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專題報導

Practice of Echocardiography: From Outpatient to Bed-side Critical Care

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Abstract

Echocardiography is widely used modality in clinical practice. In this article, we made a brief review of new advanced modalities of echocardiography in recent years, including tissue Doppler imaging, speckle-tracking imaging and 3D echocardiography. We also descripted the applications of echocardiography from outpatient to critical care in different populations such as heart failure, acute myocardial infarction and shock. (J Intern Med Taiwan 2017; 28: 124-132)

Key Words: Tissue Doppler imaging, Speckle-tracking imaging, 3D echocardiography, Heart failure, Acute myocardial infarction, Shock

Introduction

Echocardiography is a widely used modality and its advantages include non-invasiveness, cost-effectiveness and widely availability. It is important in diagnosing cardiac diseases and evaluating heart function in broad groups of patients, from stable outpatients to patients with critical conditions. In this article, we reviewed the new advanced modalities and the clinical applications of echocardiography.

Advanced Modalities of Echocardiography

Traditional modalities of echocardiography included transthoracic and trans-esophageal approaches with M-mode imaging, two-dimensional (2D) imaging and Doppler analysis of flow velocities (continuous/pulse-wave Doppler and Color Doppler images). However, many cardiac diseases and heart function could not be fully evaluated with them, so that other technologies were developed.

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Tissue Doppler Imaging (TDI)

TDI is another application of Doppler imaging but its targets are tissue so that the filters are set to exclude the moving blood characterized with high velocities and low-intensity reflection. Therefore, velocities of movement cardiac tissue in the direction of ultrasound beam can be obtained. TDI can be expressed in 2D or M-mode images and velocities of specific sample volumes could be measured with pulse-wave TDI, regardless real-time or off-line analysis. (Figure 1) The advantages of TDI based on its extra-ordinary high frame rates, which strongly enhance its temporal resolution and thus fine and dedicated cardiac mechanical functions can be assessed in detail. It can be used to characterize myocardial functions (systolic or diastolic), including velocity and timing events of cardiac motions. Parameters such as difference of time-to-peak velocity between medial and lateral mitral annulus, standard deviation of time-to-peak velocity in different segments, can be used to evaluate cardiac dyssynchrony. Moreover, E/E' (ratio of early diastolic velocity of mitral inflow to early diastolic velocity of mitral annulus) can be used to estimate left ventricular (LV) filling pressure. However, angle-dependency is its innate limitation because of the principle of Doppler images while circumferential mechanic of tissue could not be evaluated. Although with this limitation, parameters derivate from TDI already became the indispensable components evaluating LV diastolic function in current published guidelines.[1-3]

Speckle-tracking Imaging/Echocardiography (STE)

2D echocardiography is a convenient modality and it can appraise myocardial motion and the structures of hearts. However, the evaluation of mechanics could only be qualitative or semi-quantitative using 2D echocardiography. With technology of STE, it can trace the speckles from 2D images in any movement direction of interest so that strain (deformation imaging) and strain rate can be appraised. (Figure 1) In contrast to TDI, the advantages of STE are angle-independency and a variety of strains could been described, including longitudinal, radial, circumferential, transverse or principle strains and even torsion, which estimate myocardial mechanics and deformations components of various directions. The understanding of these may shed light on myocardial adaptions and performances in a pre-clinical stage and further add incremental values beyond conventional echocardiographic measurements. Therefore, this kind of deformation imaging using STE became a very popular modality in clinical researches of different study populations.

Three-dimensional (3D) Echocardiography

2D images was the cornerstone of echocardiography but the development of 3D images made it more promising although additional transducers were need to acquire these images. In the early ear of 3D trans-esophageal echocardiography, it was necessary to acquire images of different angles and then reconstructed them to a full volume set. Current technology of 3D echocardiography allows full volume images acquisition in a few or even single cardiac cycles, making it less time-consuming and the images smoother. The advantages of this modality are its ability for calculation of cardiac volumes or LV mass and for more comprehensive whole heart structural or morphological descriptions. Furthermore, 3D TEE has gained much attraction and substantially improved our understandings of valvular structure and functions, and further aid in pre-procedural evaluation (such as mitral valve repair or plasty and mitral clips) and sizing of prosthesis in trans-catheter aortic valve implantation (TAVI). In recent years, 3D STE was also developed while combing the technology of 3D echocardiography and speckle-tracking imaging.[4] Figure 2 showed some applications in 3D echocardiography.

The Patients with Heart Failure (HF)

Echocardiography has an important role in evaluating the patients with HF.[2,3] Initial evaluation of these populations include clarify the etiology of HF. Valvular heart diseases regardless of regurgitation or stenosis can be easily diagnosed with 2D echocardiography and Doppler analysis. Regional wall motion abnormality can be found in those with acute coronary syndrome, hibernation due to chronic myocardial ischemia or prior myocardial

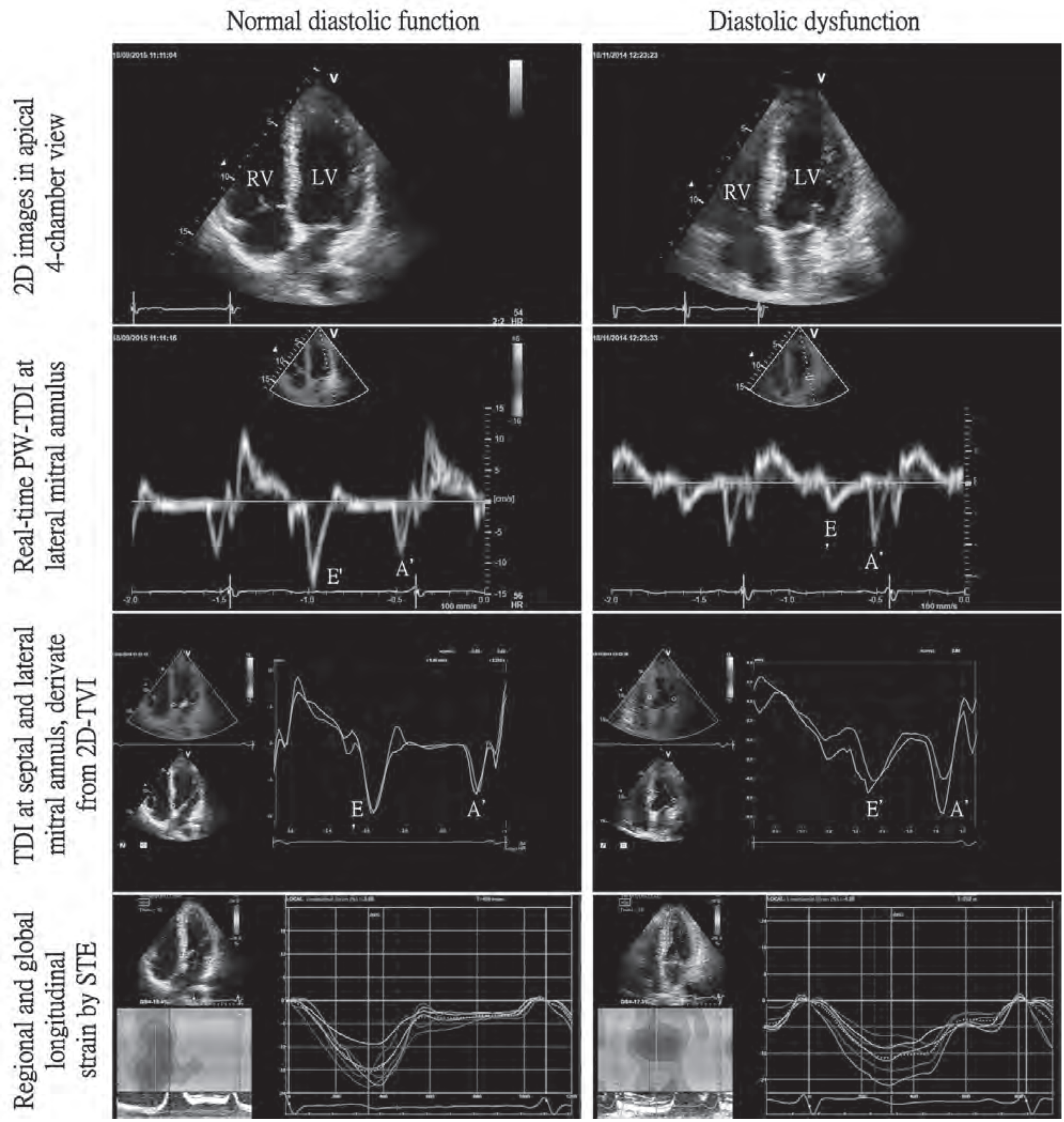

Figure 1. Demonstration of tissue Doppler imaging and speckle tracking echocardiography.
Left panel and right panel showed the echocardiographic images in two patients with normal and abnormal diastolic function respectively. The valve of E' was lower in the right panel, indicating diastolic dysfunction. 2D, two-dimensional; LV, left ventricle; LVEF, left ventricular ejection fraction; PW, pulse-wave; RV, right ventricle; STE, speckle tracking echocardiography; TDI, tissue Doppler imaging; TVI, tissue velocity imaging.

infarction. Stress echocardiography with exercise or dobutamine was proved to increase sensitivity of detecting myocardial ischemia and can be used to evaluate the viability of myocardium. Echocardiography can also easily identify various types of cardiomyopathy, congenital heart diseases, or pulmonary hypertension. It can also be used to categorize of HF groups, such as right side/left side/both sides HF or reduced/middle ranges/preserved ejection fraction HF. Disclosing the etiologies of heart failure leads to specific management, such as percutaneous coronary intervention/coronary bypass surgery for coronary artery diseases or surgery for severe valvular diseases.[5-7]

The Utilization and Clinical use of Echocardiography in Intensive Care

The Patients with Acute Coronary Syndrome (ACS)

In the patient with ACS, echocardiography can

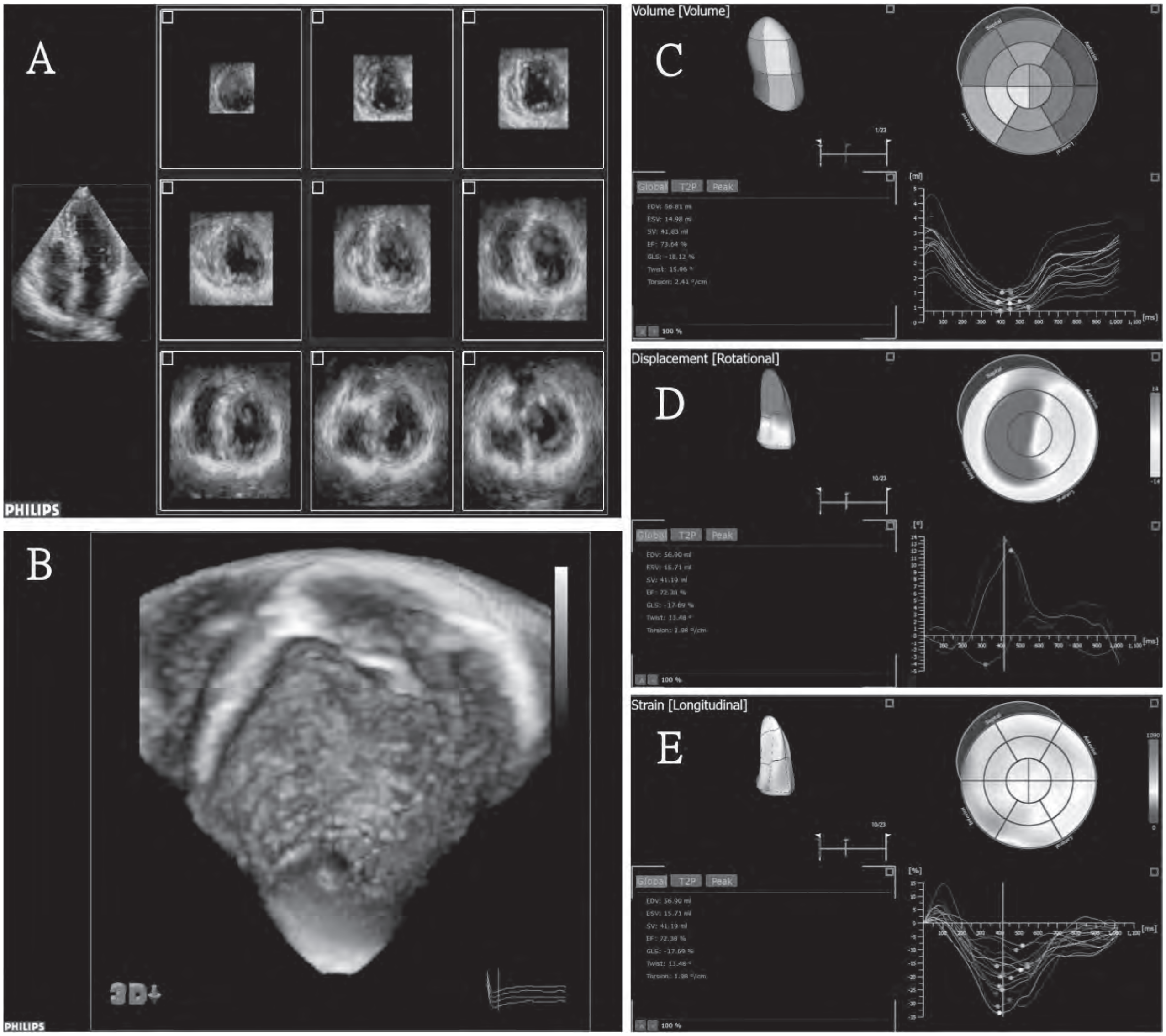

Figure 2. Application of 3D echocardiography.
(A) Tomography of LV by 3D echocardiography. (B) Prominent spongy LV trabecula in a case with non-compaction cardiomyopathy. (C-D) Off-line analysis with third-party software for calculation of regional volume changes (C), twist and torsion (D) and regional longitudinal strain (E) from a 3D volume set.
3D, three dimensional; LV, left ventricular.

be used to evaluate LV systolic function. Regional wall motion abnormality in patients without elevation of cardiac biomarkers can disclose the underling coronary artery disease. Moreover, survey of mechanical complications of acute myocardial infarction (AMI) is usually urgent and indispensable.[8,9] Pericardial effusion may indicate post-infarction pericarditis or even free-wall rupture and it may be easily detected by 2D echocardiography. Patients with moderate to large amount of pericardial effusion (≥ 10mm) had more frequent hemopericardium, and higher risk of cardiac tamponade, free wall rupture and mortality.[10,11] Diastolic collapse of right ventricle may warn the presence of cardiac tamponade and therapeutic pericardiocentesis may be necessary if hemodynamic compromise occur. Drop of fragment of papillary muscle toward left atrium in systolic phase accompanying severe mitral regurgitation can be observed in whom complicated with papillary muscle rupture. (Figure 3A and 3B) Ventricular septum rupture can be highly suspected if a harsh pan-systolic murmur was heard at left lower sternal border and can be confirmed by color Doppler images. (Figure 3C and 3D) Focused surveying apical septum with 2D and color Doppler images in standard and modified apical-four chamber views are important method to detect this kind of defect in the cases with left descending artery occlusion. Severity of the shunt can be evaluated with the ratio of pulmonary to systolic flow (Qp/Qs), which was easily calculated using echocardiography. These mechanical complications of AMI are usually disastrous and need early diagnosis and surgical intervention to save their lives.

Identification of Cardiogenic Causes of Shock

Shock, usually defined as organs hypo-perfusion or hypotension, may lead to multiple-organ failure and mortality if left untreated or delay treatment. Therefore, early identifying the causes is the principle of management. Echocardiography can

Table 1. Etiologies of cardiogenic shock in patients without life-threatening cardiac arrhythmia and their possible findings in echocardiography

Causes of shock	Findings, cues or parameters in echocardiography
Impaired LV systolic function	Reduced LVEF, decreased MAPSE, reduced global longitudinal and circumferential strain of LV
Impaired RV systolic function	Reduced RVEF, decreased TAPSE
Mechanical complications of AMI	Cardiac tamponade (see below), papillary muscle rupture (drop of fragment of papillary muscle towards LA in systole with severe mitral regurgitation), ventricular septal rupture (defect in apical septum in whom with left anterior descending artery occlusion)
Valvular stenosis	Suspected if limitation of valvular opening in 2D images; severe aortic valve stenosis (AVA < $1cm^2$ and mean trans-aortic PG >40mmHg), severe mitral valve stenosis (MVA < $1cm^2$)
HCM with LVOT obstruction	Left ventricular hypertrophic (usually wall thickness > 1.5mm), signs of dynamic LVOT obstruction (SAM, late systolic peaking or Dagger shape of Doppler with PG > 30mmHg in LVOT)
Cardiac tumors (e.g., myxoma)	Most cardiac tumor is myxoma which typically locate in atrium and attached to interatrial septum. If large enough, it may protrude across mitral or tricuspid valves, leading to decreased ventricular filling
Pulmonary embolism	RV enlargement, pulmonary hypertension, hypokinesis of RV free wall with sparing RV apex (McConnell's sign)
Cardiac tamponade	Pericardial effusion with collapse of RV in diastole; tamponade may occur even in case with small amount of pericardial effusion, especially if the fluid is accumulated acutely.

AMI, acute myocardial infarction; HCM, hypertrophic cardiomyopathy; LV, left ventricular; LVEF, left ventricular ejection fraction; LVOT, left ventricular outlet; MAPSE, mitral annular plane systolic excursion; PG, pressure gradient; RV, right ventricular; RVEF, right ventricular ejection fraction; SAM, systolic movement of anterior mitral leaflet; TAPSE, tricuspid annular plane systolic excursion.

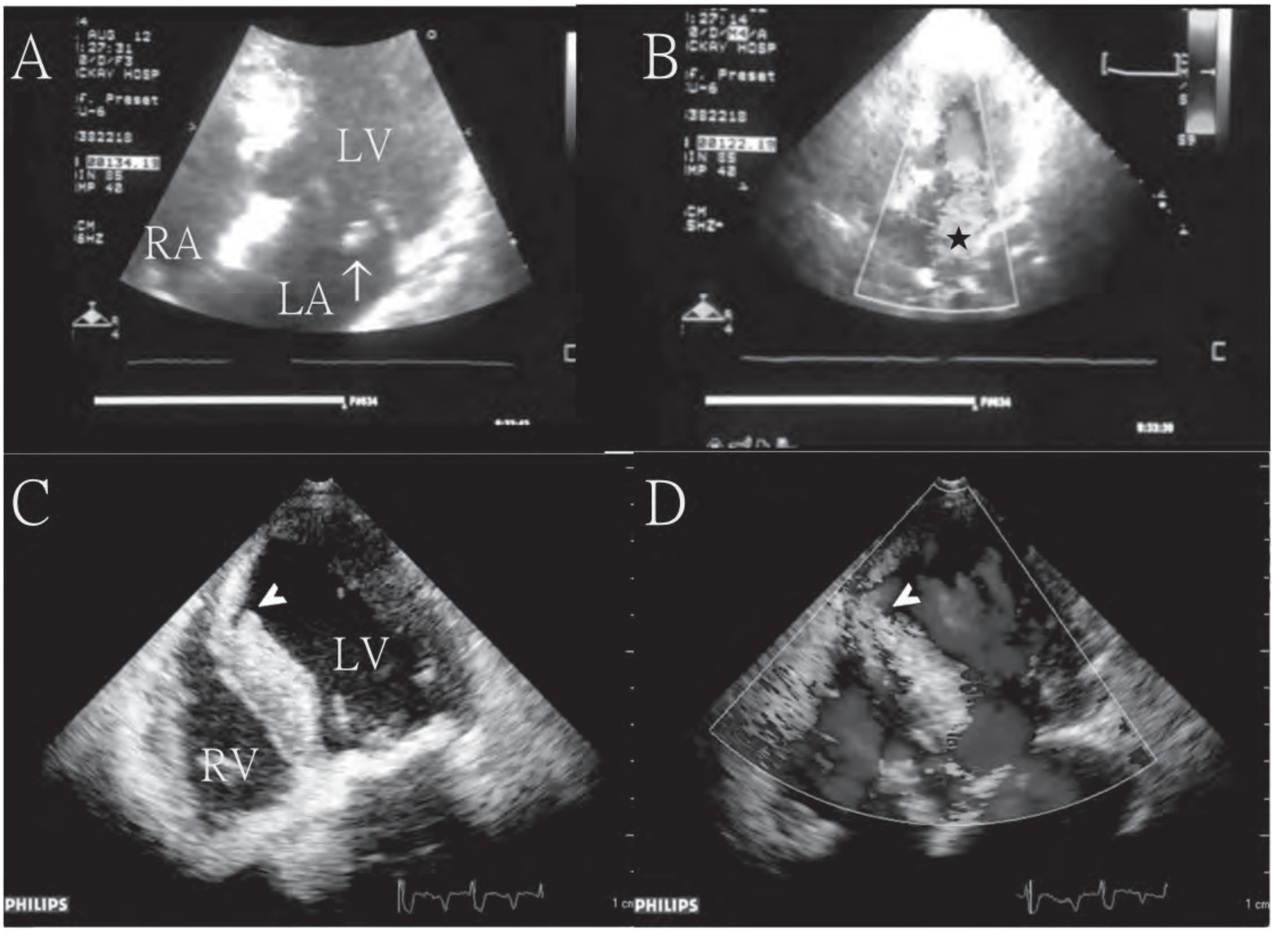

Figure 3. Echocardiographic images of mechanical complications in acute myocardial infarction.
(A) and (B) revealed the echocardiographic findings in a patient with papillary muscle rupture. Drop of fragmented head of papillary muscle into LA in systole (white arrow) with severe mitral regurgitation (black star) were showed. (C) and (B) demonstrated the images in a patient with ventricular sepal rupture. White arrowhead pointed out the defect and left-to-right shunt at apical interventricular septum.
LV, left ventricle; LA, right atrium; RV, right ventricle.

easily to exclude cardiogenic shock in who have ongoing hypotension or shock but significant abnormal cardiac structure is absent and cardiac systolic function is preserved. It was also suggested to be the preferred modality to initially evaluate the type of shock as opposed to more invasive technologies.[12] Many cardiac abnormalities could lead to hemodynamic compromise and early diagnosis is urgent to stabilize these patients. (Table 1) For example, shock or even cardiovascular collapse could not be relieved in cardiac tamponade if not draining out the fluid. Echocardiography is also important in locating the safe puncture site of pericardiocentesis. Severe left ventricular hypertrophy with signs of dynamic left ventricular outlet obstruction detected by echocardiography can point out hypertrophic cardiomyopathy as the cause of hemodynamic compromise. Pulmonary embolism may lead to hypoxia, shock or sudden death. Current published guideline suggested evaluating the presence of right ventricular (RV) dysfunction as an important component in stratifying the risk of these patients.[13] Echocardiographic findings of RV dysfunction include RV dilation and/or ratio of end-diastolic RV to LV diameter > 0.9 or 1.0, RV free wall hypokinesis , increased velocity of tricuspid regurgitation jet. Hypokinesis of RV free wall with sparing RV apex (McConnell's sign) may be found in massive pulmonary embolism. Among the cases with unknown causes of shock or receiving cardiac resuscitation, clinical condition may be too unstable to perform chest computed tomography. Echocardiography usually can be used to rule out massive pulmonary embolism as the major etiology of shock if the above typical findings are absent. Moreover, thrombolytic therapy could be considered in whom with shock and RV dysfunction.

Determining Fluid Responsiveness in Shock

In the patients with hypotension or shock, intravenous fluid resuscitation is often the initial management. However, inappropriate over-challenge of fluid could be harmful. Traditionally, many static parameters such as central venous pressure, pulmonary capillary wedge pressure and global end-diastolic volume were used to guide whether further fluid challenge necessary. As mention above, E/E' has also good correlation to LV filling pressure. However, these static parameters were not proved their ability to predict the fluid responsiveness. Otherwise, dynamic parameters such as stroke volume variation, pulse pressure variation were showed to have better power for this purpose but the obtain of these parameters usually need the equipment with artery pressure contour analysis. Echocardiographic demonstration of respiratory variation of inferior vena cava diameter in the patients with shock and mechanical ventilation can be used to predict fluid responsiveness. [14,15] Responsiveness of fluid challenge can also be predicted by evaluation the change of aortic velocity-time integral (which is in proportion to stroke volume) using Doppler images of echocardiography before and after passive legs raising test.

The Patient Receiving Venous-artery Mode of Extracorporeal Membrane Oxygenation System (VA-ECMO)

In the patient with profound cardiogenic shock, mechanical support with VA-ECMO can be used to bridge to recover or heart transplantation. Echocardiography is useful to monitor absence of aortic valve opening and LV distension, which may initiate the attempts of LV decompression.[16] Frequent evaluation of cardiac function by echocardiography should be performed to avoid the inappropriately prolong use of VA-ECMO.[17] VA-ECMO system should be weaned and removed as soon as possible if echocardiography indicate the recovering of cardiac function and other clinical indicators are acceptable, for examples, stable blood pressure with low dose of vasopressors and normal serum lactic acid. Although there is no consensus of weaning criteria, Aissaoui N et al suggested that those passed ECMO weaning trial with minimal blood flow and aortic VTI $\geq$ 10 cm, LVEF > 20–25%, and lateral mitral annulus peak systolic velocity $\geq$6 cm/s may tolerant to removal of ECMO.[18]

Conclusion

Echocardiography is a convenient and easily available tool to evaluate the cardiac structure and function. Due to the ongoing development of technologies and modalities, the applications of this tool are more widespread, regardless of outpatient or critical care populations. It is not only the specialty of cardiologist, but also important in clinical practice when attending patients with emergent and critical conditions. Promotion and generalization of focused echocardiography may make the decision making of physicians more effective and confident.

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心臟超音波的應用：從門診到床邊重症照顧

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摘 要

心臟超音波在臨床上廣泛地被使用。在這篇文章中，我們對近年來這檢查方法的新的發展作一個簡要的回顧，其中包括組織都卜勒影像、班點追踪影像和三維心臟超音波。並從一般門診到重症族群，如心臟衰竭、急性心肌梗塞和休克等病患，說明心臟超音波的臨床使用。