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Echocardiography for the assessment of unexplained perioperative hypotension

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Abstract

Minor and major perturbations in hemodynamic status are commonplace in the perioperative period. Arguably, of all the noninvasive (and invasive) diagnostic modalities available in the clinician's armamentarium, echocardiography in all its forms – when used and interpreted appropriately, is rapidly able to provide the clinician with the data necessary to formulate therapeutic plans in the critically ill patient. This review aims to provide the non-cardiac trained anesthesiologist and intensivist a brief introduction to the utility of this readily available tool in the perioperative period.

Keywords: echocardiography-transthoracic, echocardiography-transesophageal, hypotension, shock, tamponade

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Introduction

The use of echocardiography in the management of the unstable patient is not new. Hallmarks of the perioperative period include fluid shifts and constantly changing hemodynamics – both of which are very easily assessed using either form of echocardiography: transthoracic (TTE) or transesophageal (TEE). This manuscript aims to provide the general anesthesiologist a broad overview of some of the applications of echocardiography (primarily TEE), in the assessment of the hemodynamically unstable patient.

The hemodynamically unstable patient presents many challenges. In the perioperative period, the clinical setting determines the approach to the patient: acute *vs* chronic; trauma *vs* non-trauma. Systemic hypotension is a common problem in critically ill patients and, regardless of etiology, almost always demands a prompt and appropriate therapeutic intervention. This, of course, is dependent on determining its etiology. Even in the presence of full invasive hemodynamic monitoring, the relative contributions of left and right ventricular systolic and diastolic function, diminished preload and afterload (and the effects of anesthetic drugs on all of the above) are often unclear in the unstable patient. The use of TTE or TEE in this situation is helpful to effectively complement the available data and aid the clinician in the analysis of the key question: *is the cause of the hypotension cardiogenic or non-cardiogenic?*

Unlike the relatively stable situation of the cardiology echocardiography laboratory, the unstable, hypotensive patient in the operating room (OR) or intensive care unit (ICU) presents the challenges of multiple confounding factors of positive pressure ventilation, sedation, cardiac pacing (and its sequelae), the use of multiple inotropic and vasoconstrictive medications, and the alterations in carbon dioxide tensions – all of which dramatically alter ventricular loading conditions to a much greater degree than in routine echocardiologic practice. The end result is a radically altered circulatory homeostasis, and even more dynamic echocardiographic findings [1]. The OR and/or the ICU echocardiographer must consider all these factors before accurate image interpretation can be made. Thus, what is "normal" in the non-operative, non-intensive care unit settings, may not necessarily apply. In the patient

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with an acute, persistent and life-threatening hemodynamic abnormality, the emergent use of intraoperative or perioperative TEE has now been given a class 2a level of recommendation in the 2007 American College of Cardiology/American Heart Association (ACC/AHA) Perioperative Guidelines [2].

Mode of echocardiography

Trans-Thoracic Echocardiography (TTE)

In the unstable patient, more often than not, the first option available depends on the clinical arena – emergency department, trauma room, or general medical, surgical or cardiothoracic intensive care unit. In such settings, the TTE has the immediate advantage of ease of use, non-invasiveness, and the relatively lower operator skill that is required compared with TEE. Basic views – parasternal, apical, subcostal and suprasternal – can be obtained while resuscitation is being performed.

However, TTE also has multiple limitations. Frequently, images obtained from the TTE approach are inadequate, inaccessible or equivocal. Typical situations are in obese patients, due to mechanical interference from dressings, tapes, drains and chest tubes. Patients with severe COPD as well as large pneumothorax also make image generation with TTE difficult. Perhaps the biggest disadvantage of TTE is that it is technically impossible to maintain a stable, unchanged transthoracic window for prolonged periods. If TTE is the only option, some degree of improvement can be obtained in image quality using IV contrast.

Trans-Esophageal Echocardiography (TEE)

TEE is able to overcome all of the above-mentioned TTE shortcomings, in addition to providing much higher resolution images. However, additional training and expertise related to probe insertion are relative disadvantages. Additionally, insertion of the TEE is relatively invasive, and care must be exercised to avoid injury to the pharynx, esophagus and stomach. Even in the unstable patient, if the clinician suspects any esophageal pathology such as recent esophageal or antral surgery, strictures, bleeding esophageal varices or penetrating trauma to the chest, the esophageal intubation should not be attempted until a thorough evaluation of the upper gastrointestinal tract integrity has been performed. The trachea of an uncooperative or hypoxemic patient may need to be intubated and the lungs may need to be mechanically ventilated for a thorough TEE examination. Rare complications related to TEE probe insertion include cardiac arrhythmias, myocardial ischemia, pulmonary aspiration, bronchospasm and tracheal or great vessel compression/displacement (primarily in the pediatric population), esophageal rupture, and injury to esophageal varices, leading to hemorrhage [3, 4]. Although the acoustic windows for TEE are unquestionably superior to TTE, it has several limitations – TEE routinely underestimates true intracardiac volumes, foreshortens the left ventricular (LV) apex and is extremely poor in imaging the distal ascending aorta [5].

Portable devices (hand-held echo, HHE) are new to the clinical arena and are already being used in central venous cannulation, abdominal paracentesis in the trauma ER, ultrasound guided thoracentesis as well as quick cardiac triage in the battlefield situation. We can expect a much greater role for these devices in the future. It must be emphasized that these devices, which range in size from portable machines on wheels to pocket-sized imaging devices, are not a substitute for the gold standard (stationary high-end, comprehensive echo systems). Current pocket-sized devices offer diagnostic quality 2D imaging, as well as Doppler (Color and Pulse) (Table 1) [6].

Table 1. Indications for portable and pocket sized echo devices

1.	Complement to a physical examination in the coronary and intensive care unit.
2.	Tool for a fast initial screening in an emergency setting.
3.	Cardiologic counselling in- or outside healthcare facilities and hospitals.
4.	First cardiac evaluation in ambulances.
5.	Screening programmes in schools, industry and community activities.
6.	Triaging candidates for a complete echocardiographic examination.
7.	Teaching tool.
8.	Semi-quantification of extravascular lung water.

From: Sicari et al. Eur J Echocardiogr 2011; 12: 85-87

HHE have some obvious advantages: they are lightweight, battery powered and relatively inexpensive. They are best viewed as an extension of the physical examination and particularly useful in focused examinations as well as aiding in central venous cannulation and other procedures in the clinical arena [7].

Cardiac examination

Regardless of the etiology of hypotension in the perioperative period (acute *vs* chronic, trauma *vs* non-trauma, post-cardiac surgery *vs* non-cardiac surgery), a thorough and consistent exam has to be performed on every patient, although one might have a clinical suspicion focusing on one or more areas. For example, in the patient with chest trauma, the most significant

injuries that must be excluded are pericardial tamponade, aortic dissection, lung contusion or pneumothorax from fractured ribs, and a range of cardiac traumatic injuries, from myocardial contusion to penetrating cardiac trauma, valve injuries and cardiac rupture.

The core elements of the exam regardless of modality (TTE vs TEE) in the evaluation of the hypotensive patient are:

Left ventricle (LV): internal dimensions (end-systolic and end-diastolic volumes), segmental wall motion abnormalities, estimates of systolic function (including ejection fraction) and diastolic filling parameters.

Aortic valve and root: aortic valve anatomy and function, aortic root appearance and dimensions.

Mitral valve and left atrium: mitral valve apparatus, leaflet anatomy, evidence of stenosis or regurgitation, left atrial size, pulmonary vein flows in both upper and lower right and left sided veins, presence of atrial appendage thrombi.

Right heart function assessment: right ventricular wall thickness, size and systolic function (qualitative), right atrial size, inferior vena cava size, tricuspid valve assessment, estimation of pulmonary artery pressure from the tricuspid regurgitant jet.

Ascending and descending aorta assessment: keeping in mind that the distal ascending aorta is poorly visualized with TEE, evaluation of aortic atheromata.

Pulmonary artery assessment: rule out presence of pulmonary emboli in major branch arteries.

Right and left chest assessment: rule out presence of pleural effusions, pneumothorax, hemothorax.

Pericardial assessment: rule out effusion/tamponade.

TEE-aided assessment of volume status in the hypotensive patient

The pulmonary artery (Swan-Ganz) catheter is still widely used and is possibly the gold standard in monitoring volume status of the unstable patient, and especially in assessing the adequacy of volume resuscitation. However, the pulmonary artery catheter is associated with multiple pitfalls, especially in the assessment of preload. TEE, on the other hand, has the added advantage of being able to assess both wall motion and valvular function simultaneously. Left ventricular end-diastolic volume, left ventricular end-diastolic area, inferior vena cava size, and fluid responsiveness are essential to adequately assess volume status by TEE. Criteria to diagnose hypovolemia include an end-diastolic diameter < 25 mm, systolic obliteration of the LV cavity, and an end-diastolic area < 55 sq cm [8]. These measurements are easily obtained from the transgastric mid-papillary short axis view (Fig. 1).

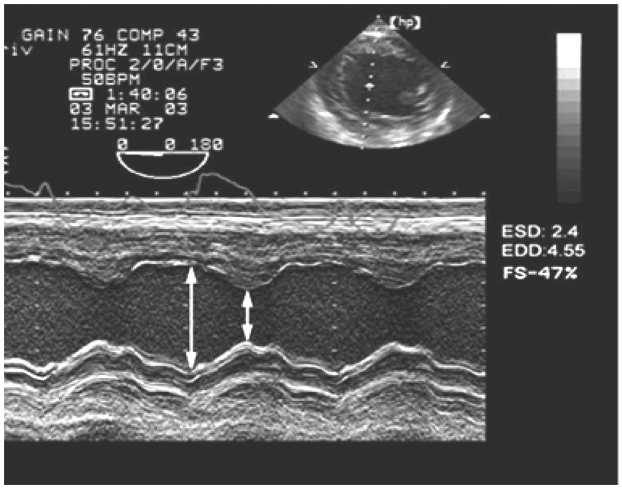

Fig. 1. Fractional shortening: ESD – end systolic diameter, EDD – end diastolic diameter. Long arrow: end-diastolic diameter; short arrow: end-systolic diameter

TEE-aided assessment of ventricular contractility in the hypotensive patient

TEE is invaluable in the assessment of global and focal systolic function. Some qualitative methods of contractility assessment include measurement of ejection fraction, fractional shortening, fractional area change, dP/dt using the mitral regurgitant jet and Tissue Doppler imaging. The latter two techniques are not generally employed in hemodynamically unstable patients.

Ejection fraction: this is obtained by dividing the stroke volume by the end-diastolic volume. Echocardiographically, the stroke volume is calculated as the difference between the end-diastolic and end-systolic volumes. The modified Simpson's method [5] is often used for this purpose, which calculates the ejection fraction in two perpendicular planes and averages them. With TEE, the mid-esophageal four-chamber and two-chamber planes are used most commonly.

Fractional area change (FAC): this is calculated using the mid-papillary transgastric short-axis view, measuring the left ventricular end-diastolic and end-systolic areas, and is expressed as: FAC = LVEDA-LVESA/LVEDA, calculated as % (Fig. 2, 3). FAC = (9.76-4.69)/9.76 (*100) = 52%.

This measure is heavily afterload-dependent and, to a lesser degree, preload-dependent.

More complex indices of contractility include the systolic index of contractility (dP/dt) as well as Tissue Doppler Imaging (TDI), which are less commonly used in the acutely unstable patient. TDI is a well established pulse-wave Doppler tool, used to assess left ventricular diastolic function, conventionally used in conjunction with transmitral inflow measurements. It has the

advantage of being relatively preload independent, measuring mitral annular motion. However, these tools are labor intensive and not generally used in the critically ill and unstable patient.

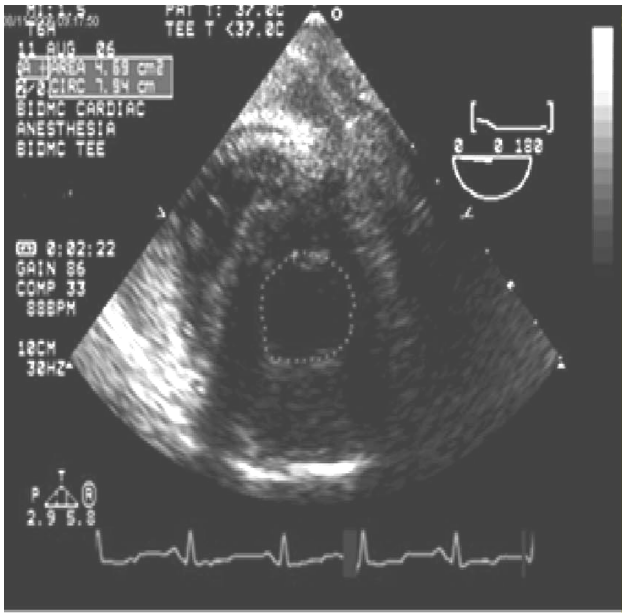

Fig. 2. Fractional area: systole, the traced out area above represents the end systolic area of the LV

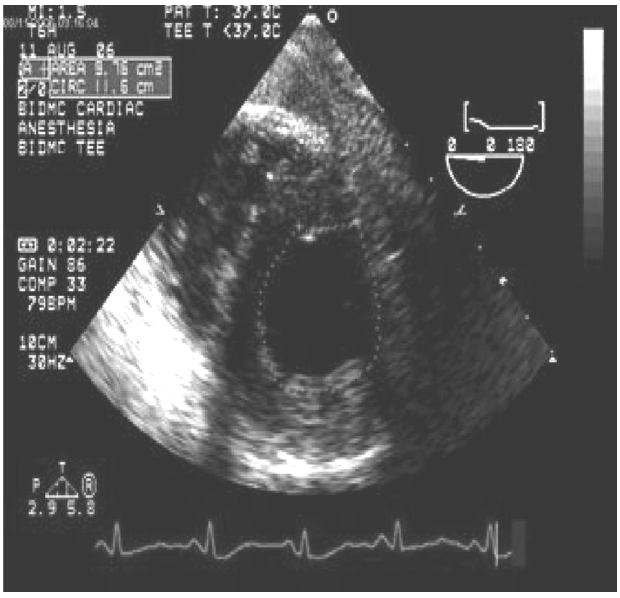

Fig. 3. Fractional area: diastole, the traced out area above represents the end diastolic area of the LV

Right Ventricle (RV) assessment: RV assessment is crucial in the hemodynamically unstable patient. The mid-esophageal 4-chamber view, RV inflow-outflow view, transgastric short axis and transgastric inflow views are the typically obtained views. The RV mid-esophageal 4-chamber view tends to provide the most immediate information pertaining to the RV size, thickness, volume and function from base to apex.

Afterload assessment: this is accomplished relatively easily, and afterload can be assumed to be low in the setting of a low MAP (mean arterial pressure), normal LV end-diastolic diameter in conjunction with a collapsing LV at end-systole.

Use of TEE in specific diagnostic situations

Pericardial effusion and tamponade

Echocardiography, in any mode (TTE or TEE), is exquisitely sensitive and specific in the diagnosis of constrictive and restrictive physiology. The most sensitive finding in tamponade is RV collapse during diastole, particularly in conjunction with right atrial inversion. Pulse wave Doppler is even more sensitive, particularly in the spontaneously breathing patient, with variation of RV inflow and LV inflow with inspiration and exhalation.

Pulmonary embolism (PE)

Echocardiography is not the gold standard for the diagnosis of PE; however, in the acutely unstable and hypotensive patient, both forms of echo may provide invaluable clues to the etiology of the instability (particularly in the hypotensive and hypoxemic patient). TEE has a sensitivity of 71% and a specificity of 81% for the diagnosis of PE [9-11], but it is uncommon to be able to visualize the thrombus unless it is in the proximal main right or left pulmonary arterial trunks. In addition, indirect signs of right ventricular failure – flattening of the interventricular septum, dilatation and hypokinesis of the RV, worsening tricuspid regurgitation and right atrial dilatation – all might point to the diagnosis of PE [12, 13].

LV outflow tract obstruction

LV outflow tract (LVOT) obstruction is an under-recognized entity in the intensive care unit. The typical patient has longstanding, poorly controlled hypertension or significant aortic stenosis, which leads to a non-dilated, hypertrophic, and hyperdynamic LV. A small LVOT and a long anterior mitral leaflet will predispose to systolic anterior motion of the mitral valve apparatus (Fig. 4).

In such a situation, there is a very high velocity ejection, causing Venturi effect in LVOT. The anterior mitral leaflet is pulled into the LVOT during ventricular ejection, resulting in a late-peaking intracavitary gradient. The forward blood flow through the aortic valve is interrupted, and there is unimpeded mitral regurgitant flow. The dynamic LVOT obstruction is exacerbated by tachycardia and by use of inotropic agents, or when the preload and afterload are reduced [13].

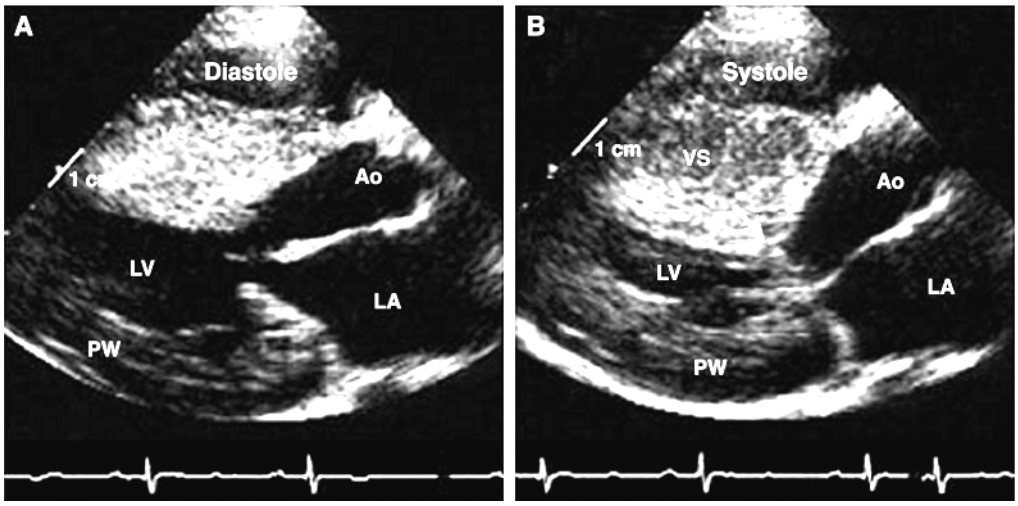

Fig. 4. LVOT obstruction in severe hypertrophic cardiomyopathy
(after Nishimura RA, Holmes DR Jr. N Engl J Med 2004; 350: 1320-1327)

The echocardiographic findings are systolic anterior motion (subvalvular or valvular) and bidirectional turbulent jets (LVOT and mitral regurgitation), and this is best appreciated in the mid-esophageal long-axis view of the LVOT and the mitral valve. There is a variable amount of mitral regurgitation and outflow obstruction, and there is an intracavitary gradient with a mid-systolic closure of the aortic valve. Decreasing or stopping the inotropic support altogether, initiation of vasopressor therapy, or if possible, beta blockade are the keys to the management of systolic anterior motion/ LVOT obstruction [13].

Aortic dissection

Regardless of etiology, aortic dissection is a leading cause of hemodynamic instability in the perioperative period. TEE signs of aortic dissection include aortic insufficiency, presence of a flap in the aorta (likely the origin of dissection), presence of false and true lumens, and involvement of the arch vessels, cardiac function, and pericardial effusion/tamponade. The important echocardiographic caveat to keep in mind when imaging aortic dissection is to visualize the dissection flap in two orthogonal planes and to be aware of artifacts.

Conclusion

The hemodynamically unstable patient presents many challenges in the perioperative period. Echocardiography in any form has been proven over the years to be instrumental in making rapid diagnoses, particularly in the patient with acute hemodynamic instability. Echocardiography is able to aid the clinician with the answer to the question, "why is the patient hypotensive?" The skilled clinician must however take into consideration the entire clinical picture, which is usually rapidly evolving, and must employ a comprehensive echo technique, using 2D echo as well as all indicated Doppler techniques that are essential in making quantitative diagnoses that involve intra cardiac pressures and hemodynamic parameters.

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Ecocardiografia pentru evaluarea unei hipotensiuni perioperatorii inexplicabile

Rezumat

În perioada perioperatorie apar frecvent modificări ale hemodinamicii, minore sau majore. Dintre toate modalitățile neinvazive (şi invazive) de diagnostic aflate în armamentariumul clinicianului, ecocardiografia în toate modalitățile sale, dacă este utilizată şi interpretată adecvat, oferă rapid datele necesare pentru formularea planului terapeutic la pacientul critic. Prezentul referat are scopul să ofere anesteziologului şi intensivistului neantrenat cardiologic o scurtă introducere asupra utilității unui instrument aflat la îndemână în perioada perioperatorie

Cuvinte cheie: ecocardiografie-transtoracică, ecocardiografie-transesofagiană, hipotensiune, şoc, tamponadă