Two-dimensional echocardiography in the diagnosis of ischemic heart disease

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ABSTRACT
Ischemic heart disease (IHD) also known as coronary artery disease (CAD) is one of the major causes of morbidity and mortality. Two-dimensional echocardiography (2D echo) is a non-invasive diagnostic technique that provides information regarding the cardiac function and hemodynamics. This paper was designed to update the reader on the fundamental principles and current applications of 2D echo imaging recommended in patients with known or suspected IHD. Also the recent advances on the prognostic and diagnostic value and the future directions of 2D echo in the evaluation of IHD will be addressed. Although the noninvasive imaging modalities for the evaluation of IHD have expanded over the last decade, 2D echo remains the most cost-effective and risk-effective imaging choice in most settings. The main drawback of echocardiography remains in the limited echogenicity of many patients and its undeniable operator dependence. However, improvement of existing well-established echocardiographic methods (2D echo, stress echocardiography, contrast echocardiography) in conjunction with the development of new emerging echocardiography methods (3D echo, tissue Doppler imaging (TDI), speckle tracking imaging) are anticipated to increase the clinical utility of echocardiography in IHD.

1. Introduction

Ischemic heart disease (IHD) also known as coronary artery disease (CAD) is one of the major causes of morbidity and mortality. A large number of patients present daily to the emergency department with the chief complaint of chest pain. The challenge for the physician is to identify patients who require intervention, particularly when acute coronary syndromes (ACSs) present with atypical symptoms or nondiagnostic electrocardiography (ECG) changes or normal cardiac enzyme levels. Since the mortality and morbidity of IHD, improve following early treatment, timely diagnosis is of vital importance not only to help the patient, but also to reduce hospital stay and economic costs (Esmaeilzadeh, Parsaei, & Maleki, 2013; Votavová, Linhartová, Kořínek, Marek, & Linhart, 2015).

Imaging techniques represent the key method for disease extent and severity assessment and evaluation of hemodynamic complications. Two-dimensional echocardiography (2D echo) is one of the most useful imaging methods due to its availability, ease of use, price, capacity to serve as bedside technique and repeatability. It is the most employed cardiovascular imaging modality for assessment of cardiovascular disease and is often performed in patients without a history of IHD. It is well established that several echocardiographic measurements provide powerful prognostic information for cardiovascular outcomes, such as presence of left ventricular hypertrophy, aortic sclerosis and left ventricular ejection fraction (LVEF). Also 2D echo is also very useful when it comes to rule out the possibility of other etiologies of acute chest pain or dyspnea, such as aortic dissection and pericardial effusion (Chaves, Kuller, O'Leary, Manolio, & Newman, 2004; Esmaeilzadeh et al., 2013; Votavová et al., 2015).

This paper will update the reader on the fundamental principles and current applications of 2D echo imaging recommended in patients with known or suspected IHD. Also the recent advances on the prognostic and diagnostic value and the future directions of 2D echo in the evaluation of IHD will be addressed.

2. Literature review

An inclusive literature review was conducted to update the reader on the fundamental principles and current applications of 2D echo imaging recommended in patients with known or suspected IHD. In addition, the recent advances on the prognostic and diagnostic value and the future directions of 2D echo in the evaluation of IHD will be addressed. The ScienceDirect, PubMed,
3. 2D echo in the diagnosis of IHD

3.1. 2D echo in the evaluation of regional and global systolic function

2D echo is a non-invasive diagnostic technique for the provision of information on cardiac function and hemodynamics and is the most frequently utilized cardiovascular diagnostic test after ECG and chest X-ray (Esmaeilzadeh et al., 2013). Major consequences of ischemia include an impairment of regional systolic contractility. If severe ischemia persists myocardial necrosis develops, followed by scarring which affects the regional function permanently. The regional myocardial function is usually assessed only visually by evaluating wall thickening and endocardial motion of myocardial segments. It is widely recognized that myocardial movements may be caused by adjacent segment tethering or overall left ventricular (LV) displacement. It seems, therefore, preferable that regional deformation should be analyzed by using methods that are at least partially independent of tethering, such as speckle tracking though keeping in mind that even the deformation may be passive (Lang et al., 2015).

In IHD cases regional wall motion should be assessed on multiple image views in the parasternal long-axis and short-axis views and the apical four-chamber, two-chamber, and three-chamber views. The subcostal views can prove extremely helpful, especially when parasternal or apical views are of poor quality, and off-axis or foreshortened views should be avoided in that they render the interpretation of regional wall motion difficult and increase the likelihood of error. Second harmonic imaging with high signal-to-noise ratio can augment the clarity of the images (Esmaeilzadeh et al., 2013). The use of deformation imaging, nowadays mostly using the strain and strain rate derived from speckle tracking, should allow less subjective evaluation of myocardial contraction as compared to simple visual assessment. The speckle tracking echocardiography replaced techniques based on tissue Doppler imaging (TDI) originally used for myocardial motion and deformation assessment. The strain and strain rate derived from 2D echo are based on computer algorithms tracking the movement of speckles clusters of natural acoustic markers generated within the myocardium by an interaction with ultrasonic waves. These techniques are independent of the ultrasound beam propagation angle and allow evaluation of longitudinal, radial, and circumferential strains (Hoit, 2011). In the normal myocardium strains and strain rates are nearly homogeneously distributed and even subtle changes may suggest myocardial contractile impairment. Jamal et al. (2002) proposed that particularly the longitudinal strain decrease correlates with the presence of decreased coronary perfusion in segments that appear visually normal (Figure 1).

Assessment of global systolic function parameters should be based on 2D or three-dimensional (3D) echocardiographic imaging. Although 3D echo begins to change the clinical practice in many ways, the 2D approach is still prevailing. LV volumes should be measured from apical four and two chamber views. During scanning attention should be paid to maximize cavity areas to avoid LV foreshortening. The most commonly used methods for 2D volume calculations is the Simpson’s biplane method of disc summation (Figure 2) (Lang et al., 2015; Votavová et al., 2015).

Upper normal limits of 2D echo end-diastolic volumes are proposed at 74 mL/m² for men and 61 mL/m² for women. In contrast to previous recommendations proposing a uniform lower limit for ejection fraction (EF) at 55%, current guidelines suggest that EF of <52% in a man and <54% of women are suggestive of abnormal LV systolic function (Lang et al., 2015, 2005). In addition to measurements of left and right regional and global ventricular function, 2D echo allows a reasonably precise evaluation of cardiac output. The most clinically accepted technique is combining the measurement of LV outflow tract dimension (LVOT) and velocity time integral (VTI_{LVOT}) of the flow through the LVOT measured from apical views (Figure 3). The cardiac output is then calculated as: \( \pi \times \left( \frac{\text{LVOT}^2}{4} \right) \times \text{VTI}_{\text{LVOT}} \times \text{heart rate}. \) This
approach is very useful, particularly in acute settings for evaluation of the overall hemodynamic situation (Votavová et al., 2015).

3.2. 2D echo in the evaluation of LV filling

2D echo provides crucial information for predicting ventricular remodeling and functional recovery, LV size and volume, regional wall motion abnormality, myocardial viability, LV filling pressures, severity of mitral regurgitation, and systolic pulmonary artery pressure (Esmaeilzadeh et al., 2013). The recognition of diastolic dysfunction or worsening of diastolic function can be indicative of the IHD presence at rest even without the systolic dysfunction or obvious wall motion abnormalities (McMurray et al., 2012). 2D echo allows evaluation of LV filling using Doppler measurements of transmittal flow and pulsed wave TDI recordings of mitral annular movements (Figure 4) (Votavová et al., 2015). The evaluation should be completed by analyzing the pulmonary venous inflow pattern, using Valsalva maneuvers and considering the left atrial size and volume. The prognosis of the patients depends also on left atrium (LA) volumes, which should be preferred over linear atrial measurements and performed by using two perpendicular apical views, applying either disc summation methods or area-length (Gillebert, De Pauw, & Timmermans, 2013; Tsang et al., 2006). The tracing of LA is closed at the level of mitral annulus and LA appendage or pulmonary vein inflows are not included (Lang et al., 2015).

Figure 1. 2D Apical two-chamber view with speckle tracking showing a significant decrease of longitudinal strain within the basal inferior wall (yellow segment, arrow) with a clear post-systolic deformation (arrow) on the yellow curve (Jamal et al., 2002).

Figure 2. Biplane disc summation method (modified Simpson’s rule) for LV volumes and LVEF calculations (Votavová et al., 2015).
3.3. 2D echo in the evaluation of ischemic mitral valve regurgitation

The pathophysiology of ischemic mitral valve regurgitation or ischemic mitral regurgitation (IMR) is complex (Votavová et al., 2015). Functional mitral regurgitation occurs when the leaflets and chordae are relatively normal, but systolic coaption and apposition of the leaflets are lessened (Figure 5) (Sutton & Scott, 2002). In most cases the IMR develops as a consequence of myocardial infarction (MI) inducing LV cavity dilatation.
and systolic dysfunction. This leads to mitral leaflet tethering and to an inappropriate co-aptation of the mitral valve leaflets. The cavity dilatation contributes by secondary mitral annular dilatation and loss of annular contraction (Votavová et al., 2015).

In addition, global LV dysfunction is associated with a decrease in closing forces necessary for the appropriate mitral valve closure. In patients with IHD, the posterior leaflet motion in systole is restricted or tethered secondary to the inadequate contraction of the posterolateral wall. The resulting malcoaptation and malapposition is allied to a posteriorly directed mitral regurgitation jet. The dilation of the mitral annulus also may contribute to the development of mitral regurgitation. Mitral regurgitation, in turn, leads to LV volume overload resulting in further cavity dilatation, which exacerbates the vicious circle by aggravating the mitral regurgitation. In patients with IHD, functional mitral regurgitation is associated principally with an inferior MI and the lateral displacement of the posterior papillary muscle. It is also worthy of note that significant IMR is correlated with a poor outcome (Badiwala, Verma, & Rao, 2009; Esmaeilzadeh et al., 2013; Grigioni et al., 2005; Levine & Schwammenthal, 2001; Otsuji et al., 2001).

2D echo allows quantitation of IMR and detailed assessment of underlying mechanisms. The quantitation should not be based solely on semi-quantitative evaluation of the regurgitant jet area. A mean value of >8 mm obtained from several views seems to identify a severe mitral insufficiency regardless of the etiology (Piérard & Carabello, 2010). A quantitative analysis based either on Doppler volumetric method or proximal isovelocity surface area principle (PISA) is preferable (Figure 6) (Votavová et al., 2015). Unfortunately, the estimation of LVOT area is often inaccurate and mitral valve orifice has an elliptic shape dynamically changing throughout the diastole. Also, the PISA method may lead to underestimation or overestimation of the regurgitant volume and orifice, as well as PISA radius is changing during systole. Therefore, a simple comparison of mitral to aortic VTI may be helpful, severe MR should be suspected whenever their ratio exceeds 1.4 and detailed assessment of mitral anatomy is recommended (Lancellotti et al., 2010; Piérard & Carabello, 2010).

Severity grading of IMR differs from organic mitral regurgitation. Severe IMR is defined by regurgitant volume >30 mL and effective regurgitant orifice (ERO) >20 mm². Currently, there is an expert consensus that mitral valve surgery should be offered to patients with severe IMR undergoing surgical and may be considered as an isolated surgical procedure. The indication of surgery in patients with moderate IMR (ERO >10 mm² but <20 mm²) is controversial (Smith et al., 2014). Several other parameters have been suggested for evaluation of IMR mechanisms, including leaflet angle measurements and posterior displacement of papillary muscles assessments. Before any indication of surgery, it is important to determine the origin of the jet and its direction (Lancellotti et al., 2010).

3.4. 2D echo in the localization of acute myocardial infarction (AMI)

The potential value of 2D echo as a diagnostic tool in acute or subacute complications of MI was discovered very early, and a large number of studies reported its high sensitivity, both qualitatively and quantitatively (Peels, Visser, Kupper, Visser, & Roos, 1990; Sabia et al., 1991). As a general rule, for the differentiation of normal from infarcted myocardium, wall thickening is preferred to wall motion. Moreover, 2D echo is extremely accurate for the localization of the infarction. Exceptions are multi-vessel disease, previous infarction, and overlap between the perfusion territories on the right and circumflex coronary arteries. There is a significant relationship between infarction and contractile dysfunction; consequently, the absence of wall motion abnormality or wall thinning rules out a clinically significant infarction (Esmaeilzadeh et al., 2013).

In addition, a meticulously performed Doppler echocardiographic examination can provide sufficient information to determine the hemodynamic category after an infarction without increased mortality. This noninvasive measurement of the cardiac output and

![Figure 6](image-url)
pulmonary capillary wedge pressure (PCWP) in patients with AMI and cardiac failure can guide therapy and predict prognosis. In post-infarction patients with a LVEF smaller than 35%, a mitral deceleration time less than 120 ms is deemed highly predictive of a PCWP greater than 20 mmHg. Also, in patients with AMI, a systolic fraction of the pulmonary venous flow smaller than 45% was highly correlated with a PCWP greater than 18 mmHg. TDI measurement of mitral annular velocities is a well-validated method for PCWP estimation. The measurement of peak mitral early diastolic filling velocity/velocity of propagation (E/Vp) by color motion mode (M-mode) Doppler in patients with AMI is strongly allied with PCWP. An E/Vp equal to or greater than 2 is believed to predict a PCWP equal to or greater than 18 mmHg with a respective sensitivity and specificity of 95% and 98% (Gerber & Foster, 2007).

Elevated pulmonary artery pressure is allied to increased mortality in AMI patients. Doppler echocardiography can estimate systolic pulmonary artery pressure by using tricuspid regurgitation and the Bernoulli equation. Pulmonary artery pressure can also be measured based on the size and the respiratory variation of the inferior vena cava using 2D echo imaging. Needless to say, hemodynamic information obtained from an echocardiographic examination only at a single point in time should be complemented by continued invasive monitoring in patients with ongoing instability (Gerber & Foster, 2007; Goldstein, 2002). Moreover, 2D echo is a vital, non-invasive, and readily available tool in the diagnosis and evaluation the mechanical complications of AMI. The major mechanical complications of AMI are papillary muscle rupture with severe mitral regurgitation (Figure 7), ventricular free wall rupture with tamponade or pseudoaneurysm formation (Figure 8), and ventricular septal rupture (Figure 9) (Esmaeilzadeh et al., 2013; Figueras et al., 2010; Imazio et al., 2009; Votavová et al., 2015).

Figure 7. 2D echo showing a ruptured papillary muscle prolapsing together with the posterior leaflet to the left atrium (Votavová et al., 2015).

Figure 8. A Doppler echocardiography in the subcostal view shows a direct visualization of a free wall rupture (arrow) (Esmaeilzadeh et al., 2013).
Finally, the 2D echo is very helpful in identifying the post-infarction pericarditis developing during the subacute phase of MI, that occurs between 3 and 10 days from admission. Before the era of reperfusion presence of some pericardial effusion was reported to be as high as 25–28%. Currently, only about 4% patients with AMI treated by emergency percutaneous coronary intervention (PCI) have some degree of pericardial effusion. However, an effusion exceeding 10 mm in the parasternal long axis was reported to be associated with some risk of free wall myocardial rupture (Figueras et al., 2010; Imazio et al., 2009). Thus, 2D echo is a sensitive technique for the diagnosis of pericardial effusion along with pericarditis; the absence of fluid, however, does not exclude pericarditis (Greaves, 2002).

4. The recent advances on the prognostic and diagnostic value of 2D echo evaluation of IHD

4.1. Three-dimensional (3D) echocardiography

The 3D echo recent advances have enabled real-time volumetric acquisitions. Initial methods required manual rotation of the transducer to sequentially collect images in multiple planes, which were then reconstructed offline. Advances in material science, parallel processing electronics, and software have enabled the development of phased array transducers that can image large pyramidal volumes in real time. Corresponding improvements in software have enabled both online and offline visualization of volumetric datasets. As a result, 3D imaging is now a routine part of both transthoracic and transesophageal echocardiography protocols in many laboratories. For the evaluation of IHD, there are several important advantages of 3D volumetric imaging over 2D echo. Volumetric data sets also allow more reliable and accurate quantification of chamber volume and mass. The ability to rapidly and simultaneously acquire multiple views may simplify echocardiography and may improve diagnostic accuracy (Abusaid & Ahmad, 2012; Hung et al., 2007; Kleijn, Aly, Terwee, van Rossum, & Kamp, 2011).

4.2. TDI and speckle tracking methods

Two methods hold promise in this area are TDI and speckle tracking. As in traditional pulse Doppler imaging, the TDI measures the velocities in a region of interest. However, in contrast to traditional pulse Doppler imaging, a low-pass filter is applied to exclude high-velocity signals from moving blood, enabling measurement of myocardial tissue velocities. Speckle tracking methods use computer algorithms to evaluate changes in distance between ‘speckles’ observed in normal myocardium to compute the strain and the strain rate. Both TDI and speckle tracking methods have been used for assessment of systolic and diastolic dysfunction in the setting of IHD. Currently, most echocardiography systems include capabilities for acquiring and analyzing TDI images. Software for speckle tracking is available from multiple vendors both for offline and for real-time analysis. However, because speckle tracking analysis is time consuming, few laboratories have integrated it into routine workflows (Asanuma et al., 2012; Shah & Solomon, 2012).

5. Future directions of 2D echo evaluation of IHD

Within the last two decades, the standard laboratory echocardiography machine has shrunk from the size of a household refrigerator to potentially the size of a laptop computer. The most recent advance has been the development of a truly hand-held device which may be carried within a coat pocket. Such devices, offer diagnostic quality 2D images with simplified color Doppler and will become an adjunct to the physical examination. These devices will have most to offer in the setting of IHD and heart diseases. In IHD, 2D echo has been shown to be of value at all stages of the progression of the disease, ranging from acute chest pain presentations, confirmation of acute infarction, acute infarct complications, and the evaluation and management of chronic IHD. The integration of
echocardiography and clinical decision making is well illustrated by the use of the test in patients presenting with chest pain. 2D imaging obtained during pain or shortly thereafter has a negative predictive value of 95% for the identification of infarction, with similar sensitivity for patients presenting with documented infarction (Cheitlin et al., 2003; Marwick, 2009).

As the epidemics of hypertension and obesity extend to the developing world, the ability to identify and characterize LV dysfunction will permit the better selection of patients for preventive and therapeutic strategies. Thus, the availability of relatively inexpensive, portable echocardiography machines may have a major impact on the identification and management of IHD in the developing world. The ability of high-technology echocardiography to operate in a low-infrastructure environment is unique among the imaging techniques. Also, it seems likely that there will be increasing requirements for formal training in echocardiography for potential users of the technique among emergency room and intensive care physicians, analogous to that provided during cardiology training for evaluation of IHD (Marwick, 2009).

6. Conclusion

In conclusion, 2D echo is central to the diagnosis, management, and prognosis of the entire spectrum of acute or chronic IHD. Although the noninvasive imaging modalities for the evaluation of IHD have expanded over the last decade, 2D echo remains the most cost-effective and risk-effective imaging choice in most settings. Several features in 2D echo provide incremental value over clinical information in predicting the presence of physiological and anatomical IHD in patients without known IHD. The main drawback of 2D echo remains in the limited echogenicity of many patients and its undeniable operator dependence. However, besides the possibility of bringing the echocardiographic imaging to the bedside of our patients improvement of existing well-established echocardiographic methods (2D echo, stress echocardiography, contrast echocardiography) in conjunction with the development of new emerging echocardiography methods (3D echo, TDI, speckle tracking imaging) are anticipated to increase the clinical utility of echocardiography in IHD.

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