Echocardiographic assessment of cardiovascular failure

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In the last few years echocardiography has gained an increasing role in critical care settings as invaluable tool for hemodynamic assessment of the unstable patient, due to its unique features of dynamic bedside imaging technique which can yield both morphologic and functional information. The main characteristics of cardiovascular function can be thoroughly explored, and a practical clinically-oriented approach can lead to answer the crucial questions of patient management, integrating (and often substituting) invasive monitoring, and allowing invasive monitoring pitfalls correction. Therapeutic impact of transesophageal echocardiography (TEE) has proven to be substantial in intensive care unit (ICU) population, although large randomized controlled studies are currently missing. Echocardiography requires specific training, but short training focused on the key hemodynamic information obtained from the shocked patient is proving to be effective. Echocardiographic hemodynamic evaluation should become part of routine assessment in the ICU soon, and critical care teams could achieve a hierarchic organization with respect to echocardiographic skills, with all members being at least able to perform a basic ultrasound examination of the heart, and a fewer who have gone through higher level formal training and board certification.

Key words: **Bedside ultrasonography - Heart failure, congestive - Critical care - Echocardiography - Intensive Care Unit - Hemodynamics - Echocardiography, transesophageal.**

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In recent years, bedside ultrasonography has gained wide acceptance as a precious tool in the management of the critically ill patient, and among its many applications, echocardiography (ECHO) is of course the one with the greatest yield of high-clinical impact information when cardiovascular omeostasis is jeopardized by illness.[1-24] The growing spread of this technique among intensivists and emergency physicians has also been enhanced by technical advances in ultrasound imaging, and by the recent availability of new generation hand carried ultrasound devices. Among hemodynamic monitoring systems, ECHO has the unique feature of being the only one providing a bedside real time imaging of heart, besides the capability of measuring blood flow and myocardial tissue speed. Transthoracic (TTE) and transesophageal echocardiography (TEE) can both be highly effective in the intensive care unit (ICU), with the latter technique still remaining superior in terms of diagnostically in fine hemodynamic assessment of the mechanically ventilated patient.

ECHO allows a comprehensive functional

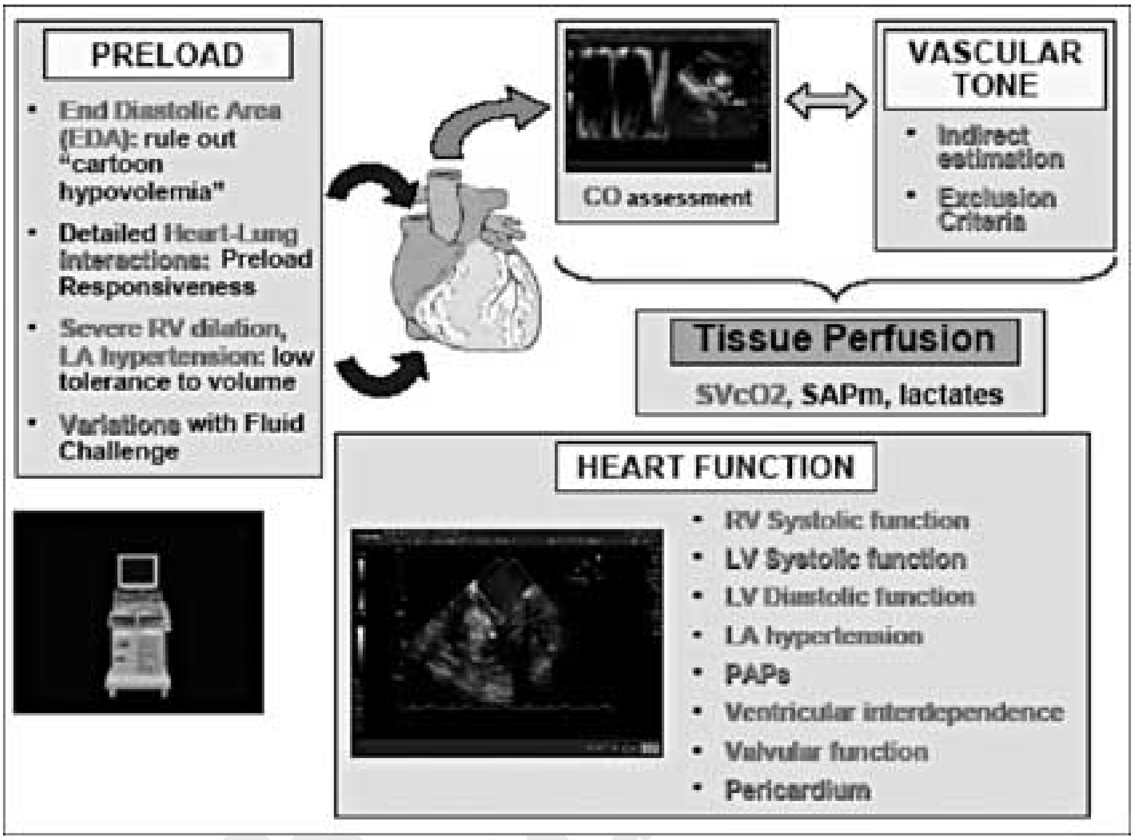

Figure 1.—Hemodynamic assessment of the critically ill patient.

Figure 2.—Information obtained by means of an ECHO exam.

hemodynamic assessment of the critically ill patient, being able to evaluate all the factors of cardiovascular function, namely: 1) preload; 2) global heart function; and 3) afterload (Figure 1); the latter with greater approximation than traditional invasive hemodynamics, (pulmonary artery catheter, PAC, the current gold standard for hemodynamic monitoring in critical care), but the first 2 with overwhelming superiority, especially with regards to preload and preload-dependency assessment, and to specific issues defining the function of the heart as an effective pump (right and left ventricular systolic function, diastolic function, valvular function, ventricular interdependence, pericardium).

A great bulk of information can thus rapidly be obtained by means of an ECHO exam in the hypotensive/inadequately perfused patient (Figure 2):

1) Evaluation of heart chamber dimensions and wall thickness of the right (RV) and left ventricle (LV) give immediate hints on the pathophysiological past of the examined heart: any dilated chamber other than the RV

witnesses a chronic process of volume or pressure overload. This may help relate the subsequent findings to an actual heart pathology or to one preceding the acute cardiovascular derangement.

2) The emptying capability of the LV (not the true inotropic state) can be reliably assessed with indexes measuring the difference between end-diastolic and end-systolic chamber dimensions (ejection fraction, EF; fractional area change, FAC) thus quantifying its systolic function.

3) RV systolic function is assessed by evaluating its size and shape (also compared to LV size) and measuring RV kinesis in a semiquantitative manner (but also a RV area shortening fraction and a tricuspid annular plane systolic excursion, TAPSE, can be measured).

4) Pulmonary arterial systolic pressure can be accurately gauged by measuring the ventricular-atrial gradient of a tricuspid regurgitant flow (even when negligible regurgitation is present), and adding it to the almost always available invasive CVP.

5) Stroke volume (SV), and thus cardiac output (CO) and index are calculated by a Doppler measurement of left ventricular outflow tract (LVOT) flow and a 2-D measurement of the transverse section of the LVOT crossed by the above mentioned flow (the product of them is equal to the SV); this only allows estimation of CO and CI, with limits of agreement with thermodilution reaching about ± 1 L/min. But in clinical practice a semiquantification of CO (*i.e.* the rough indication of very-low/ low/ normal/high CO) and accurate measurement of its variations after therapeutic manipulations (rather than an absolute value of CO), almost always fit with the bedside physician information needs.

6) Preload assessment is certainly one of the major assets of ECHO: it allows detection of severe hypovolemia (a marked reduction in both LV end-systolic and end-diastolic areas, LVESA and LVEDA), of LVEDA variations with volume status manipulations, and sensitive and specific detection of preload dependence, through measurement of respiratory LVOT flow variations, superior vena cava and inferior vena cava sizes variations, in the mechanically ventilated patient. ECHO also promptly recognizes situations of low tolerance to fluid therapy (severe RV dilation, LV elevated filling pressures).

7) Doppler analysis of mitral valve diastolic flow, pulmonary veins flow, mitral inflow propagation velocity, mitral annulus tissue velocity can give a sensitive and specific estimation of LV filling pressure, with greater reliability in the presence of systolic dysfunction. The variations of such noninvasive measurements following therapy (inotropes, volume, vasodilation etc.) correspond to the targeted LV filling pressure variations. Furthermore they can also unmask falsely elevated invasive LV filling pressures (high Wedge) in certain situations (chronic pulmonary hypertension, ventricular interdependence).

8) Accurate evaluation of valvular function can be easily obtained with imaging and Color Doppler, in order to detect gross acute valvular dysfunction (mainly LV valves) responsible for acute volume overload and associated cardiogenic shock in presence of an apparently normokinetic LV (papillary rupture or endocarditis with severe mitral valve regurgitation, aortic valve endocarditis or ascending aorta dissection producing severe regurgitation). Other gross cardiac morphologic abnormalities causing cardiovascular collapse (such as interventricular septum or free wall rupture, due to AMI or trauma) can be easily detected.

9) Diastolic dysfunction is diagnosed as the sole remaining explanation for a left atrial hypertension in simultaneous presence of elevated LV filling pressures, normokinetic small LV, and absence of acute LV valvular regurgitation. The diagnosis is also suggested by morphologic clues (significant LV hypertrophy).

10) ECHO is the test of choice for the diagnosis and management of pericardial effusion (viewed as an anechogenic space surrounding the heart); when compression of heart chambers appears, with evidence of dilated and fixed-size venae cavae, cardiac tamponade is diagnosed.

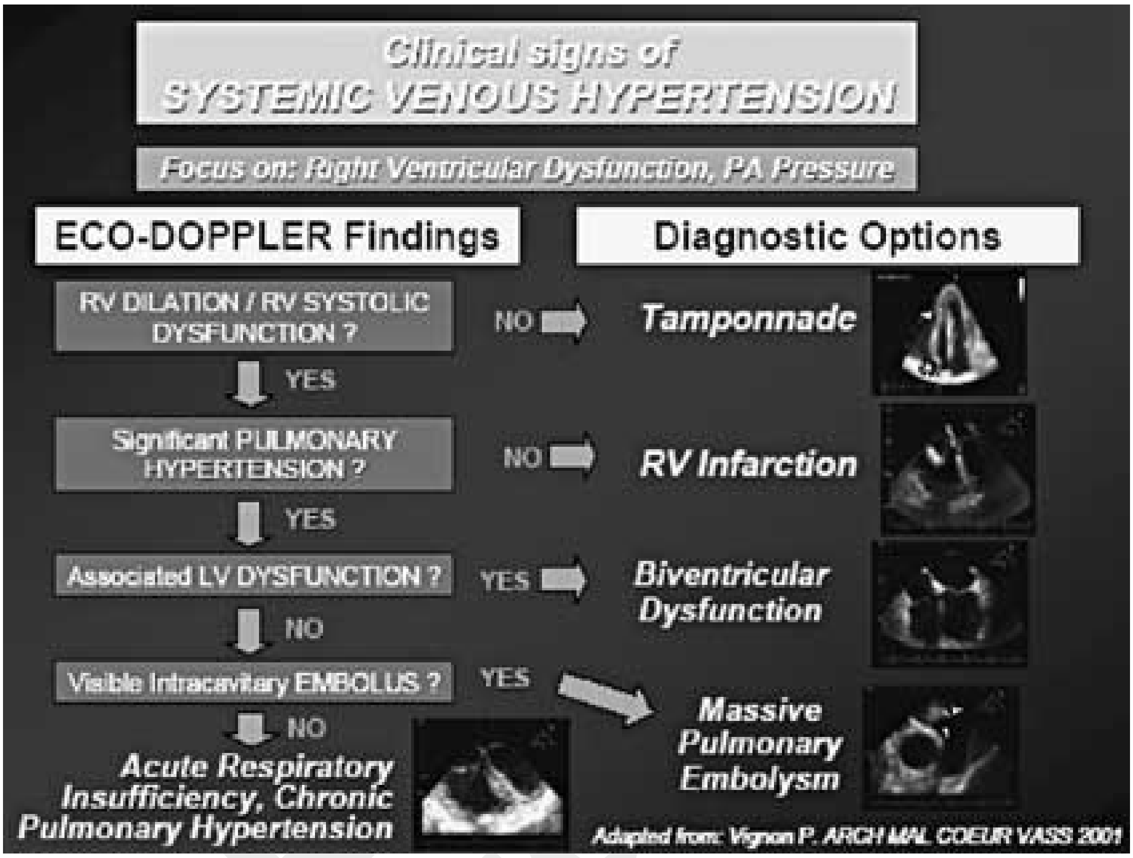

Figure 3.—Signs of systemic venous congestion.

11) Ventricular Interdependence, the left side consequence of a pathological RV process (RV dilation due to acute pressure or volume overload, in the limited space of the inextensible pericardium), is recognized in the pathological features of the RV, in behaviour of the interventricular septum, in abnormal diastolic function of the LV.

12) A state of low systemic vascular tone can finally be assumed in presence of a low LVESA coupled with a normal-high LVEDA (thus expression of a LV emptying made easier by a low afterload, and not of an empty LV), and with the exclusion criterion of hypotension with no preload dependence and no other functional abnormality.

A clinically-oriented approach to the ECHO exam in the hemodinamically unstable patient searches for the above mentioned information relying on the apparently dominating pathological cardiovascular feature, namely the signs of systemic venous congestion (Figure 3), pulmonary venous congestion (Figure 4), or neither with the suspicion of hypovolemia or vasoplegia (Figure 5). Remarkable differences exist between the ECHO assessment of cardiovascular failure and the invasive assessment with PAC, with a usually high rate of discrepancies and a frequent modification of inadequate PAC-guided therapy. Besides, its non invasive nature and quickness, undeniable advantages of ECHO consist of:

— revealing specific diagnosis (LV valvular dysfunction, LV acute ischemia, pulmonary embolism, decompensation of a pre-existing LV failure etc.) rather than classes of hemodynamic derangement (high wedge – high systemic resistances shock, high CO – low resistances shock etc.);

— providing direct imaging of the size and

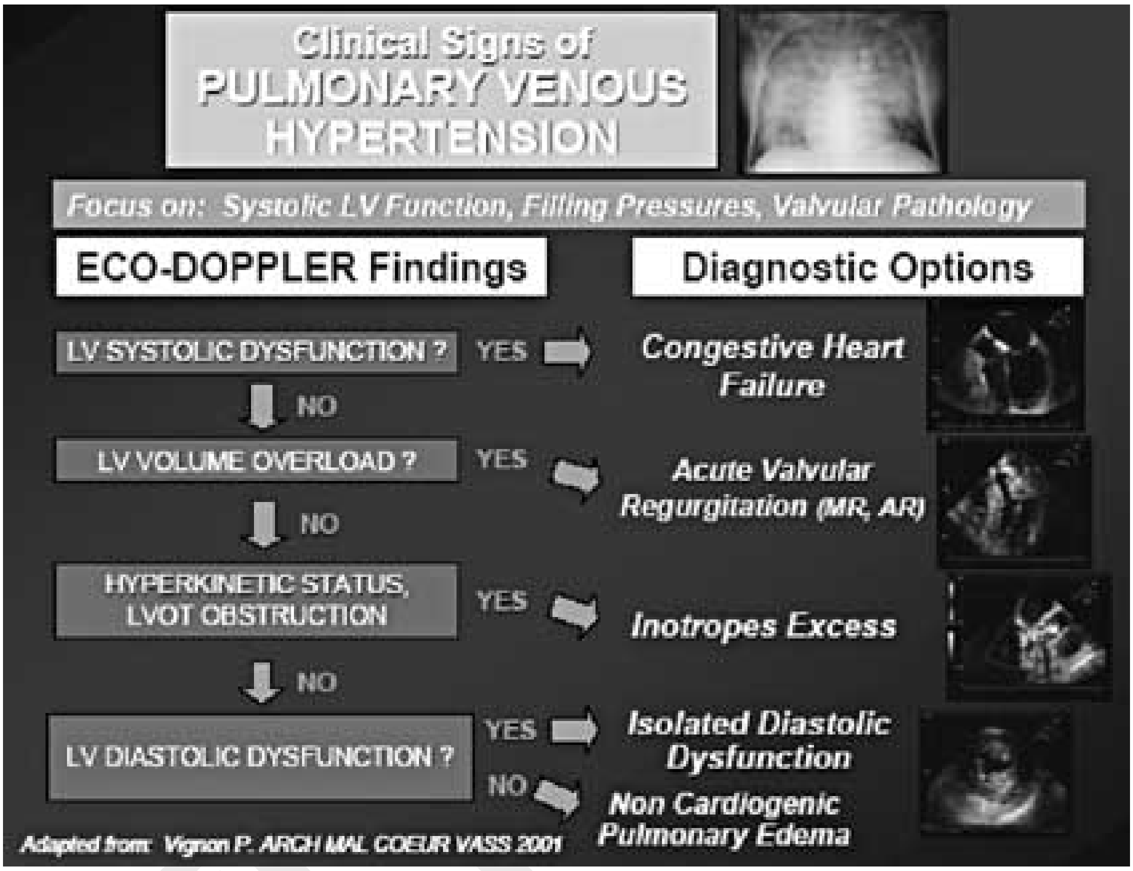

Figure 4.—Signs of pulmonary venous congestion.

wall thickness of both ventricles, thus allowing a reliable estimation of cardiac functional reserve: the same SV measured by PAC can be the output of a greatly dilated – severely hypokinetic LV (minimal reserve) rather than a normal size – normokinetic LV (great tolerance to contractile state reduction or afterload increase);

— assessing heart preload (which is volume, not pressure) better than PAC, also enabling an accurate detection of a preload dependency (*i.e.* a heart on the ascending part of the Frank-Starling curve), through a complete assessment of heart-lung interactions; it can also unmask the false positives of the pulse pressure variations technique (such as severe RV failure) through the venae cavae size variation measurement;

— unmasking major PAC pitfalls: LVOT dynamic obstruction, LV diastolic dysfunction, RV failure with ventricular interdependence share high Wedge pressures in the absence of LV systolic dysfunction, thus being unresponsive to traditional LV failure therapeutic support (vasodilation, inotropic enhancement) which is rather proven to be harmful in these situations.

Anyway, ECHO and PAC should be considered complementary techniques, being the first better for emergency hemodynamic assessment, and the latter for continuous monitoring. Although ECHO is currently not suitable for continuous monitoring, repeated assessments (especially after therapeutic interventions or sudden changes in the patient's hemodynamic status) provide the key hemodynamic information for the management of the unstable critically ill patient. Large randomized controlled studies demonstrating superiority of ECHO over other monitoring

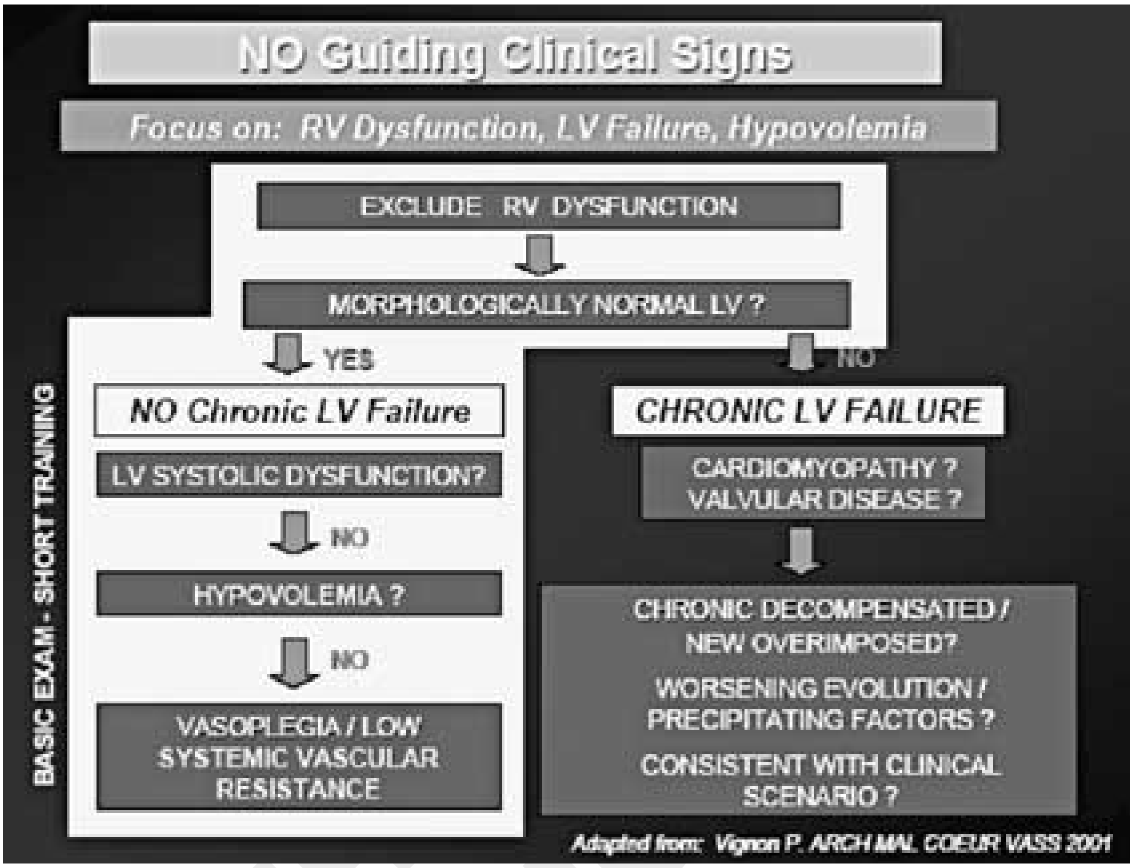

Figure 5.—Signs of hypovolemia or vasoplegia.

techniques on patients outcome are few at the moment, but overall therapeutic impact is relevant in all clinical studies performed in ICU populations, reaching 2/3 of the patients submitted to TEE (68.5% weighted mean, being therapeutic interventions either medical therapy or surgery) as recently published by Hüttemann .

ECHO is actually an operator-dependent technique, certainly requiring specific training. But contrary to sophistication of a complete cardiac examination performed in an ECHO Lab, ECHO in a shocked patient is aimed at quickly gathering the crucial rough information to decide on treatment (fluids?, inotropes? vasoconstrictors? vasodilators? diuretics?, surgery? etc.), and a short focused training has shown to be effective to reach this goal. Intensivists are not supposed to substitute cardiologists, but ECHO hemodynamic evaluation should soon become part of routine assessment in the ICU, and critical care teams could achieve a "pyramidal" organization with respect to ECHO skills, with all members being at least able to perform a basic ultrasound examination of the heart, and a few who have gone through a higher level training and board certification.

Riassunto

Valutazione ecocardiografica dell'insufficienza cardiovascolare

Negli ultimi anni l'ecocardiografia ha guadagnato un ruolo sempre più importante nell'ambito dell'assistenza al paziente critico, quale strumento insostituibile per la valutazione emodinamica del paziente instabile: Questo grazie alla sua capacità unica di fornire immagini dinamiche al letto del malato, che possono fornire informazioni sia morfologiche che fun-

zionali. Gli aspetti di base della funzionalità cardiovascolare possono essere attentamente esaminati e si può applicare un approccio clinico-pratico per rispondere alle domande fondamentali circa la gestione dei pazienti, integrando (e spesso sostituendo) il monitoraggio invasivo e consentendone la correzione degli errori. L'impatto terapeutico dell'ecocardiografia transesofagea sui pazienti ricoverati in un'unità di terapia intensiva è stato ampiamente dimostrato, sebbene manchino ancora degli studi clinici randomizzati e controllati con numerosità adeguata del campione. L'ecocardiografia richiede un addestramento specifico, ma si è dimostrato efficace anche un breve periodo di addestramento mirato ad ottenere le informazioni emodinamiche chiave nei pazienti sotto shock. La valutazione emodinamica tramite ecocardiografia dovrebbe rapidamente entrare a far parte della valutazione di routine nelle unità di terapia intensiva e il personale medico che vi opera dovrebbe raggiungere una chiara distinzione dei ruoli circa l'abilità di eseguire indagini ecocardiografiche. Tutti i membri dello staff dovrebbero essere in grado di eseguire un esame ecografico di base del cuore, mentre alcuni di essi dovrebbero specializzarsi in queste tecniche seguendo corsi di addestramento certificati.

Parole chiave: Ecocardiografia, metodi - Scompenso cardiaco - Paziente critico - Unità di Teraapia Intensiva - Emodinamica.

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