers alone cannot guarantee high-quality echo studies. It is also necessary to have adequate echo systems, management, and organization, and this underpins the EAE's establishment of procedures for both individual and laboratory accreditation.[32]

Study interpretation

The EAE has developed procedures to assess competence for standard adult TTE and TEE, as well as for CHD echocardiography.[32]

However, high-quality study interpretation is not guaranteed by the existence of accredited echocardiographers. High-quality echo laboratories should provide evidence of both accuracy and reproducibility of echo studies' interpretation (*Table 7*). There are different approaches to assess accuracy in echocardiography: random re-reporting of studies; comparison of echo results with those obtained using other imaging modalities; analysis of computerized databases[35]; reviewing a master set of cases by each reader of the laboratory.[36]

Reproducibility should be assessed by measuring intra- and inter-reader variability of the most critical parameters [i.e. left ventricular (LV) ejection fraction and/or volumes, transaortic gradients, valve areas].

Laboratories may choose to develop a master set of cases with the most frequent diagnoses to calibrate interpretations and reduce inter-reader variability.

In summary, it is important that routine periodical checks of accuracy and reproducibility are undertaken to confirm that reasonable standards for both are met.

Reporting

A high-quality echo report should be accurate, complete, and answer unambiguously the clinical question for which the study was requested. It should also be easy to understand by the referring physician. The minimal data set of parameters that should be contained in a high-quality echo report has been published by the EAE.[10] In addition, the EAE has listed measurements and morphological

Table 7 Action items and quality measures in the 'dimensions of care' framework for echocardiography

Step	Quality goals	Action items	Quality measures
Laboratory infrastructure	Ensure baseline standards for equipment and staff proficiency	• Apply for standard laboratory accreditation[11] • EAE and/or national certification for both sonographers and physicians • Aim for advanced laboratory accreditation for stress echo and TEE[11] • Monitor number of studies performed/reported by each sonographer/physician	• Percentage of echo studies performed by certified sonographers • Percentage of echo studies performed/reported by certified physicians • CME credits for both sonographers and clinicians
Patient selection	Appropriateness	• Introduce appropriateness criteria for TTE, TEE, and stress echocardiography • Develop specific study order forms to help referring clinicians in selecting appropriate indications • Monitor case-mix of echo studies	• Percentage studies meeting appropriateness criteria • Percentage of in- and out-patient studies reported as normal
Study performance	Diagnostic quality studies	• Adopt EAE recommendations for standardization of performance, digital storage, and reporting of echocardiographic studies[10] • Adopt EAE recommendations for stress echo[17] • Adopt EAE recommendations for TEE[14] • Ensure adequate time for each echo modality[11] • Develop specific protocols for the use of contrast	• Number of studies reviewed monthly for completeness by the clinical and/or technical head of the laboratory • Percentage of complete studies according to EAE recommendations[10] • Percentage of non-interpretable studies • Number of studies performed/interpreted daily by each sonographer/physician • Percentage of studies performed with the use of contrast
	Patient safety	– Monitoring in- and out-patient waiting list – Develop specific time-frame for performing echo study according to the clinical priority – Monitoring major complications of stress echo (death, acute myocardial infarction, major arrhythmias) and of TEE	– Percentage of patient who were studied within the pre-defined time-frame set for each clinical priority – Percentage of patients with documented signed informed consent prior to TEE or stress echo – Percentage of unsuccessful intubations in patients in whom TEE was attempted

Study interpretation	Accuracy	• Adopt existing standards for measuring and interpreting echo studies[10,37] • Compare results with other imaging techniques or with surgical findings • Adopt digital archiving of images and data[10]	• Percentage of patients with an explicit clinical indication to echo • Percentage of patients with abnormal stress echo and normal coronary arteries at coronary angiography • Bias and limits of agreement of LV volumes vs. cardiac MR or nuclear • Bias and limits of agreement of transaortic gradients with cardiac catheterization • Number of studies reviewed monthly for interpretation by the clinical head of the laboratory
	Reproducibility	– Develop procedures for determining intra- and inter-reader variability of reporting physicians	– Intra- and inter-reader reproducibility of LV ejection fraction – Intra- and inter-reader reproducibility of aortic/prosthetic effective orifice area
Reporting	Completeness	• Develop computerized software for structured reporting for all echo modalities[10] • Adopt minimal data sets for comprehensive reporting of echo studies[10]	• Percentage of reports meeting requirements of the minimal data set for reporting[10] • Percentage of reports in which the clinical indication for the study has been clearly stated • Percentage of reports in which a comparison with previous studies (when available) has been provided
	Timelines	– Define procedures to provide timely report to referring physicians	
Improved patient care (outcomes)	Satisfaction	• Develop customer satisfaction assessment tools	• Percentage of patients/referring physicians reporting a satisfaction score above a pre-determined value
	Impact on clinical management	– Develop methods for measuring patient outcomes and impact on medical decision making	• Percentage of patients referred to cardiac scintigraphy after a definitively positive or negative stress echo for coronary artery disease

descriptors of cardiovascular structures that should be used to develop structured reporting databases.[10] Once such databases are in place, monitoring the quality of reporting can be easily performed by measuring the percentage of reports containing essential parameters for a given clinical condition.

Finally, reports should be transmitted to referring physicians on time. Reports from routine studies should usually be issued on the day of the examination. For urgent or in-patient studies, at least a preliminary report should usually be issued immediately, and timelines standards should be developed for particular clinical situations (i.e. high-risk findings should be promptly notified to the referring physician).[11]

Implementation of quality-improvement recommendations

The essence of improving the quality of an echo laboratory is that all professionals involved in the process of producing an echo study (cardiologists, sonographers, nurses, administrative personnel, managers, and other healthcare professionals) work as a team. The aim of such a team is to identify and analyse problems using objective measures of quality performance (*Table 7*), develop possible solutions, test effective applications of such solutions, and implement changes. It would be useless to have only the head of the echo laboratory involved in the quality-improvement process.

One of the main difficulties to start a quality-improvement programme is the concern about how to handle human errors detected during quality assessment. It should be pointed out that the purpose of any quality-improvement programme is not to find faults, but rather to identify dimensions of care which need improvement. The focus should always be on the patient and the echocardiographic product, and not on identifying professional errors. However, to increase adherence to the programme, it is mandatory to prepare mechanisms allowing correction of errors without exposing participant professionals to liability.

Another important obstacle to overcome when starting a quality-improvement programme is adequate resource availability. Collecting the various measures needed to monitor the process requires expertise, time, and money and cannot be done without an adequate database which incorporates quality-measurement parameters (e.g. proper ordering information, clinical priority class, type of machine used, standardized reporting). Constructing such information systems is costly. External review, particularly if core laboratory or expert panels are involved, may cost even more.

Therefore, it is mandatory for every quality-improvement programme to share the importance of such a process with local hospital managers who should agree to invest in procedures aimed at improving patient care.

One possible approach is detailed below:

- After having obtained adequate resources to run a quality-improvement programme, divide all professionals working in the echo laboratory into task groups for analysis of specific components of the framework depicted in *Figure 1*.
- Start by analysing simple parameters (e.g. caseload, cardiologist, and sonographer qualifications) and reviewing the various recommendations listed in this document.
- Next, task groups should be organized to assess the various components of the framework. During this step, methods and quality measures should be tested to monitor the different areas within each dimension and specific problems should be identified.
- Following this process, suggest and test solutions to problems and implement those which have been proved effective over time.

As the technology used in echocardiography evolves and the scope of applications changes and increases, the recommendations included in this document will need further revision and updating.

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References

1. Cheitlin MD, Armstrong WF, Aurigemma GP, Beller GA, Bierman FZ, Davis JL *et al*. ACC/AHA/ASE 2003 guideline update for the clinical application of echocardiography: summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASE Committee to Update the 1997 Guidelines for the Clinical Application of Echocardiography). *J Am Soc Echocardiogr* 2003;**16**:1091–110.
2. Flachskampf FA, Voigt JU, Daniel WG. Cardiac ultrasound. In: Camm JA, Lüscher TF, Serruys PW, eds. *The ESC Textbook of Cardiovascular Medicine*. 2nd ed. Oxford University Press; 2009.
3. British Society of Echocardiography Guidelines. Training in echocardiography. *Br Heart J* 1994;**71**:2–5.
4. Roudaut R, Touche T, Cohen A, Cormier B, Dehant P, Diebold B *et al*. Guidelines of the French Society of Cardiology on the training of echocardiographers and the performing of echocardiography. *Arch Mal Coeur Vaiss* 1994;**87**:791–8.
5. Decoodt P, Gillebert TC. European certification of clinical competence in adult echocardiography issued in Belgium. The Steering Committee of the Belgian Working Group on Echocardiography and Cardiac Doppler. *Acta Cardiol* 1995;**50**:265–71.
6. Quiñones MA, Douglas PS, Foster E, Gorcsan J III, Lewis JF, Pearlman AS *et al*. ACC/AHA clinical competence statement on echocardiography: a report of the American College of Cardiology/American Heart Association/American College of Physicians–American Society of Internal Medicine Task Force on Clinical Competence. *J Am Coll Cardiol* 2003;**41**: 687–708.
7. Ryan T, Armstrong WF, Khandheria BK. ACCF COCATS 3 training statement: Task Force 4: training in echocardiography. *J Am Coll Cardiol* 2008;**51**:361–7.
8. The European Society of Cardiology Core Curriculum for the general cardiologist, http://www.escardio.org/education/coresyllabus/Pages/core-curriculum.aspx.
9. The European Association of Echocardiography Core Syllabus, http://www.escardio.org/communities/EAE/education/Pages/core-syllabus.aspx.
10. Evangelista A, Flachskampf F, Lancellotti P, Badano L, Aguilar R, Monaghan M *et al*. European Association of Echocardiography recommendations for standardization of performance, digital storage and reporting of echocardiographic studies. *Eur J Echocardiogr* 2008;**9**:438–48.
11. Nihoyannopoulos P, Fox K, Fraser A, Pinto F. EAE laboratory standards and accreditation. *Eur J Echocardiogr* 2007;**8**:80–7.
12. Fraser AG, Buser PT, Bax JJ, Dassen WR, Nihoyannopoulos P, Schwitter J *et al*. The future of cardiovascular imaging and non-invasive diagnosis. A joint statement from the European Association of Echocardiography, the Working Groups on Cardiovascular Magnetic Resonance, Computers in Cardiology, and Nuclear Cardiology, of the European Society of Cardiology, the European Association of Nuclear Medicine, and the Association for European Paediatric Cardiology. *Eur J Echocardiogr* 2006;**7**:268–73.
13. Douglas PS, Khandheria B, Stainback RF, Weissman NJ, Brindis RG, Patel MR *et al*. ACCF/ASE/ACEP/ASNC/SCAI/SCCT/SCMR 2007 appropriateness criteria for transthoracic and transesophageal echocardiography: a report of the American College of Cardiology Foundation Quality

Strategic Directions Committee Appropriateness Criteria Working Group, American Society of Echocardiography, American College of Emergency Physicians, American Society of Nuclear Cardiology, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, and the Society for Cardiovascular Magnetic Resonance endorsed by the American College of Chest Physicians and the Society of Critical Care Medicine. *J Am Coll Cardiol* 2007;**50**: 187–204.

14. Flachskampf FA, Decoodt P, Fraser AG, Daniel WG, Roelandt JR, Subgroup on Transesophageal Echocardiography and Valvular Heart Disease, Working Group on Echocardiography of the European Society of Cardiology. Guidelines from the Working Group. Recommendations for performing transesophageal echocardiography. *Eur J Echocardiogr* 2001;**2**:8–21.
15. Shanewise JS, Cheung AT, Aronson S, Stewart WJ, Weiss RL, Mark JB *et al*. ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. *J Am Soc Echocardiogr* 1999;**12**:884–900.
16. Practice guidelines for perioperative transesophageal echocardiography: a report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. *Anesthesiology* 1996;**84**:986–1006.
17. Sicari R, Nihoyannopoulos P, Evangelista A, Kasprzak J, Lancellotti P, Poldermans D *et al*. Stress echocardiography expert consensus statement: European Association of Echocardiography (EAE) (a registered branch of the ESC). *Eur J Echocardiogr* 2008;**9**:415–37.
18. Picano E, Lattanzi F, Orlandini A, Marini C, L'Abbate A. Stress echocardiography and the human factor: the importance of being expert. *J Am Coll Cardiol* 1991;**24**:928–33.
19. Varga A, Picano E, Dodi C, Barbieri A, Pratali L, Gaddi O. Madness and method in stress echo reading. *Eur Heart J* 1999;**20**:1271–5.
20. Ali SM, Egeblad H, Saunamnaki K, Carstensen S, Steenscard-Hansen F, Hausno S. Reproducibility of digital exercise echocardiography. *Eur Heart J* 1995;**16**:1510–9.
21. Franke A, Hoffmann R, Kuhl HP, Lepper W, Breithardt OA, Schormann M *et al*. Non-contrast second harmonic imaging improves interobserver agreement and accuracy of dobutamine stress echocardiography in patients with impaired image quality. *Heart* 2000;**83**:133–40.
22. Zamorano J, Sánchez V, Moreno R, Almería C, Rodrigo J, Serra V *et al*. Contrast agents provide a faster learning curve in dipyridamole stress echocardiography. *Int J Cardiovasc Imaging* 2002;**18**:415–9.
23. Senior R, Becher H, Monaghan M, Agati L, Zamorano J, Vanoverschelde JL *et al*. Contrast echocardiography: evidence-based recommendations by European Association of Echocardiography. *Eur J Echocardiogr* 2009;**10**: 194–212.
24. Imran MB, Palinkas A, Pasanisi EM, De Nes M, Picano E. Optimal reading criteria in stress echocardiography. *Am J Cardiol* 2002;**90**:444–5.
25. Becher H, Chambers J, Fox K, Jones R, Leech GJ, Masani N *et al*. BSE procedure guidelines for the clinical application of stress echocardiography, recommendations for performance and interpretation of stress echocardiography: a report of the British Society of Echocardiography Policy Committee. *Heart* 2004;**90**:23–30.
26. Pellikka PA, Nagueh SF, Elhendy AA, Kuehl CA, Sawada SG. American Society of Echocardiography Recommendations for Performance, Interpretation, and Application of Stress Echocardiography. *J Am Soc Echocardiogr* 2007;**20**:1021–41.
27. Deanfield J, Thaulow E, Warnes C, Webb G, Kolbel F, Hoffman A *et al*. Management of grown up congenital heart disease. The Task Force on the Management of Grown Up Congenital Heart Disease of the European Society of Cardiology. *Eur Heart J* 2003;**24**:1035–84.
28. The Intersocietal Commission for the Accreditation of Echocardiography Laboratories. http://www.intersocietal.org/icael/apply/standards.htm (27 September 2009).
29. Lopez-Sendon J, Mills P, Weber H, Michels R, Di Mario C, Filippatos GS *et al*. Recommendations on sub-speciality accreditation in cardiology: The Coordination Task Force on Sub-speciality Accreditation of the European Board for the Speciality of Cardiology. *Eur Heart J* 2007;**28**: 2163–71.
30. Fox KF, Flachskampf F, Zamorano JL, Badano L, Fraser AG, Pinto FJ. Report on the first written exam held as part of the European Association of Echocardiography Accreditation Process in Adult Transthoracic Echocardiography. *Eur J Echocardiogr* 2004;**5**:320–5.
31. Fox KF, Popescu BA, Janiszewski S, Nihoyannopoulos P, Fraser AG, Pinto FJ. Report on the European Association of Echocardiography Accreditations in Echocardiography: December 2003 to September 2006. *Eur J Echocardiogr* 2007;**8**:74–9.
32. The European Association of Echocardiography Accreditation in Echocardiography. http://www.escardio.org/communities/EAE/accreditation/Pages/welcome.aspx (27 September 2009).
33. Recommendations for continuous quality improvement in echocardiography. American Society of Echocardiography. *J Am Soc Echocardiogr* 1995; **8**:S1–28.
34. Douglas P, Iskandrian AE, Krumholz HM, Gillam L, Hendel R, Jollis J *et al*. Achieving quality in cardiovascular imaging: proceedings from the American College of Cardiology–Duke University Medical Center Think-Tank on quality in cardiovascular imaging. *J Am Coll Cardiol* 2006;**48**:2141–51.
35. Berger AK, Gottdiener JS, Yohe MA, Guerrero JL. Epidemiological approach to quality assessment in echocardiographic diagnosis. *J Am Coll Cardiol* 1999;**34**:1831–6.
36. Fox KF, Porter A, Unsworth B, Collier T, Leech G, Mayet J. Report on a national echocardiography quality control exercise. *Eur J Echocardiogr* 2009;**10**:614–8.
37. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA *et al*. Recommendations for chamber quantification. *Eur J Echocardiogr* 2006;**7**:79–108.