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European Association of Echocardiography recommendations for standardization of performance, digital storage and reporting of echocardiographic studies

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In view of the European Association of Echocardiography (EAE) mission statement "To promote excellence in clinical diagnosis, research, technical development, and education in cardiovascular ultrasound in Europe" and the increasing demand for standardization and quality control, the EAE have established recommendations and guidelines for standardization of echocardiography performance, data acquisition (images, measurements and morphologic descriptors), digital storage and reporting of echocardiographic studies. The aim of these recommendations is to provide a European consensus document on the minimum acceptable requirements for the clinical practice of echocardiography today and thus improve the quality and consistency of echocardiographic practice in Europe.

Introduction

Echocardiography is the most widely used imaging technique in clinical cardiology practice since it provides comprehensive evaluation of cardiac and vascular structures and function. The technique can immediately affect the diagnostic and management work-up of the patient, dictate therapeutic decisions, determine response to therapy and predict patient outcome. The real-time nature, portability and low cost of echocardiography, with the amount and quality of the provided information renders it the technique of choice for the diagnosis and follow-up of most heart diseases.[1–3] Two- (2D) and three-dimensional (3D) imaging can accurately assess cardiac chamber size, wall thickness, ventricular function, valvular anatomy, and the size of great vessels. Pulsed-wave (PW), continuous-wave (CW) and colour-flow Doppler echocardiography provides measurements of blood flow velocities and assessment of intracardiac pressures and haemodynamics, and thus detect and quantify stenosis, regurgitation, and other abnormal flow states. Echocardiography has replaced many other technologies in clinical decision-making and the assessment of functional and structural changes after therapeutic interventions.

Recent developments in echocardiography such as harmonic imaging, broadband transducers, tissue Doppler imaging, deformation imaging, 3D-echocardiography and second generation intravenous contrast agents have widened the applications of the technique.[4–8] However, many of these newer developments do not necessarily have to be currently included in all routine transthoracic echo studies.

Advances in computer technology have made it possible to capture, store, and manage echo data digitally and use computerized reports of echocardiographic studies.[9,10] The European Association of Echocardiography (EAE) (created in 2003 as an evolution of the former Working Group of Echocardiography founded in 1978) is currently representing 50 countries with different ways of working, levels of technology and health systems, which give rise to significant heterogeneity in the practice of echocardiography. In view of the EAE mission statement "To promote excellence in

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clinical diagnosis, research, technical development, and education in cardiovascular ultrasound in Europe" and the increasing demand for standardization and quality control, the EAE formed a committee to establish recommendations and guidelines for standardization of echocardiography performance, data acquisition (images, measurements, and morphologic descriptors), digital storage, and reporting of echocardiographic studies.

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Complete echocardiographic study

A complete transthoracic study includes 2D and, usually, M-mode echocardiography as well as spectral and colour Doppler techniques. 2D echocardiography is currently the major imaging method used to assess cardiac anatomy and function, with M-mode supplying additional information when indicated. Examiner skill is required to obtain multiple precise tomographic anatomical slices by aiming an ultrasound probe at the heart. M-mode is obtained by selecting any of the individual sector lines from which a 2D image is constructed. M-mode may be useful for quantifying linear dimensions of the cardiac chambers and walls when the correct direction is verified under 2D imaging. The main advantage of M-mode is its high temporal resolution. However, limitations, such as relative malalignment of the M-mode line direction and erroneous geometrical assumptions, should be considered. With improved resolution and technical capabilities of modern 2D systems, measurements are often taken directly from 2D images or applying the anatomical M-mode. These approaches facilitate correct perpendicular alignment for measurement of intra-cardiac structures.

Doppler modalities complement 2D echocardiography by providing functional information on intracardiac flow haemodynamics, including measurement of systolic and diastolic blood flow velocities and volumes, assessment of the severity of valvular lesions, and location and severity of intracardiac shunts. PW Doppler is useful for locating and timing blood flow within the physiological range of velocities. CW Doppler, which lacks spatial resolution, is useful for accurately measuring the highest flow velocities and therefore estimating the gradients across valves or interventricular defects. Colour-flow mapping, by estimating mean velocities along each sector line of the 2D image and displaying the information as colour-coded pixels, provides a composite picture of flow over a larger area and is most useful for screening valves for regurgitation and stenosis and detecting the presence of intracardiac shunts. Colour-flow M-mode is useful for timing blood flow information.

A complete echocardiographic study includes examination of the morphology and function of all cardiac chambers and valves and the great vessels from multiple views (*Table 1*).

Table 1 Cardiac and vascular structures routinely evaluated as part of a complete adult echocardiographic report

1.	Left ventricle
2.	Mitral valve
3.	Left atrium
4.	Aortic valve
5.	Aorta
6.	Right ventricle
7.	Tricuspid valve
8.	Right atrium
9.	Pulmonary valve
10.	Pulmonary artery
11.	Pericardium
12.	Inferior vena cava
13.	Pulmonary veins

Basic aspects of echocardiography

Ultrasound machines

The technical requirements for ultrasound machines used in diagnostic echocardiography are defined in the recently published EAE laboratory standards and accreditation document.[11] Ultrasound machines should be equipped, as a minimum, with the following: Broadband 2D imaging, M-mode imaging, spectral pulsed- and CW Doppler and colour-flow imaging (or other forms of flow imaging) as well as the capability of recording on CD, DVD or digital download via a network. Storage capability is mandatory for subsequent review and comparison of studies. Other systems without these capabilities may be used for focused or limited examinations, which should be clearly stated as such. However, a complete system should be available in every laboratory to perform a complete echocardiographic examination. Each machine should also have a video screen or other display method of such size and quality that the operator and any observer can view the study clearly from the bedside.

The system should also incorporate ergonomic design, with variable height and rotation of the display screen and keyboard/control panel. Repetitive strain injury and back problems are becoming common among echocardiographers. They can result in loss of work time due to illness and may be the source of work-related injury litigation. Ultrasound systems with flexible display and control panel positions facilitate the use of ergonomic scanning postures and allow the friendly use of the system in places where space and access are limited.

Echocardiography request

With the exception of life-threatening emergencies, an echocardiographic procedure should not be performed without a written request. The request should be present in the patient's hospital chart, electronic patient record or outpatient record, and methods for verifying its presence should be in place. The request should clearly state the reasons for the study and the clinical query to be answered.

Acquisition and interpretation

The minimal standard acquisition protocol for transthoracic echocardiography is shown in *Table 2*. These data sets are the minimum required for a complete echocardiogram that should be obtained in every patient (even in completely normal studies). Zoom views are optional but desirable when more detailed examination of a particular structure

Table 2 Minimal standard digital acquisition protocol for transthoracic echocardiography

View	Data type
Parasternal long-axis view of the LV (2D + colour Doppler + M-mode)[a]	Loop
Parasternal short-axis view at aortic valve level (2D + colour Doppler + M-mode)[a]	Loop
Parasternal short-axis view at mitral valve level (2D)[a]	Loop
Parasternal short-axis view at mid-papillary level (2D)	Loop
Parasternal RV inflow-tract view (2D + colour Doppler)[a]	Loop
Parasternal RV outflow-tract view (2D + colour Doppler)[a]	Loop
Apical four-chamber view (2D + colour Doppler)[a]	Loop
Apical five-chamber view (2D + colour Doppler)[a]	Loop
Apical two-chamber view (2D + colour Doppler)[a]	Loop
Apical long-axis view (2D + colour Doppler)[a]	Loop
Subcostal four-chamber view (2D + colour Doppler)[a]-atrial septum	Loop
Subcostal-inferior vena cava collapse during inspiration or sniff (+M-mode)	Loop
Suprasternal long-axis view of the aortic arch (2D + colour Doppler)[a,b]	Loop
Transmitral velocities (PW Doppler)	Spectral Doppler (still frame)
LV outflow tract velocities (PW Doppler)	Spectral Doppler (still frame)
Transaortic/outflow tract velocities (CW Doppler)	Spectral Doppler (still frame)
Tricuspid regurgitant velocities (CW Doppler)	Spectral Doppler (still frame)
Transpulmonary velocities (PW Doppler)	Spectral Doppler (still frame)
Tissue Doppler on mitral annulus (septal, lateral velocities)	Spectral Doppler (still frame)

[a]Doppler studies with colour-flow imaging may be performed at the end of the grey-scale (B-mode) imaging. M-mode optional in still frames and not necessary in both long- and short-axis views.
[b]In adults this projection may not always be required.
Abbreviations: LV, left ventricle; 2D, two-dimensional echocardiography; PW, pulsed-wave Doppler; CW, continuous-wave Doppler.

Table 3 Echocardiographic measurements at the echocardiographic report

	Normal values by 2D or M-mode
LV dimensions:	
2D or 3D volumes[a]	EDV: 35–75 mL/m^2
	ESV: 12–30 mL/m^2
M-mode diameters (end-diastolic–end-systolic) or 2D 'guided'	EDD: 22–32 mm/m^2
	ESD: 14–21 mm/m^2
Septum and posterior wall thickness	IVS: 6–10 mm
	PW: 6–10 mm
LV ejection fraction: volume-based quantitation advisable	>55%
LV regional wall motion abnormalities: from 1 (normal) to 4 (dyskinetic)[b]	
Left atrium: at least two orthogonal diameters, preferably volume[a]	27–40 mm
	<29 mL/m^2
Right ventricle: size (normal or dilated)	
Right ventricle systolic function: (normal, depressed: mild, moderate, severe)	
Right atrium: size (normal or dilated)	
Aortic root: maximum diameter at sinus level[c]	<39 mm
	<21 mm/m^2
Inferior vena cava: diameters (inspiration–expiration)	<17 mm
Mitral valvular area planimetry[d]	
Comments: open-text field	

[a]Preferably indexed.
[b]Using the 16 or 17 segment models.
[c]If abnormal or suspected pathology: sinotubular junction and ascending aorta.
[d]In mitral stenosis.
Normal values from ASE recommendations.[13]
Abbreviations as in *Table 2*.

is required. In each cine-loop or still frame, at least one but preferably three cardiac cycles should be recorded; with attention paid to that the captured cycles are representative (i.e. avoidance of post-extrasystolic beats). In the case of abnormalities, additional views and acquisitions are almost always required (both 2D and/or Doppler).

In all studies it is necessary to measure the size of the four cardiac chambers and great vessels, assess left ventricular (LV) systolic and diastolic function, and valvular function, estimate pulmonary artery systolic pressure and describe the pericardium (*Tables 3* and *4*). Occasionally, only a limited or focused study may be performed. This should be

Table 4 Doppler measurements at the echocardiographic report

LV diastolic function
Normal or three degrees of dysfunction[a]
Velocity: *E*-wave, *A*-wave[b]
Deceleration time
Tissue Doppler PW Doppler at mitral annulus: *e′*-wave velocity[c]
Valvular heart disease: evaluation of corresponding affected valve
Mitral valve
Mean gradient[d]
PHT mitral valve area[d]
Regurgitation: none, mild, moderate, severe or 0–4 degrees[f]
Aortic valve
Maximum velocity
Mean gradient[d]
Area (continuity equation: VTI at LVOT)[e]
Regurgitation: none, mild, moderate, severe or 0–4 degrees[f]
Tricuspid valve
Mean diastolic gradient[d]
Regurgitation: none, mild, moderate, severe or 0–4 degrees[f]
Maximum RV–RA systolic gradient for PA systolic pressure estimation[g].
Pulmonary valve
Maximum velocity
Mean gradient[d]
Regurgitation: none, mild, moderate, severe or 0–4 degrees[f]
Comments: open-text field

[a]1 to 3: impaired relaxation, pseudonormal, and restrictive.
[b]Respiratory changes evaluated when necessary.
[c]For LV filling pressure estimation using E/e′ ratio. If E/e′ ratio consistent with elevation of LV filling pressure, PA systolic pressure estimation is recommended.
[d]If stenosis suspected.
[e]Particularly in cases of stenosis with LV systolic dysfunction or whenever stroke volume abnormalities are suspected.
[f]Is right to present quantitative data (ERO, regurgitant volume, vena contracta, colour surface area, etc.) but a defined degree of severity should also be reported.
[g]For PA systolic pressure calculation, estimated RA pressure is added.
Abbreviations: PHT, pressure half-time; LVOT, left ventricle outflow tract; RV, right ventricle; RA, right atrium; PA, pulmonary artery.

clearly stated. In these cases, the patient has usually undergone a recent complete study, and there is no clinical reason to suspect that any changes have occurred outside the specific region of interest. Here, a single question regarding a single region of the heart is addressed. Different time allocations and charges that reflect the equipment and personnel time involved should be in place for such limited studies. Although it is not essential to record images and loops in studies of this type, consideration should be given to the medico-legal implications of not doing so.

Accredited physicians, or sonographers in some countries,[12] are ultimately responsible for the performance and quality of all echocardiographic studies conducted under their supervision.[2] The time allocated for a standard transthoracic study should be at least 30 min. An average routine echocardiographic study, including acquisition, interpretation and report, takes between 30 and 40 min. However, some studies may be prolonged to 60 min or more when full quantification of complex valve pathology or congenital heart disease is required as well as when application of new modalities such as tissue velocity imaging, 3D, and contrast echocardiography are applied. Trainees, sonographers, and physicians should all pay particular attention to the duration of their examinations because of discomfort that may be caused to the patient or operator (associated with excessively long studies) and maintain reasonable standards of efficiency. Every echocardiographic laboratory should periodically review the quality of studies performed as a whole and by individual examiners.

Measurements and reproducibility

Quantification of cardiac chamber size and function ranks among the most frequent requests in echocardiography.[13] However, echocardiography, like many imaging techniques, is dependent on the operator's skill in acquiring images and taking correct measurements.[14–16] Consensus on how to acquire and measure will improve reproducibility and enhance the reliability of echocardiographic measurements in the same patient examined at different times by the same or independent observers. Training and accreditation are thus key factors in reducing the variability in measurements. Variations in echocardiographic measurements arise from a variety of sources and raise the question of whether differences in measurement are due to technology (machine variability), acquisition methodology of the images or their interpretation (the latter two can generate intra- and inter-observer variability). Reproducibility is essentially affected by image quality and the scanning operator's experience in obtaining and assessing the echo-Doppler information. For this reason, dedicated sonographers are more likely to produce high quality and reproducible studies. Regular quality controls and audits should form a part of the regular tasks of every echocardiographic laboratory.

Reproducibility may vary with different echocardiographic techniques, in different laboratories and in the patient population. Uniformity in the definition of what constitutes a complete echocardiogram and standardization of measurement methods are necessary to minimize observer variability and facilitate inter-study comparison. In addition, to reduce variability, physicians and/or sonographers should be acquainted with the echocardiographic equipment used in their echo-lab, and be adequately trained in image acquisition, measurements, and calculations. It is recommended that those who perform and report echocardiographic studies unsupervised be fully accredited by their national authorities or preferably by the EAE. To limit the effects of equipment variability on reproducibility, it is recommended to use preferably the same machine and select the same set-up or system preset when repeating studies on the same patient. Intra-reader and inter-reader variability should be tested and each laboratory should confirm the accuracy of data. It is essential to know the views used to analyse and measure some specific parameters and this information should be stated in the final report. This is clearly advisable when the acquisition is not taken from a typical window or when valvular gradients such as aortic stenosis are to be quantified. In clinical practice, a single representative cardiac cycle may be used for measurement as long as the patient is in stable sinus rhythm. In patients with atrial fibrillation, a minimum of three heartbeats should be measured and results averaged to minimize beat-to-beat variability.

Finally, to avoid translational error, images should be acquired at end-expiration or during quiet respiration.

Assessment of LV size is one of the most important components of LV function quantification.[13] Changes in LV dimensions are frequently interpreted as indices of progression or regression of a disease state that affects the left heart. Linear measurements from M-mode and 2D have proved to be reproducible with low intra-observer and inter-observer variability.[3,17,18] Proper patient positioning helps to optimize imaging from parasternal and apical views. 2D and 3D-echocardiographic assessment of LV volumes and ejection fraction rely on the accurate visualization of the endocardial border. With the general use of harmonic imaging and availability of contrast agents that improve endocardial border detection, LV ejection fraction should be measured from LV volumes rather than estimated visually. When $<$80% of the endocardial border is adequately visualized, the use of contrast agents for endocardial border delineation is strongly recommended. A single dimension from M-mode or 2D is not recommended as a method for calculating LV volumes and/or ejection fraction. Unless 3D echocardiography is used, the 2D based biplane (four- and two-chamber view) disc-summation method is recommended in abnormally shaped ventricles whereas the single-plane area length algorithm is an alternative method in normally shaped ventricles with global dysfunction Visualization of true apex is important to avoid LV foreshortening and is less of a problem in 3D studies compared with 2D.

To estimate left atrial (LA) size, volume is preferred over linear dimension because the former enables accurate assessment of the asymmetric remodelling of the LA.[19] The area–length formula can be computed from the apical four-chamber view to obtain LA volume. However, this method makes assumptions that may be inaccurate. Because the majority of prior research and clinical studies have used the biplane area–length formula, it is the recommended method[13] However, in future it is likely that 3D echo methods will emerge as the best method to calculate LA volumes. Indexed LA volume should become a routine laboratory measurement because it reflects the burden and chronicity of elevated LV filling pressure and is a strong predictor of outcome.

LV filling pressure is assessed in several ways including mitral and pulmonary venous flow examination and the measurement of early diastolic mitral annular velocity by Tissue Velocity Imaging.[20–22] Measurements to be performed on the transmitral Doppler flow tracing are best obtained at the tips of the valve leaflets whereas the integral of *E* and *A* velocities for flow calculation should be obtained at the mitral annulus site.[23] Unless contrast is used, with current technology, the Doppler flow tracing within the pulmonary veins can be recorded from the transthoracic apical view in only 80% of patients. For assessment of LV filling pressure, the E/e' ratio (early mitral inflow velocity/early diastolic mitral annular velocity)[24] is preferred to the ratio between *E* and colour M-mode flow propagation velocity (V_p). Indeed, e' appears to be less subject to observer variability than V_p.[3] In patients with depressed LV systolic function, E/A ratio, *E*-deceleration time and measurements of pulmonary vein velocity are excellent indicators of filling pressures.[25–27] In the presence of atrial fibrillation, there is no *A*-wave in mitral inflow and it is impossible to measure pulmonary vein *A*-wave duration. V_p and E/e' may also be useful in this situation. *E*-deceleration time is still useful in atrial fibrillation but only if *E* velocity ends before the onset of QRS[28] (recommendations in upcoming diastolic function document).

The normal right ventricle (RV) is a complex crescent-shaped structure wrapped around the LV and is incompletely visualized in any single 2D echocardiographic view. Although multiple methods for quantitative echocardiographic assessment of RV structure and function have been proposed, this remains mostly qualitative in daily clinical practice. Tricuspid annular plane systolic excursion (TAPSE) of $<$15 mm has been associated with poor prognosis in a variety of cardiovascular diseases.[29] 3D echo acquisition of RV image data sets and subsequent off-line analysis using specialized RV volume software is likely to be the method of choice for this type of analysis in future.

When recording flow velocities, the ultrasound beam guided by the 2D image and sometimes assisted by colour flow imaging needs to be parallel to the direction of blood flow to obtain the optimal flow signal. Any deviation from a parallel intercept will result in underestimation of the actual jet velocity. To perform reliable measurements, it is essential to acquire adequate transthoracic Doppler spectral envelope (the most stable and noise-free velocity profile). Recordings are usually made at a sweep rate of 50–100 mm/s. Adjustments on the scale, baseline, Doppler gain, and wall filter should be performed to optimize the quality of the spectral flow displays. The continuity equation is most commonly applied to calculate the effective (i.e functional) area of stenotic orifices and is still valid in the presence of valve insufficiency. In presence of aortic stenosis, the maximum aortic velocity should be sought using multiple windows (apical, right parasternal, suprasternal) by CW Doppler. The highest-velocity signal obtained is assumed to represent the most parallel intercept angle. Measurement of the outflow tract diameter is prone to the greatest intra- and inter-reader variability.[3,30] Use of the zoom and taking care to avoid foreshortening of the LV outflow tract will reduce errors in quantifying aortic orifice area. For the outflow tract velocity, a clear non-aliased signal (laminar flow $<$1.5 m/s) should be obtained to avoid overestimation due to pre-stenotic acceleration. Care should be taken to ensure that both the outflow tract diameter and velocity are measured at equivalent or same positions. The window used to record the highest jet velocity, the probe used (i.e. non-imaging CW transducer or steerable probe), the diameter of the LV outflow tract, and the method applied for calculating valve area should be reported.[31,32] These recommendations will improve reproducibility by limiting inter-study variation during comparative assessment.

Pressure half-time (PHT) is one method for evaluating mitral valve area. PHT is determined by placing the CW Doppler beam across the mitral valve. During atrial fibrillation, at least five cardiac cycles (often up to 10 beats depending on R–R cycle variability) are measured. The longest cycle is the most representative for valve area calculation but it underestimates mean pressure gradient. PHT suffers from several caveats and is inaccurate in cases of moderate to severe aortic regurgitation,[33] immediately after balloon valvuloplasty,[34,35] and in patients with mild stenosis when the initial gradient is low. Both mitral or aortic valve area can also be estimated by direct planimetry.

Doppler-derived valve area requires less technical expertise and provides lower variability than direct planimetry,[36] unless 3D echocardiography is used to select the optimal plane when planimetering the mitral orifice area.[37] Calcification can limit the optimal visualization of the valve-opening contour and this may be more of an issue when stenosis is severe and, by definition, the valve area is small and the margin for measurement error greater. Routine evaluation of mitral stenosis severity should combine measurements of mean gradient and valve area using planimetry and PHT method (recommendations upcoming valvular stenosis document).

Semiquantitative estimation of valvular regurgitation suffers from high subjectivity and variability.[32,38,39] The evaluation of regurgitation severity should integrate multiple parameters.[38] This helps to minimize the effects of technical or measurement errors that are inherent in the various methods available. Colour flow mapping of the regurgitant jet appears to be the easiest method to estimate the degree of regurgitation but its accuracy is limited by several physical factors (gain setting, colour scale, pulse repetition frequency), receiving chamber compliance, direction of the jet (Coanda effect) and the patient's blood pressure. Observer agreement of qualitative assessment of severity of regurgitation using colour Doppler flow mapping is very low.[38] The jet width at the vena contracta (VC) is considerably less sensitive to technical factors and independent of flow rate.[40] However, it is theoretically limited by the lateral resolution of colour Doppler echocardiography, which is frequently inadequate to distinguish minor variations in VC width. The standard 2D technique is to obtain a parasternal long-axis view, set the colour sector size and imaging depth as narrow as possible to provide maximum frame rate and use the zoom to expand the selected zone to optimize visualization of the VC.[40] The selected cine-loop is reviewed frame by frame to find the best frame for measurement. The largest diameter of a clearly defined VC is measured.

The PISA method (proximal isovelocity surface area), a quantitative approach, is acceptably reproducible in mitral and tricuspid regurgitation.[41] Observer variability for measurement of PISA radius is affected by several factors: echocardiographer expertise, correct identification of the centre of the regurgitant orifice (as the radius is squared in the proximal convergence formula, a 10% error in radius measurement will cause more than 20% error in flow rate), the dynamic variation in the orifice area and shape throughout systole, and the non-hemispheric shape of the convergence zone.[42,43]

The best technique for comparing serial changes in quantification is to display similar serial images side-by-side and have the same measurement on both images taken by the same person, at the same time.[44]

Storage

Digital storage of echocardiograms is preferred to analogue videotape storage because it offers higher quality, lack of degradation over time (as occurs with video storage), inherent calibration, better accessibility, more convenient retrieval in particular, and more flexible display options (e.g. easy side-by-side comparison of cine-loops). Echocardiographic data are stored either locally on a hard disk or exchangeable media such as magneto-optical disks, or transferred via a network to a more permanent storage site.[45] It may be necessary to first store data locally and then periodically transfer it from the machine hard disk or another medium to the long-term archive. Long-term archiving is offered by the industry in several forms, from magneto-optical disk 'juke boxes' to stacks of hard disks (RAID arrays) and to magnetic tape drives. These solutions, whilst all fulfilling their purpose, differ considerably in memory capacity, retrieval speed and cost. Back-up storage should also be considered.

Although videotape storage is inexpensive and permits practically unlimited continuous documentation, there continues to be niche applications for additional video storage, especially whenever images have to be captured immediately with no time for selecting loops. Such a situation may occur during emergency echocardiography, stress echocardiography, transoesophageal echocardiography, during intravenous saline or other contrast administration or, in particular, when echo accompanies interventions (e.g. closure of atrial septal defects or percutaneous alcohol ablation in hypertrophic obstructive cardiomyopathy). Nevertheless, it is desirable even in the cases cited for representative images to be additionally captured digitally for easier retrieval. In these circumstances, it is important to increase the number of acquired loops captured from usually one to a minimum of five consecutive cycles. Prosthesis obstruction is another situation in which the abnormalities may not be constant. Due to the sometimes-intermittent nature of prosthetic obstruction, careful capture digitally over a series of beats (at least two) and effort to catch sudden increases or intermittently absent gradients is warranted.

The latest generation of echo systems allow retrospective acquisition of up to 2 min of real-time images, almost completely obviating the need for videotape. The recent availability of DVD recording facilities, which enable several hours of continuous recording onto one disk will make videotape recording redundant in the near future.

The most vexing problem to date has been the integration of echocardiographic data acquired by equipment from different vendors into one storage system. Although in principle this compatibility is what the universally accepted DICOM[46] standard is supposed to guarantee, in practice numerous problems exist. For example, different types of 'DICOM-compatible' compression, different approaches to the processing of Doppler data and other variations raise problems. These problems are usually solved with difficulty and need to be addressed and tested carefully when implementing a network and storage system that has to handle data from different vendors. Scientific societies and industry are cooperating, among other efforts, in the Integrating Healthcare (IHE) Enterprise (see http://www.cocir.org), to solve these problems. Digital data storage for a busy echo laboratory creates huge demands for memory space, typically considerably larger than those of the catheterization laboratory at the same institution because the volume of echo studies is usually greater. Despite 'clinical compression' (the selection of representative cine-loops in each view) and digital compression (using lossless compression algorithms such as run-length encoding or validated lossy compression such as JPEG), a standard study will require at least 30 MB upward of digital space. Hence, the

minimum yearly memory space necessary for a laboratory performing 5000 echos a year will typically be in the range of 150–200 GB.

In summary, routine digital storage of echo data is recommended and other analogue media, such as videotapes, should be replaced as soon as possible.[47] In some cases, additional video recording may be recommended, e.g. when echo is performed under difficult conditions and high time pressure, or when accompanying a procedure. To ensure a reliable digital database, the following requirements should be met:

- A standard protocol enumerating standard views and other echo data to be routinely acquired and stored digitally. A recommended minimal data set for a normal transthoracic echocardiography study is shown in *Table 2*.
- Compatibility of different echo machines with the network and a data management and storage system must be ensured.
- Ideally, the data management of the laboratory should interface with other digital data management systems in the hospital (e.g. via a Health Level 7 interface) to ensure that patient identity and examination dates are uniformly registered.
- Provision of sufficient memory space, precautions against data loss (i.e. data backup), periodic software and hardware servicing and protection of medical data against unauthorized use must be ensured.

All studies should be recorded and stored on some form of medium for subsequent analysis and review. Studies used for diagnostic purposes and not stored should not be reimbursed and this may also have medico-legal applications. Legal requirements as to the duration of mandatory data storage obviously have to be met. However, unlike radiographic data, there are often no legally binding specifications for the storage of echo images. In view of today's technical possibilities, it seems wise to ultimately aim for very long-term storage (at least in the range of the patients' life expectancy), even if this necessitates a storage solution that does not permit short-time retrieval (i.e. magnetic tape).

Standard report on echocardiography

An echocardiogram is a diagnostic test performed to answer clinical questions and to guide treatments. For this reason, an echo report should offer the results of a systematic approach with a logical structure using understandable language, according to current definitions of medical terms, and supported by precise measurements of fundamental data. The use of such an approach is very important to avoid confusion, since a report is made to be read and understood by other physicians who are not always echocardiographers or even cardiologists.

At present, echocardiography faces the problem of data overload. In any echocardiographic laboratory, in addition to the rising number of patients to be studied, an impressive amount of information is generated from the different modalities (M-mode, 2D and 3D echocardiography and Doppler), approaches (transthoracic, transoesophageal, epicardial, intravascular), and applications (stress, contrast, tissue velocity imaging, 2D strain and perfusion) used to study the heart with the use of ultrasound. Furthermore, the lack of standardization of terms for echocardiographic definitions and quantitative parameters has impaired some clinical utilities such as comparison of serial echo reports performed in the same patients or the capability to share data among laboratories, thereby limiting the potential value of the distribution of this information for clinical, scientific and administrative purposes.

Identification of 'minimal data sets' of essential quantitative and morphological variables to be recorded and inserted in a standard manner in echocardiographic reports is fundamental to facilitate: (i) promotion of quality of echocardiographic studies by identifying descriptors of complete and accurate echo reports; (ii) development of standardized databases and software applications for echo reporting, required for the transition to digital echocardiography acquisition and reporting systems; (iii) improvement in communication among laboratories, echocardiographers and other medical staff responsible for patient management; and (iv) multicentre registries and outcome and cost-effectiveness analyses.

Previous national initiatives

Several attempts have been previously made to promote standardization of the content of echocardiographic study reports. In 2002, the American Society of Echocardiography published a recommendation document on measurements and descriptive items that should be included in a standardized and comprehensive echocardiography report.[48] The British Society of Echocardiography produced a minimum data set for a standard adult transthoracic echocardiogram. This document offers information on the views to be obtained, echo modalities to employ, cardiovascular structures to be assessed using each echo modality with relative measurements to be made, and derived calculations (unpublished results). The Italian Society of Echocardiography published a consensus document on the organizational aspects of echocardiography in Italy. As part of this work, a task force dedicated to reporting produced different documents now available on the web,[49] including general basic information, quantitative parameters, descriptive statements for reporting morphological findings and a summary of mandatory information (quantitative and descriptive) for the development of echo-reporting software and databases. Since 1994, the Spanish Working Group of Cardiac Imaging has developed and distributed more than 400 licences of 'Ecocardio', a software package that includes a database and a reporting application for echocardiography.

The success of these and future initiatives will depend on standard report applications organized in a common structure, which allows quick and easy access to information based on a minimal mandatory data set (agreed by consensus), but flexible enough to guarantee personal or institutional variations according to specific interests.

Ideal design and architecture of software systems for echocardiographic reports

Programs for echocardiographic reports usually use relational databases. These programs should be part of, or integrated into, the general hospital information system in order to exchange data with clinical charts and demographic databases and integrate the results of echocardiography with data stemming from other imaging techniques.

Different formats are available, but the final software system should be compatible with Health Level 7 (HL7), currently the most commonly standard used for the exchange, integration and retrieval of electronic health information, and should support IHE Integration Profiles. The software should also be compatible with the DICOM Structured Reporting extension to the DICOM standard to allow direct transmission of quantitative data from the echo system to the report.[50] Migration of records from old applications should be guaranteed with minimal risk of data loss before facing changes from one system to another.

In order to improve standardization, it is preferable to design software applications compliant with current recommendations for reporting and maintaining standard nomenclature and reference values for measurements according to the guidelines of the principal scientific associations in cardiology, and more specifically, in echocardiography.

Essential variables that should be included in the report

It is recommended to organize the adult transthoracic echocardiography report in different sections, since this facilitates elaboration, reading and understanding of the report, and data storage (for comparisons and queries). A correctly organized report should reflect the results of an echocardiogram performed using a standard acquisition and interpretation strategy addressing the main questions that motivated the study. There are many ways to organize the results of measurements and qualitative variables. Some will prefer sections based on anatomic structures (chambers, valves, great vessels, pericardium, etc.) describing morphological and functional findings, reporting measurements for each anatomic structure and detailing the results of each technical modality. A further possibility is to organize results according to the modalities used during the study (M-mode, 2D, Doppler, etc.). Each section of the findings should end with a small open field for comments. The basic components of the structure of a Report are summarized in *Table 5*.

Table 5 Basic structure of a report in echocardiography

1. Heading: general data
2. Findings: core of the report, data that support conclusions
   Quantitative and qualitative evaluation of cardiovascular structures employing different technical modalities
      (a) Echocardiography: M-mode, bidimensional (and 3D)
      (b) Doppler: colour, pulsed-wave (PW), continuous-wave (CW) and tissue Doppler
   Additional modalities
      (c) Transoesophageal echocardiography.
      (d) Stress echo.
      (e) Other modalities (approaches): 3D, Intravascular, etc.

   For better comprehension, each section should end with some short comments
3. Summary
   'Essence' of the report, written to be understood by any physician
4. Signature and date
   Person responsible and date of reporting and the name of anyone senior who has reviewed the study

Heading

Mandatory items

Patient identification, demographics, and test indication (*Table 6*). These data should be considered mandatory to begin any report, even for emergency studies. Software programs may block introduction of data if some mandatory data is lacking (i.e. patient ID) and request confirmation to avoid repeated introductions or errors. Patient information in echocardiographic databases should be protected according to clinical data regulations.

Recommended items

Data such as patient height, weight, and derived body surface area, together with heart rate and cardiac rhythm are very useful for interpreting morphological and functional quantitative data. Blood pressure may be useful in clinical conditions where changes in afterload may affect echo findings (i.e. aortic or mitral regurgitation). Prior diagnosis and clinical data on current status support the reason for study and are, on many occasions, essential for study performance and interpretation. Information on the echocardiographic machine, applications used and image quality is useful for the physician who reads the report to judge completeness, reliability, and robustness of clinical conclusions (e.g. exclusion of infective endocarditis by means of a poor quality transthoracic study raises issues about the reliability of the conclusion). Other information regarding type of image storage media and location is recommended to facilitate the review and quality control. Finally, information on study appropriateness and clinical priority provides useful parameters for monitoring the quality of the echocardiographic laboratory and feedback on requests to the ordering physician.

Findings

Information on cardiovascular structures examined can be quantitative (i.e. chamber dimension) or qualitative, morphological (i.e. bicuspid aortic valve) or functional (mitral valve systolic anterior motion). Measurements should be introduced as numeric values, but other kinds of qualitative information need pre-specified categorized fields, sometimes with a limited number of categories

Table 6 Variables at the heading section of an echocardiographic report

Registration in the system[a]: Patient ID, location and demographics
Name, clinical history number or another single identifier[a]
Gender
Date of birth[b]
Study date[b]
Indication of the study: main reason for ordering the test[c]
Location of the patient (outpatient, inpatient, service, cardiology, CCU, etc.)
Name of responsible consultant or physician requesting echo
Image quality

[a]Identifier should be the same used for imaging storage.
[b]Age automatically calculated for each study date.
[c]Desirably suitable for encoding: chest pain, mitral stenosis, LV systolic function, etc., and might allow combination of codes, i.e: aortic dissection and pericardial effusion.

(e.g. degrees of regurgitation). However, on other occasions a larger number of categories are required to describe a condition. Encoding of variables and integration of lists of diseases, diagnoses or protocols is advisable. Free-text fields are also necessary for comments although incorporation of the content of these non-encoded variables may be very difficult when statistics, queries, and information exchange are required.

Two-dimensional and M-mode echocardiography

Quantification of chamber methodology and reference values should be assessed according to the previous section in this article and with the Recommendations published in this Journal in 2006.[48]

Mandatory items

Dimensions: LV and LA dimensions should be reported in all studies. In cases of aortic disease or predisposition (i.e. Marfań s Syndrome), measurements should be taken at three levels (sinus, sinotubular junction and proximal ascending aorta). Although multiple methods have been reported, assessment of RV size remains mostly qualitative. Inferior vena cava diameter and its change during quiet respiration are fundamental to estimate right atrial (RA) pressures (*Table 3*).

Functional aspects: LV systolic function should be reported in every echocardiogram, and when measured the biplane discs' summation method (Simpson's rule) is recommended to calculate LV volumes. When regional wall motion abnormalities are detected in the LV, they should be reported based on the 16-segment model. A 17-segment model of LV was proposed in 2002 with the addition of the apical cap.[51] As the tip of the normal apex (segment 17) does not move, this model should be predominantly used for myocardial perfusion studies or for comparative studies with other imaging techniques. Given its complex geometry, RV systolic function is difficult to assess quantitatively and is generally estimated qualitatively in clinical practice. In the future, it is likely that 3D echocardiography will prove the technique of choice for RV assessment.

Pathological changes of normal structures (thickening, rupture, perforation, etc.), abnormal structures (masses, membranes, etc.) or functional aspects (decrease in or excess of mobility of a valve) are often difficult to categorize and should be described in the corresponding field for comments.

Recommended items

Measurements of LV and RV outflow tract diameters are used for non-invasive haemodynamic calculations (cardiac output, valve area, shunts, etc.). However, as they may constitute an important source of error, experience and accuracy are fundamental using quantitative techniques. In patients with mitral stenosis, 2D and 3D area planimetry, when adequate imaging is obtained, is helpful to assess stenosis severity, especially in situations such as post-percutaneous valvuloplasty.[34,35]

As an estimate of RV systolic function, despite its regional nature and load dependence, TAPSE is often used for serial evaluation, particularly in the absence of regional wall motion abnormalities.[29]

Qualitative assessment of pericardial effusion is superior to simple measurements such as M-mode separation between pericardial layers; however, the latter could be very useful for follow-up monitoring. For this purpose it is important to document patient position since this may effect the relative separation between the pericardial layers. On occasions, owing to special circumstances (suboptimal transthoracic window, emergency) or focalized studies, standard measurements are incomplete or not possible; nevertheless, qualitative assessment, both morphological and functional of evaluated structures, is highly recommended. For the exceptional case where visualization of a specific important structure is not achieved, it should be clearly stated on the report.

Doppler

This section covers the results of functional evaluation using colour Doppler, spectral Doppler, PW and CW Doppler, and tissue Doppler when available.

Mandatory items

Mitral filling: *E*- and *A*-wave velocities, and *E*-wave deceleration time are widely used for characterization of diastolic function, in the evaluation of atrio ventricular (AV) dyssynchrony or conditions such as tamponade or constriction. For these reasons, their evaluation is mandatory, including respiratory variations (using a superimposed respiration trace) when necessary. LV diastolic function can usually be described in three degrees: mild (impaired relaxation pattern), moderate (pseudonormal), and severe (restrictive), combined with an estimator of LV filling. The E/E' ratio is the recommended method for assessing LV filling pressure. To obtain this calculation an average of septal and lateral E' is recommended (*Table 4*).[52]

Functional assessment of heart valves, pulmonary artery systolic pressure estimation, and evaluation of suspected shunts or gradients inside the heart (fixed or dynamic) or in great vessels (coarctation) are considered mandatory for any comprehensive echocardiographic report. Mean and instantaneous gradients should be reported for obstructive lesions or stenotic valves (including normally functioning prostheses).[32] For aortic stenosis, valve area calculation by continuity equation is desirable, especially in cases of LV systolic dysfunction or whenever stroke volume is reduced (low cardiac output, significant aortic regurgitation) PHT and planimetry may be the methods of choice for calculating valve area in most cases of mitral stenosis in the absence of limiting factors previously described.[33–36] In cases of mechanical prostheses at mitral position, the mean gradient is the preferred parameter since PHT is not useful for estimating the effective orifice area.[3,32,53]

Multiple criteria can be used for the evaluation of regurgitation severity; however, no one method has proved superior to others except in particular circumstances. Regardless of the method employed, the severity of valve regurgitation should be expressed in the report as mild, moderate or severe. A semi-quantitative scale from 0 to 4 could be used and in these cases grade 3 implies moderate-to-severe regurgitation. The use of quantitative methods (ERO, regurgitant volume, etc.) is advisable since they may be useful for decision-making; however, a high level of experience is required to make these calculations.[38,54]

Recommended items

Other estimators of pulmonary artery systolic pressure, such as acceleration time of PW Doppler at the pulmonary valve, can be useful, especially in the absence of tricuspid regurgitation for RV–RA gradient calculation.[55] When a shunt is detected or suspected, it is recommended to make calculations of systemic and pulmonary stroke volume and the Q_p/Q_s ratio[32]

The transmitral inflow *E*-wave peak-velocity and V_p ratio can be used as an alternative to E/e' for LV filling pressure estimation, especially when tissue Doppler is not available.[56] V_p is also very helpful for the differential diagnosis between restriction and constriction. Not all the variables in a report database have the same importance for healthcare, a specific research project or administrative purposes. Decisions on what is fundamental in a report are challenging, but necessary to take advantage of the maximum potential of relational databases.

Comments and conclusions

Open-text field or preformed descriptive statements that echocardiographers may choose to describe the main findings of the study should be used. In this section it is recommended to include some statements answering the reasons for the study and the clinical queries, emphasize abnormal findings, and compare the important differences and similarities of the current study with previous ones. Major limitations or particular conditions (clinical, haemodynamics, etc.) prone to influencing the results should be reported. An echocardiographic study report should end with clear conclusions, emphasizing the main findings of the diagnosis and severity of the heart diseases. It is the essence of the report and must be written to be understood by any physician. Whenever the result of the study dictates the need for an urgent change in management, the responsible physician needs to be informed.

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