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REVIEW ARTICLE

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When appearances deceive: Echocardiographic changes due to common chest pathology

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Most indications for performing echocardiography focus on the evaluation of properties intrinsic to the heart. However, numerous extra-cardiac conditions indirectly convey changes to the echocardiographic appearance through alterations in the governing physiology. Pulmonary embolism increases pulmonary arterial pressure if a sufficient cross-sectional area of the pulmonary vascular bed is occluded. This may result in dilatation of the right ventricle and, in severe cases, concomitant early diastolic septal collapse into the left ventricle. Acute respiratory failure has been shown to yield a similar echocardiographic appearance in experimental conditions due to the resultant pulmonary vasoconstriction. Echocardiography in the presence of pulmonary disease can reveal underlying cardiac pathologies such as pulmonary hypertension that contribute to the clinical severity of respiratory distress. Positive pressure ventilation affects preload, afterload, and compliance of both ventricles. The echocardiographic net result cannot be uniformly anticipated, but provides information on the deciding physiology or pathophysiology. Mediastinal pathology including tumors, herniation of abdominal content, and pleural effusion can often be visualized directly with echocardiography. Mediastinal pathologies adjacent to the heart may compress the myocardium directly, thus facilitating echocardiographic and clinical signs of tamponade in the absence of pericardial effusion. In conclusion, many pathologies of extra-cardiac origin influence the echocardiographic appearance of the heart. These changes do not reflect properties of the myocardium but may well be mistaken for it. Hence, these conditions are essential knowledge to all physicians performing echocardiography across the spectrum from advanced cardiological diagnostics to rapid point-of-care focused cardiac ultrasonography.

KEYWORDS
2D echocardiography, acute respiratory distress syndrome, cardiac tamponade, pleural effusion, pulmonary embolism

1 | INTRODUCTION

The number of echocardiographies performed is increasing steadily. The increase in echocardiographic examinations is not confined to the cardiology specialty,[1] and point-of-care echocardiography is disseminating quickly in the fields of emergency medicine, critical care, and anesthesiology.[2] There are many indications for performing echocardiography primarily focusing on properties intrinsic to the heart such as myocardial and valve function and detection of structural pathology.[3] However, the heart as a pump is also subject

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to extrinsic influence and control such as preload, afterload, and heart rate. Therefore, all extra-cardiac pathological states and iatrogenic therapies impacting on these extrinsic determining factors affect heart function and hence its echocardiographic appearance. To ensure correct image interpretation, all physicians performing echocardiography regardless of medical speciality should know these extra-cardiac potential confounders and how they influence echocardiography.

This review aims at describing how common, extra-cardiac pathology in the chest and treatments influencing chest physiology affect the echocardiographic appearance of the heart.

2 | PULMONARY EMBOLISM

Pulmonary embolism (PE) is the most serious presentation of venous thromboembolism with an annual incidence of 1–2 cases per 1000 inhabitants. It is caused by a sudden blockage of the pulmonary arteries, usually caused by a deep venous thrombus, and may cause sudden cardiac death or lead to debilitating chronic pulmonary hypertension.[4]

Several factors such as major surgery, injury, infection, immobilization, and cancer predispose to PE.[5,6] These factors all affect one or more of the fundamental causes of thrombosis as suggested by Virchow: venous stasis, damage to the vessel wall, or increased coagulation.[7]

Symptoms of PE are often dyspnea, chest pain, syncope, and/or hemoptysis.[8] However, symptoms are nonspecific and a prediction score is often applied to evaluate the probability of PE[9] and to determine cases in need of additional diagnostic workup. Echocardiography has a sensitivity of 70% with a specificity of 57% for the diagnosis of PE, and thus, in general, not the imaging modality of choice during diagnostic workup. However, echocardiography is indicated in hemodynamically unstable patients.[10] When PE is suspected and CT-angiography is unavailable, echocardiography can detect either right ventricular (RV) dysfunction or an intracavity thrombus and treatment should be considered before other diagnostic tests are performed.[11]

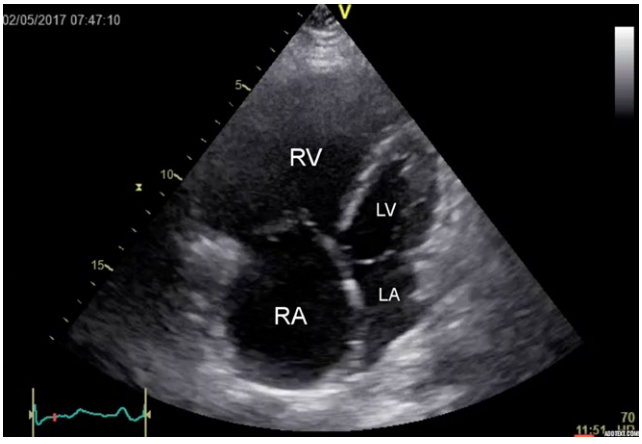

FIGURE 1 Apical four-chamber view. Dilatation of the right ventricle in chronic thromboembolic pulmonary hypertension. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle

Importantly, RV dysfunction evaluated by echocardiography is an independent predictor of 30-day mortality in hemodynamically stable patients with PE.[12] Hence, in such patients echocardiography is applied in combination with biomarkers such as troponins and the PE severity index[13,14] to risk stratify the patients into those in need of hospitalization and those to be considered for early discharge and outpatient treatment.[11]

2.1 | Pathophysiological changes to the right ventricle during pulmonary embolism

The echocardiographic characteristics of PE all reflect the abrupt changes in the pulmonary pressures that affect RV function and size. More than 30%–50% of the total cross-sectional area of the pulmonary arterial bed has to be occluded before any RV changes are detectable.[15] The mechanical obstruction causes an increase in the pulmonary resistance,[16] and thus RV afterload, which may be exacerbated by the release of vasocontrictive agents as reviewed previously.[17] The RV wall tension and oxygen demand increase while coronary oxygen delivery may be compromised due to reduced oxygen saturation and increased wall tension. The nonconditioned RV will dilate and may become dysfunctional (Figure 1); the RV ejection time increases. This causes bouncing of the septum into the left ventricle (LV) during early diastole (Figure 2), which further compromises LV filling, and hence preload.[18] Cardiac output may subsequently decrease, causing hypotension and initiate a vicious cycle that may lead to severe circulatory compromise and ultimately cardiac arrest.[19] Depending on the initial degree of pulmonary arterial obstruction, vasoconstriction and compensatory effects, the RV pressure and pulmonary artery pressure may increase and higher tricuspid regurgitation (TR) velocity is then measured. However, the nonconditioned thin-walled RV cannot increase the mean pulmonary artery pressure above approximately 40 mm Hg.[20] These changes are both quantitatively and qualitatively measurable by echocardiography although one-third of patients with confirmed PE will have normal RV appearance.[21]

In most clinical trials, several echocardiographic measures have been applied to determine RV dysfunction. In general, the findings can be divided into quantitative and qualitative.

2.2 | Quantitative echocardiographic measures

During the evaluation of PE, quantitative echocardiographic measures aim to evaluate either RV function, RV volume, or pulmonary pressure. The tricuspid annular plane systolic excursion (TAPSE) is a measurement of the longitudinal RV function[22] and is easily obtained in most patients despite poor imaging conditions.[23] RV volume can be assessed in several echocardiographic views and systolic function such as fractional area change can be evaluated.[22,24] These views include four-chamber, parasternal long (PLAX)- and

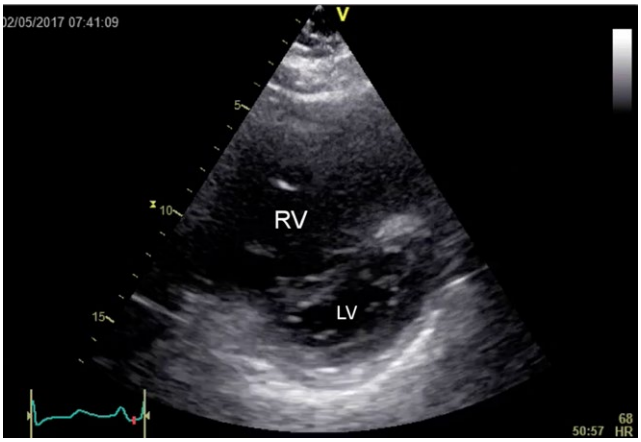

FIGURE 2 D-shaping of the left ventricle during early diastole. LV = left ventricle; RV = right ventricle

short (SAX)-axis views.[24] In the context of PE, clinical trials have reported the RV diameter in the parasternal views,[25] whereas the ratio between RV and LV diameter (RV/LV ratio) has been measured in end-diastole on 2D recordings of the four-chamber view.[26,27] However, comprehensive RV volume assessment includes multiple echocardiographic views.[24] Several clinical trials report noninvasive evaluation of pulmonary arterial pressure. This is often estimated by continuous-wave (CW) Doppler to evaluated peak TR velocity.[25,26,28,29] The "60/60" sign is considered indicative of RV dysfunction when the estimated pulmonary artery pressure by CW Doppler of the TR jet is less than 60 mm Hg and the acceleration time in the pulmonary artery measured by pulsed wave Doppler is very short (<60 ms)[30] due to wave reflection from the occluded proximal pulmonary vasculature.[31,32]

2.3 | Qualitative echocardiographic findings

The qualitative evaluation of RV dysfunction is per se more observer-dependent.[12] Patients with the McConnell's sign display akinesia of the mid-free wall but have normal contraction at the apex.[33] This pattern differs from the global RV dysfunction in patients with chronic pulmonary hypertension (Figure 1). Early diastolic septal bounce or bowing (sometimes termed D-configuration)[26,27,34] can appear due to prolonged RV contraction time, and in addition, the septum may appear flattened during systole.[34,35] Beside these qualitative 2D signs of PE, a slow rise in peak velocity of the TR regurgitation flow-pattern may be seen and the Doppler envelope in the RV outflow tract may become notched (termed RVOT notching). This finding is, however, not specific for PE, but indicates increased pulmonary resistance which may also occur in other conditions[36] and is conceivably caused by the wave reflection from the obstructed pulmonary vasculature.[31,32]

Failure of respiratory collapse of the inferior vena cava is less used in clinical trials, but reflects central venous congestion due to increased RV diastolic pressure secondary to increased pulmonary pressure when PE is present[37] (Appendix A).

2.4 | Prognostic echocardiographic findings

The mentioned echocardiographic measures and findings all evaluate RV dysfunction, and in most clinical trials, several indices need to be present simultaneously before RV dysfunction is considered. Despite this array of echocardiographic measures, only low TAPSE[23] and short pulmonary artery acceleration time[23,38] have been shown to be independent prognostic markers of mortality, whereas the presence of a thrombus in the RV or right atrium did not aid in prediction of mortality beyond standard risk stratification indices.[39]

2.5 | Echocardiographic changes after appropriate treatment

Studies have shown that indices of RV function, including TAPSE, RV/LV ratio, TR velocity, improve or completely normalize when treated appropriately.[38,40] These studies may be prone to follow-up bias and underrepresentation of the most severely affected patients, and the American and European guidelines differ as to whether routine echocardiographic follow-up is required.[11,41]

2.6 | Novel echocardiographic measures

Recently it was shown that among echocardiographic measures of RV function, deformation analysis (strain) by 2D speckle-tracking had the best correlation ($R = -0.69$) with RV ejection fraction measured by magnetic resonance imaging as compared to conventional echocardiographic measures including TAPSE and tricuspid annular peak systolic velocity (s′), and was a good predictor of RV dysfunction.[42] In another single center study of 66 patients presenting with PE, low regional RV mid-free wall strain as well as 3D RV ejection fraction (RVEF) were independently associated with mortality, cardiopulmonary resuscitation, or acute PE recurrence in a multivariate analyses at 6-month follow-up.[43]

2.7 | Non-cardiac ultrasound findings

In patients clinically suspected of PE, diagnosis of deep venous thrombosis by compression ultrasound of the lower extremities is highly specific (99%), but sensitivity (39%) remains low for simultaneous PE.[44]

Embolic pulmonary vascular occlusion may result in pulmonary infarction and atelectasis. These changes can be visualized by transthoracic lung ultrasonography. In a systematic review, sensitivity was 87% and specificity 82% for the diagnosis of PE by lung ultrasonography. However, the overall prevalence of PE in the included studies was high (61%), which may have affected the results and, importantly, multi-slice CT remained superior.[45] The routine use of combined ultrasonographic assessment of the lungs, heart, and deep veins in the lower extremities in patients with respiratory symptoms may help to identify patients with thromboembolic disease which would otherwise have been missed.[46–49]

In summary, urgent echocardiography is warranted in hemodynamically unstable patients, and patients at high risk of PE may be identified. In stable patients, RV dysfunction detected by echocardiography is a prognostic marker of poor outcome following PE. Thus, echocardiography should be prioritized before considering discharge of patients with PE regardless of biomarker levels.[11] Novel prognostic echocardiographic measures are emerging and in combination with ultrasound examination of the extremities and lungs may increase diagnostic and prognostic accuracy.

3 | ECHOCARDIOGRAPHIC CHANGES DUE TO ACUTE RESPIRATORY FAILURE

Hypoxia and hypercapnia affect the systemic, pulmonary, and coronary circulation[50] and may thus influence the echocardiographic appearance indirectly. In most clinical scenarios, the underlying pathology leading to respiratory derangement, including congestive heart failure, PE, and cardiomyopathy, dominates the echocardiographic picture. However, the isolated effects of acute hypoxia or hypercapnia have been described in experimental settings when subjecting healthy volunteers to altered inspiratory gas fractions.

3.1 | The left ventricle

Hypoxia lowers the peripheral resistance and triggers the sympathetic nervous system.[51] Moderate hypoxia ($SaO_2 \approx 76\%$) produced an increased heart rate (HR) and cardiac index (CI) and a mild increase in echocardiographic LV ejection fraction (EF) of 3%–8%.[52–56] Further evaluation of regional myocardial deformation during acute hypoxia showed increases in longitudinal, circumferential, and radial strain rates. Peak LV twist and peak apical rotation improved as well. The global increases in echocardiographic indices of contractility were most likely explained by a decrease in systemic vascular resistance rather than by changes in HR.[56]

Severe hypoxia or hypoxia in the presence of coronary disease may cause myocardial ischemia with loss of contractility; this issue has obviously not been systematically described in humans.

Moderate hypercapnia ($PaCO_2 > 60$ mm Hg) increases venous tone and thus stressed blood volume and cardiac preload.[57,58] Likewise, hypercapnia has been reported to increase the early and late diastolic transmitral flow velocities (E and A) without affecting the E/A ratio.[59] The effects of hypercapnia on LV myocardial performance were not described.

3.2 | The right ventricle

Hypoxia, hypercapnia, and acidosis mediate hypoxic pulmonary vasoconstriction resulting in a direction of blood flow away from poorly ventilated areas[60] and an increase in pulmonary resistance. As stroke volume is inversely related to pulmonary resistance and proportional to mean pulmonary perfusion pressure, the RV will increase systolic pressure to maintain stroke volume. This pressure increase results in a higher insufficiency jet across the tricuspid valve. Additionally, as the nonconditioned RV is poorly adapted to mean pulmonary pressure increases > 40 mm Hg,[11,61] pulmonary vasoconstriction may cause RV dilatation.

Netzer et al[62] subjected 35 healthy adults to 150 minutes of hypoxic breathing (11% oxygen inspiratory fraction) which caused a doubling of the RV end-diastolic area from 19 to 37 cm^2. The RV dilated gradually over the course of the hypoxic exposure in a time-dose-dependent manner. Further, a leftward shift of the interventricular septum causing D-shaping of the LV was noted after 60 minutes. However, this study is contradicted by several other studies in healthy volunteers exposed to either normobaric, hypoxic breathing (12% oxygen inspiratory fraction for 60[63] or 90 minutes[54]), or hypobaric hypoxia induced by simulated[64] or real[65] mountain climbing. In these studies, TR velocities increased significantly, but not to levels above 40 mm Hg, and RV area remained largely unaffected by hypoxia. In clinical settings, D-shaping of the LV is often attributed to pulmonary embolism, as explained previously. However, Netzer's study[62] and several porcine studies[66,67] have shown that septal D-shaping (Figure 3) may occur as a response to hypoxic pulmonary vasoconstriction, with or without hypercapnia, as well. In these studies, RV dimensions normalized within minutes after re-oxygenation.

Hypercapnia has an additive vasoconstrictive effect on the pulmonary vasculature along with hypoxia, producing steady increases in pulmonary artery pressure over time. However, the vasoconstrictive response has been reported to have a slow onset taking 1.5–2 hours to reach steady state.[68,69]

In conclusion, respiratory changes leading to hypoxia and hypercapnia decrease systemic resistance but increase pulmonary resistance. The echocardiographic results are increased measures of LV contractility which may be accompanied by RV dilatation and leftward septal deviation.

4 | ECHOCARDIOGRAPHY DURING POSITIVE PRESSURE VENTILATION

Most ventilatory strategies including positive end-expiratory pressure, continuous positive airway pressure and various patient-assisted and non-assisted modes of tidal ventilation entail positive airway pressure throughout part of or the whole respiratory cycle. As these modes of ventilation all affect cardiopulmonary interaction by raising intrathoracic pressure, and for the sake of reducing complexity, all modes will be referred to as positive pressure ventilation in the following.

Echocardiography practitioners will be familiar with the altered conditions for optimal cardiac imaging with positive pressure ventilation, caused by displacement of the heart. More importantly, positive pressure ventilation interacts directly with circulation by affecting the hemodynamic determinants of cardiac function and thereby it induces changes in the echocardiographic appearance.

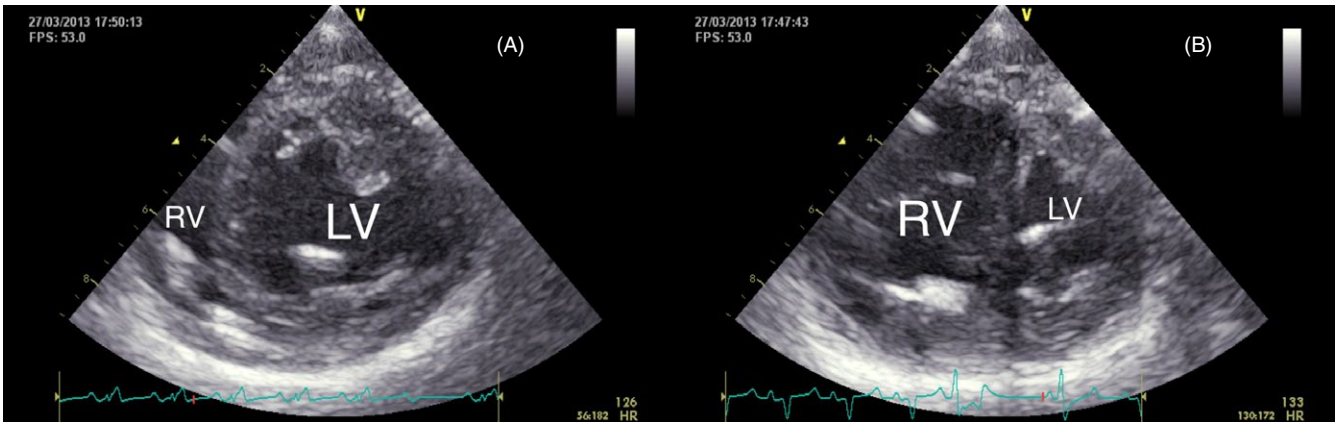

FIGURE 3 Parasternal short-axis views of an anesthetized, porcine heart at baseline (A) and after 90 s of asphyxia induced by ventilator respiratory hold (B). Flattening of the interventricular septum indicates an acute pressure increase in the right-sided circulation[66] LV = left ventricle; RV = right ventricle

4.1 | Right ventricular appearance

Echocardiographic changes to the RV are predominantly determined by alterations in pulmonary artery resistance. Enlargement,[70,71] no change or decrease in RV end-diastolic dimensions[72–74] have all been described in response to positive pressure ventilation. Cor pulmonale and consequent septal flattening may be seen in ventilated patients with severe pulmonary disease such as acute respiratory distress syndrome.[75] Likewise, the effects on RV systolic function differ[73,76] as evaluated with TAPSE, RV free wall strain, or ejection fraction. These apparently conflicting results are readily explained physiologically. Positive pressure ventilation influences pulmonary artery resistance in at least two ways. First of all, the relationship between inspired volume and pulmonary resistance is *U*-shaped, producing high resistance at low and high inspiratory volumes, whereas a nadir is seen at functional residual capacity.[77,78] The high resistance at the extremes is caused by atelectasis at low volumes and direct compression of pulmonary vasculature at high volumes, the latter representing West zone I/II physiology.[79] Secondly, positive pressure ventilation may reduce pulmonary artery resistance if alveoli, collapsed by pathological states, are recruited, hence counteracting hypoxic pulmonary vasoconstriction. In addition to the effect on pulmonary artery pressure, positive pressure ventilation reduces right ventricular transmural pressure and will tend to decrease right ventricular dimensions if the venous mean systemic pressure does not increase proportionally.[80] Hence, the resulting echocardiographic appearance of the RV relies on multiple governing factors including the patient's unstressed volume status, pulmonary function, pulmonary pathology, and the tidal volume.

4.2 | Left ventricular appearance

The end-diastolic dimensions of the LV decrease during positive pressure ventilation,[81,82] and multiple factors may contribute to this. Positive pressure ventilation reduces right ventricular preload and this will, shortly after, reduce left ventricular filling pressure. If the pulmonary artery pressure is increased concomitantly, this effect on left ventricular filling will be exacerbated. The echocardiographic result is a decrease in both early diastolic transmitral flow (pulsed Doppler E-wave) and of early relaxation velocities of the mitral valve annuli, e′.[81,82] In addition, interventricular interdependence may be of influence. If the right ventricular end-diastolic volume increases with positive pressure ventilation, pericardial constraint will keep the total heart volume constant, forcing interventricular septal leftward shift and lowering of the left ventricular end-diastolic volume.

With regard to left ventricular systolic function, positive pressure ventilation decreases LV afterload as the force necessary to eject blood is reduced.[83] Whether this affects left ventricular contractility is still debated[80] and any detectable effect with echocardiography remains to be described.

Initiation of positive pressure ventilation often demands sedation, analgesia, or both. Most commonly used sedatives including propofol, gas anesthetics, and barbiturates decrease left ventricular systolic function and may impede the HR response. These factors add to the complexity when assessing a patient receiving positive pressure ventilation with echocardiography.

In summary, positive pressure ventilation influences preload, afterload and compliance of both ventricles and the echocardiographic effects of positive pressure ventilation are results of very complex interplays. Hence, uniform echocardiographic changes due to positive pressure ventilation cannot be given but, conversely, any echocardiographic changes seen provide information on the governing physiology.

5 | CHRONIC LUNG DISEASE

Chronic lung disease is an inhomogeneous group of diseases, ranging from very common conditions such as asthma and chronic obstructive pulmonary disease (COPD) to less common such as interstitial lung diseases, multiple cystic lung diseases, granulomatosis with polyangiitis, and amyloidosis: disease severity ranges from

asymptomatic to severe chronic respiratory failure and death. The echocardiographic changes due to chronic lung disease can be directly related to chronic respiratory failure leading to pulmonary hypertension and subsequent RV failure.[84] However, studies have also described a high prevalence of unrecognized heart failure in patients with chronic lung disease.[85,86] Echocardiography can be technically challenging in patients with chronic lung diseases. This is especially the case in patients with COPD, where inadequate echocardiographic visualization correlates directly with disease severity.[87,88]

The development of pulmonary hypertension is correlated with the severity of the lung disease assessed by pulmonary function and exercise tests. Development of pulmonary hypertension is, however, not solely related to the extent of lung parenchymal involvement or respiratory failure, and pulmonary hypertension is more common in some lung diseases than others. The threshold for supplementary echocardiography in patients with chronic lung diseases should therefore be low, especially in diseases known to predispose to the development of "out-of-proportion" pulmonary hypertension, including Langerhans' cell histiocytosis, systemic sclerosis with or without interstitial lung disease, and sarcoidosis.[89–91]

Echocardiography is commonly used as the initial screening tool for pulmonary hypertension in patients with chronic lung disease, but its diagnostic accuracy is rather low and differs depending on the type of chronic lung disease. In addition, echocardiographic assessment is hampered by challenging image quality issues and the peak velocity of the TR jet can only be measured in approximately half of the patients with severe chronic lung disease. When feasible, echocardiographic can accurately estimate the pulmonary artery pressures (PAP) but only with moderate precision when compared with right heart catheterization.[92] The measurements are therefore useful for population studies but have limited value as a diagnostic tool in the individual patient. In patients with interstitial lung disease the estimation of the PAP is less accurate than on patients with obstructive lung diseases due to many false positive findings.[84]

The term cor pulmonale has previously been defined as hypertrophy of the RV, resulting from diseases affecting the function or structure of the lungs, except when these pulmonary alterations are the result of diseases that primarily affect the left side of the heart.[93] Historically, the development of cor pulmonale in patients with COPD was pathophysiologically explained by an increase in pulmonary vascular resistance. Recent studies have demonstrated that patients with COPD may develop RV hypertrophy and dilatation without concomitant presence of pulmonary hypertension (PH).[94,95] These findings have also been reported in patients with advanced lung disease prior to lung transplantation. A large proportion of these patients with obstructive lung disease or interstitial lung disease had RV abnormalities in the form of RV dilatation, hypertrophy, or systolic dysfunction. The positive predictive value of RV abnormalities for diagnosis of PH was only 39% (95% confidence interval 32%–46%) when right heart catheterization was used as the reference.[84]

Despite limitations, the noninvasive nature of echocardiography and its ability to diagnose concomitant heart disease justifies its use as an initial screening tool. Since the severity of PH does not always correlate with the severity of lung disease and unrecognized heart failure is common, a low threshold for performing echocardiography is warranted in patients with chronic lung disease.

6 | EXTRA-CARDIAC CAUSES OF TAMPONADE

Cardiac tamponade is a life-threatening clinical syndrome of varying severity related to the magnitude of cardiac chamber compression. Usually, tamponade is caused by accumulation of content in the pericardium as a result of infection, inflammation, neoplasms, trauma, or procedure complications. The extent of the clinical syndrome is related to the volume of content, the rate of accumulation, and the compliance of the pericardium.[96] However, not only pericardial content but also extra-cardiac compression of the heart can cause tamponade physiology and circulatory compromise. Regardless of the cause, echocardiography is the single most reliable diagnostic tool in the evaluation of cardiac tamponade.

6.1 | Echocardiography

In addition to the obvious advantages in the evaluation of pericardial effusions, echocardiography can indirectly evaluate some of the hemodynamic consequences in patients with tamponade. The right heart side is a low-pressure system and accumulation of fluid will often result in early diastolic collapse of the RV and late diastolic collapse of the right atrium. The intracardiac pressures are typically increased during tamponade causing abnormal interventricular septal motion and respiratory variation in ventricular chamber sizes. Compression of the cardiac chambers and reduced filling of the heart may result in increased respiratory variability in mitral inflow velocities and increased aortic outflow velocity variability (echocardiographic pulsus paradoxus). The same mechanism may contribute to inferior vena cava distension and reduced respiratory variability. Similarly, increased pulmonary vein diastolic forward flow during expiration and decreased pulmonary vein diastolic forward flow during inspiration may be observed. These changes may also be present in extra-cardiac tamponade.[97,98]

If extra-cardiac tamponade is present, echocardiography may not always be sufficient to provide a full clinical picture. Thus, chest radiography has the potential to reveal extra-cardiac pathology of pulmonary, mediastinal, or abdominal origin.[97] In addition, CT and MRI provide natural supplements to conventional chest radiography, not only to reveal detailed information about pericardial content but also to elucidate pulmonary, mediastinal, and abdominal abnormalities.

6.2 | Extra-cardiac causes of tamponade

As opposed to tamponade in relation to pericardial effusion, there are no guidelines regarding extra-cardiac causes of tamponade. The literature is sparse and primarily based on case reports. The

pathophysiology is related to cardiac chamber compression and most of the above-mentioned parameters are applicable, although significant pericardial effusion is not present.

Mediastinal tumors (Figure 4), typically lymphomas, can theoretically cause compression of all cardiac structures. However, due to mediastinal anatomy most case reports describe compression of the RVOT.[99–101] Hence, these cases do not report classical tamponade physiology and the clinical picture is rather that of right-sided heart failure.

Large pleural effusions have been reported in numerous studies to cause clinical and echocardiographic signs indicative of tamponade. Details of the pathophysiological mechanisms are covered in the section 7 *Pleural effusion*.

Herniation of abdominal content often in relation to surgery has been reported to cause cardiac tamponade through similar mechanisms as during significant pericardial effusions.[102–104] The condition can sometimes be confirmed by the ingestion of carbonated beverage during echocardiography to highlight the abdominal content in the chest. However, the condition is usually diagnosed by a combination of CT and echocardiography and the treatment is always surgery.

In conclusion, patients with clinical signs of tamponade but with no significant pericardial effusion should always undergo a thorough echocardiographic evaluation and additional imaging when suitable. Extra-cardiac causes of tamponade, although rare, should be kept in mind.

7 | PLEURAL EFFUSION

Pleural effusion is located between the two layers of the pleura and may be visualized as a hypoechoic mass in any standard echocardiographic view. Small pleural effusions may be difficult to detect but larger effusions (Figure 5A) are often found incidentally during a standard transthoracic echocardiography. When detected by incidence, a pleural effusion usually represents a clinically relevant amount of fluid.[105]

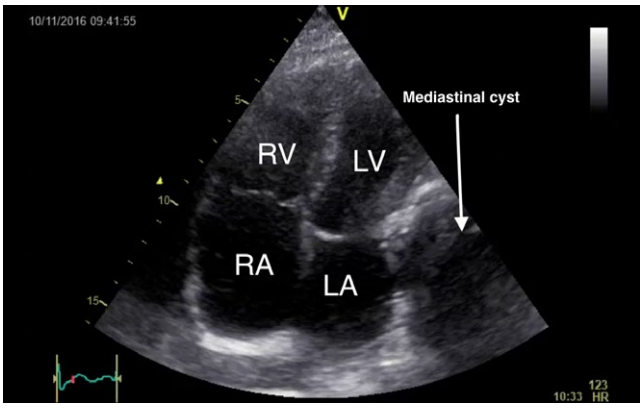

FIGURE 4 Apical four-chamber view. A calcified, mediastinal cyst compresses the left atrium resulting in a clinical picture equivalent to congestive heart failure. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle

Due to its close proximity to the pericardial sack, pleural effusion is occasionally misdiagnosed as pericardial effusion. Distinction between the two kinds of effusions is essential to avoid non-indicated pericardiocentesis (Figure 5A,B).

The easiest way to differentiate between pleural and pericardial effusions is by using the descending aorta as a landmark,[106] regardless of the view. A left-sided pleural effusion may be seen close to the descending aorta and the left atrium but will appear on the same side of both structures, ie, either posteriorly in PLAX or laterally in the apical four-chamber view. Conversely, pericardial effusions, if sufficiently large, may separate the descending aorta from the left ventricle and may be identified throughout the entire circumsphere of the heart.[105] These signs may not be clear-cut and supplementary lung ultrasonography may help to distinguish between pleural and pericardial effusions (Table 1).

Larger pleural effusions may alone or in association with small pericardial effusions produce echocardiographic changes to cardiac cavities. Several reports testify to the compression of the right atrium,[107] RV,[108] and even LV[108,109] with isolated pleural effusion. The incidence of diastolic right atrial collapse is estimated at 18% in patients with pleural effusions.[110] Right atrial collapse is normally attributed to pericardial effusion although its positive predictive value for concomitant hemodynamic tamponade depends on the duration of the collapse.[111]

Additional echocardiographic findings in patients with large pleural effusions to support tamponade physiology suspicion physiology include reduced inferior vena cava collapsibility and increased flow velocity variation during respiration across the mitral, aortic, tricuspid and pulmonary valves.[112]

Examples of pleural effusion causing hemodynamic compromise with a clinical and echocardiographic picture of tamponade have been reported.[107–109,113] In these examples, hemodynamic stability was re-established by large volume (>1000 mL) thoracenteses. The hemodynamic impact increases with the size of the pleural effusion[114] and this effect seems independent of the sidedness of effusion.[112]

Experimental data suggest that intrapleural pressure is transmitted to the pericardial space.[115] In addition, pleural effusions may exercise pressure directly on the pulmonary circulation, increasing PAP and right-sided chamber pressures[116] thus counteracting chamber collapsibility; this effect has, however, not been verified in humans.[112]

The degree of chamber compression and the resulting hemodynamic impact of pleural effusion depends on the transmural pressure gradient. Pleural effusion may itself compress the cavities of the heart, but this effect may be accelerated with concomitant diseases that reduce intracavity pressure, including Budd-Chiari's syndrome[117] or hepatopulmonary syndrome,[113] by reducing venous return or pulmonary artery resistance, respectively.

From the above it is clear that all pathological states that influence preload, afterload, and contractility, including common states such as positive pressure ventilation and dehydration, may potentiate the effects of pleural effusion. However, the pathophysiological mechanisms of how pleural effusions interact with the cardiovascular system are not well-described.

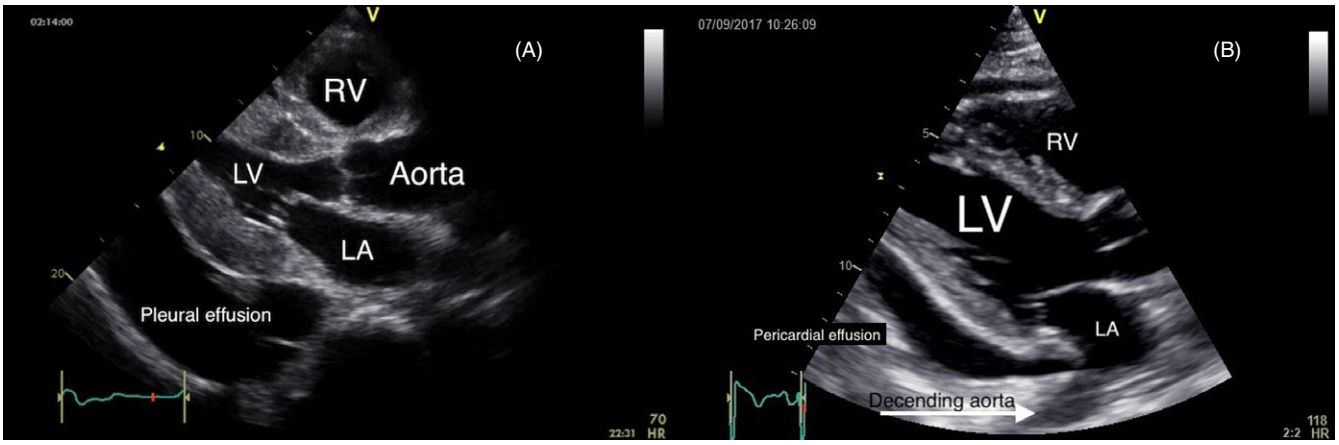

FIGURE 5 Demonstration of the ultrasonographic distinction between pleural effusion (A) and pericardial effusion (B). Pleural effusion is situated outside the mediastinum and therefore respects the interface between the left atrium and the descending aorta, whereas a pericardial effusion may separate these two structures. Note the severe left ventricular hypertrophy and dysfunction secondary to amyloidosis in A. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle

Pleural effusions are often encountered in conjunction with pericardial effusions (eg, malignancy). Large pleural effusions may increase intramediastinal pressure and accentuate the hemodynamic impact of an otherwise less significant pericardial effusion. In this case, hemodynamic instability may be alleviated by pleurocentesis, providing the opportunity to reevaluate hemodynamic and the need for pericardiocentesis.[117]

In summary, large pleural effusions are detectable in most standard echocardiographic views. Pleural effusions often coexist with pericardial effusions. A simple method to distinguish between the two in any echocardiographic view is to determine whether the effusion separates the descending aorta from the heart (pericardial effusion) or not (pleural effusion).

TABLE 1 Common locations of pleural and pericardial effusions as detected in standard echocardiographic views

Echocardiographic view	Location of pleural effusion	Location of pericardial effusion
Subcostal view	Right-sided over the diaphragmatic area of the liver	Best view to acknowledge the size of pericardial effusion, which can appear all around the heart
Parasternal long-axis view[a]	Posterior to the left ventricle and descending aorta	Circumferential or mostly posterior mass *dissecting* the left ventricle and descending aorta
Parasternal short-axis view	Large effusions may be visible laterally to the heart on either side	Usually behind the inferior wall of the left ventricle
Apical four-chamber view	Left-sided pleural effusion: lateral to the left ventricle Right-sided pleural effusion: lateral and inferior to the right ventricle	Can be located as an interrupted or unbroken circumference around the heart dissecting between the left ventricle and descending aorta.
Apical three-chamber view	Sometimes visualized posteriorly to the left ventricle and left atrium	Visible apically and posteriorly to the left ventricle
Apical two-chamber view	A large left effusion may be visible laterally and inferiorly to the LV	Visible apically and inferiorly to the LV especially in the supine patient
Mid-axillary views	Useful to estimate the volume of pleural effusion. Lung consolidation and often the descending aorta are visible through large effusions	The heart is usually not visible in this view without a considerable amount of pleural effusion

Note that pericardial effusions may present either as circumferential or regional along the circumference of the heart.

[a]Best view to distinguish pleural from pericardial effusion.

When sufficiently large, an isolated pleural effusion can facilitate classical echocardiographic signs of tamponade. The presentation of cardiac tamponade caused by pleural effusion is rare enough to pose a diagnostic challenge and echocardiography is the diagnostic modality of choice.

8 | CONCLUSION

Both common and uncommon extra-cardiac pathologies and treatment modalities alter cardiac preload, afterload, and even contractility. These conditions indirectly convey changes to the echocardiographic appearance that are not intrinsic to the myocardium, but may well be mistaken for it. Therefore, knowledge of the potentially confounding conditions and, in case of pathology, early diagnosis, are key to not only facilitating correct assessment of myocardial function and cavity volumes but may also change the overall pathophysiological conclusion and, consequently, the appropriate patient treatment completely.

Many of the extra-cardiac conditions with pronounced influence on echocardiographic appearance including pulmonary embolism, acute respiratory failure, positive pressure ventilation, and pleural effusion either directly cause or are associated with potentially severe hemodynamic instability. Hemodynamic instability warrants immediate treatment and limits the time available for a full diagnostic workup. Hence, the extra-cardiac conditions mentioned in this review are highly relevant for all physicians working with acute patients including both cardiology specialists and physicians using echocardiography merely at the point-of-care in emergency medicine, critical care and anesthesiology.

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CONFLICT OF INTEREST

All other authors have no conflicts of interest to declare.

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REFERENCES

1. Virnig BA, Shippee ND, O'Donnell B, Zeglin J, Parashuram S. Trends in the use of echocardiography, 2007 to 2011: Data Points #20 [Internet]. In: Data Points Publication Series. Rockville (MD): Agency for Healthcare Research and Quality (US); 2011. http://www.ncbi.nlm.nih.gov/books/NBK208663/. Accessed April 21, 2018.
2. Via G, Hussain A, Wells M, et al. International evidence-based recommendations for focused cardiac ultrasound. *J Am Soc Echocardiogr* 2014;27(7):683.e1–683.e33.
3. American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, et al. ACCF/ASE/AHA/ASNC/HFSA/HRS/SCAI/SCCM/SCCT/SCMR 2011 appropriate use criteria for echocardiography. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Critical Care Medicine, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance American College of Chest Physicians. *J Am Soc Echocardiogr*. 2011;24(3):229–267.
4. Cohen AT, Agnelli G, Anderson FA, et al. Venous thromboembolism (VTE) in Europe. The number of VTE events and associated morbidity and mortality. *Thromb Haemost*. 2007;98(4):756–764.
5. Rogers MAM, Levine DA, Blumberg N, Flanders SA, Chopra V, Langa KM. Triggers of hospitalization for venous thromboembolism. *Circulation*. 2012;125(17):2092–2099.
6. Schmidt M, Horvath-Puho E, Thomsen RW, Smeeth L, Sørensen HT. Acute infections and venous thromboembolism. *J Intern Med*. 2012;271(6):608–618.
7. Cervantes J, Rojas G. Virchow's Legacy: deep vein thrombosis and pulmonary embolism. *World J Surg*. 2005;29(suppl 1):S30–S34.
8. Pollack CV, Schreiber D, Goldhaber SZ, et al. Clinical characteristics, management, and outcomes of patients diagnosed with acute pulmonary embolism in the emergency department: initial report of EMPEROR (Multicenter Emergency Medicine Pulmonary Embolism in the Real World Registry). *J Am Coll Cardiol*. 2011;57(6):700–706.
9. Wells PS, Anderson DR, Rodger M, et al. Derivation of a simple clinical model to categorize patients probability of pulmonary embolism: increasing the models utility with the SimpliRED D-dimer. *Thromb Haemost*. 2000;83(3):416–420.
10. Ponikowski P, Voors AA, Anker SD, et al. 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC). Developed with the special contribution of the Heart Failure Association (HFA) of the ESC. *Eur J Heart Fail*. 2016;18(8):891–975.
11. Konstantinides SV, Torbicki A, Agnelli G, et al. 2014 ESC guidelines on the diagnosis and management of acute pulmonary embolism. *Eur Heart J*. 2014;35(43):3033–3069, 3069a-3069k.
12. Kucher N, Rossi E, De Rosa M, Goldhaber SZ. Prognostic role of echocardiography among patients with acute pulmonary embolism and a systolic arterial pressure of 90 mm Hg or higher. *Arch Intern Med*. 2005;165(15):1777–1781.
13. Aujesky D, Obrosky DS, Stone RA, et al. Derivation and validation of a prognostic model for pulmonary embolism. *Am J Respir Crit Care Med*. 2005;172(8):1041–1046.
14. Jiménez D, Aujesky D, Moores L, et al. Simplification of the pulmonary embolism severity index for prognostication in patients with acute symptomatic pulmonary embolism. *Arch Intern Med*. 2010;170(15):1383–1389.
15. McIntyre KM, Sasahara AA. The hemodynamic response to pulmonary embolism in patients without prior cardiopulmonary disease. *Am J Cardiol*. 1971;28(3):288–294.
16. Mélot C, Delcroix M, Closset J, et al. Starling resistor vs. distensible vessel models for embolic pulmonary hypertension. *Am J Physiol*. 1995;268(2 Pt 2):H817–H827.
17. Gas exchange and pulmonary hypertension following acute pulmonary thromboembolism: has the emperor got some new clothes yet? - PubMed - NCBI [Internet]. https://www-ncbi-nlm-nih-gov.

auh.aub.aau.dk/pubmed/?term=Gas+exchange+and+pulmonary+hypertension+following+acute+pulmonary+thromboembolism%3A+has+the+emperor+got+some+new+clothes+yet. Accessed August 12, 2018.

18. Marcus JT, Gan CT-J, Zwanenburg JJM, et al. Interventricular mechanical asynchrony in pulmonary arterial hypertension: left-to-right delay in peak shortening is related to right ventricular overload and left ventricular underfilling. *J Am Coll Cardiol*. 2008;51(7):750–757.
19. Lualdi JC, Goldhaber SZ. Right ventricular dysfunction after acute pulmonary embolism: pathophysiologic factors, detection, and therapeutic implications. *Am Heart J*. 1995;130(6):1276–1282.
20. Guyton AC, Lindsey AW, Gilluly JJ. The limits of right ventricular compensation following acute increase in pulmonary circulatory resistance. *Circ Res*. 1954;2(4):326–332.
21. Kurnicka K, Lichodziejewska B, Goliszek S, et al. Echocardiographic pattern of acute pulmonary embolism: analysis of 511 consecutive patients. *J Am Soc Echocardiogr*. 2016;29(9):907–913.
22. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging*. 2015;16(3):233–270.
23. Pruszczyk P, Goliszek S, Lichodziejewska B, et al. Prognostic value of echocardiography in normotensive patients with acute pulmonary embolism. *JACC Cardiovasc Imaging*. 2014;7(6):553–560.
24. Rudski LG, Lai WW, Afilalo J, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. *J Am Soc Echocardiogr*. 2010;23(7):685–713; quiz 786–788.
25. Coutance G, Cauderlier E, Ehtisham J, Hamon M, Hamon M. The prognostic value of markers of right ventricular dysfunction in pulmonary embolism: a meta-analysis. *Crit Care*. 2011;15(2):R103.
26. Meyer G, Vicaut E, Konstantinides SV. Fibrinolysis for intermediate-risk pulmonary embolism. *N Engl J Med*. 2014;371(6):581–582.
27. Grifoni S, Olivotto I, Cecchini P, et al. Utility of an integrated clinical, echocardiographic, and venous ultrasonographic approach for triage of patients with suspected pulmonary embolism. *Am J Cardiol*. 1998;82(10):1230–1235.
28. Keller K, Beule J, Schulz A, Coldewey M, Dippold W, Balzer JO. Right ventricular dysfunction in hemodynamically stable patients with acute pulmonary embolism. *Thromb Res*. 2014;133(4):555–559.
29. Sanchez O, Trinquart L, Colombet I, et al. Prognostic value of right ventricular dysfunction in patients with haemodynamically stable pulmonary embolism: a systematic review. *Eur Heart J*. 2008;29(12):1569–1577.
30. Kurzyna M, Torbicki A, Pruszczyk P, et al. Disturbed right ventricular ejection pattern as a new Doppler echocardiographic sign of acute pulmonary embolism. *Am J Cardiol*. 2002;90(5):507–511.
31. Torbicki A, Kurzyna M, Ciurzynski M, et al. Proximal pulmonary emboli modify right ventricular ejection pattern. *Eur Respir J*. 1999;13(3):616–621.
32. Furuno Y, Nagamoto Y, Fujita M, Kaku T, Sakurai S, Kuroiwa A. Reflection as a cause of mid-systolic deceleration of pulmonary flow wave in dogs with acute pulmonary hypertension: comparison of pulmonary artery constriction with pulmonary embolisation. *Cardiovasc Res*. 1991;25(2):118–124.
33. McConnell MV, Solomon SD, Rayan ME, Come PC, Goldhaber SZ, Lee RT. Regional right ventricular dysfunction detected by echocardiography in acute pulmonary embolism. *Am J Cardiol*. 1996;78(4):469–473.
34. Jardin F, Dubourg O, Guéret P, Delorme G, Bourdarias JP. Quantitative two-dimensional echocardiography in massive pulmonary embolism: emphasis on ventricular interdependence and leftward septal displacement. *J Am Coll Cardiol*. 1987;10(6):1201–1206.
35. Torbicki A, Tramarin R, Morpurgo M. Role of echo/Doppler in the diagnosis of pulmonary embolism. *Clin Cardiol*. 1992;15(11):805–810.
36. Roberts JD, Forfia PR. Diagnosis and assessment of pulmonary vascular disease by Doppler echocardiography. *Pulm Circ*. 2011;1(2):160–181.
37. Konstantinides S, Geibel A, Heusel G, Heinrich F, Kasper W, Management Strategies and Prognosis of Pulmonary Embolism-3 Trial Investigators. Heparin plus alteplase compared with heparin alone in patients with submassive pulmonary embolism. *N Engl J Med*. 2002;347(15):1143–1150.
38. Kjaergaard J, Schaadt BK, Lund JO, Hassager C. Prognostic importance of quantitative echocardiographic evaluation in patients suspected of first non-massive pulmonary embolism. *Eur J Echocardiogr*. 2009;10(1):89–95.
39. Casazza F, Becattini C, Guglielmelli E, et al. Prognostic significance of free-floating right heart thromboemboli in acute pulmonary embolism: results from the Italian Pulmonary Embolism Registry. *Thromb Haemost*. 2014;111(1):53–57.
40. Kline JA, Steuerwald MT, Marchick MR, Hernandez-Nino J, Rose GA. Prospective evaluation of right ventricular function and functional status 6 months after acute submassive pulmonary embolism: frequency of persistent or subsequent elevation in estimated pulmonary artery pressure. *Chest*. 2009;136(5):1202–1210.
41. Jaff MR, McMurtry MS, Archer SL, et al. Management of massive and submassive pulmonary embolism, iliofemoral deep vein thrombosis, and chronic thromboembolic pulmonary hypertension: a scientific statement from the American Heart Association. *Circulation*. 2011;123(16):1788–1830.
42. Lu KJ, Chen JXC, Profitis K, et al. Right ventricular global longitudinal strain is an independent predictor of right ventricular function: a multimodality study of cardiac magnetic resonance imaging, real time three-dimensional echocardiography and speckle tracking echocardiography. *Echocardiography*. 2015;32(6):966–974.
43. Vitarelli A, Barillà F, Capotosto L, et al. Right ventricular function in acute pulmonary embolism: a combined assessment by three-dimensional and speckle-tracking echocardiography. *J Am Soc Echocardiogr*. 2014;27(3):329–338.
44. Le Gal G, Righini M, Sanchez O, et al. A positive compression ultrasonography of the lower limb veins is highly predictive of pulmonary embolism on computed tomography in suspected patients. *Thromb Haemost*. 2006;95(6):963–966.
45. Squizzato A, Rancan E, Dentali F, et al. Diagnostic accuracy of lung ultrasound for pulmonary embolism: a systematic review and meta-analysis. *J Thromb Haemost*. 2013;11(7):1269–1278.
46. Laursen CB, Sloth E, Lambrechtsen J, et al. Focused sonography of the heart, lungs, and deep veins identifies missed life-threatening conditions in admitted patients with acute respiratory symptoms. *Chest*. 2013;144(6):1868–1875.
47. Nazerian P, Volpicelli G, Gigli C, et al. Diagnostic performance of wells score combined with point-of-care lung and venous ultrasound in suspected pulmonary embolism. *Acad Emerg Med*. 2017;24(3):270–280.
48. Laursen CB, Sloth E, Lassen AT, et al. Point-of-care ultrasonography in patients admitted with respiratory symptoms: a single-blind, randomised controlled trial. *Lancet Respir Med*. 2014;2(8):638–646.
49. Nazerian P, Volpicelli G, Gigli C, Lamorte A, Grifoni S, Vanni S. Diagnostic accuracy of focused cardiac and venous ultrasound examinations in patients with shock and suspected pulmonary embolism. *Intern Emerg Med*. 2017;13(4):567–574. https://doi.org/10.1007/s11739-017-1681-1
50. Boulet LM, Stembridge M, Tymko MM, Tremblay JC, Foster GE. The effects of graded changes in oxygen and carbon dioxide tension on

coronary blood velocity independent of myocardial energy demand. *Am J Physiol Heart Circ Physiol*. 2016;311(2):H326–H336.
51. Bärtsch P, Gibbs JSR. Effect of altitude on the heart and the lungs. *Circulation*. 2007;116(19):2191–2202.
52. Phillips BA, McConnell JW, Smith MD. The effects of hypoxemia on cardiac output. A dose-response curve. *Chest*. 1988;93(3):471–475.
53. Cargill RI, Kiely DG, Lipworth BJ. Left ventricular systolic performance during acute hypoxemia. *Chest*. 1995;108(4):899–902.
54. Huez S, Retailleau K, Unger P, et al. Right and left ventricular adaptation to hypoxia: a tissue Doppler imaging study. *Am J Physiol Heart Circ Physiol*. 2005;289(4):H1391–H1398.
55. Frøbert O, Moesgaard J, Toft E, Poulsen SH, Søgaard P. Influence of oxygen tension on myocardial performance. Evaluation by tissue Doppler imaging. *Cardiovasc Ultrasound*. 2004;2:22.
56. Dedobbeleer C, Hadefi A, Naeije R, Unger P. Left ventricular adaptation to acute hypoxia: a speckle-tracking echocardiography study. *J Am Soc Echocardiogr*. 2013;26(7):736–745.
57. Rothe CF, Maass-Moreno R, Flanagan AD. Effects of hypercapnia and hypoxia on the cardiovascular system: vascular capacitance and aortic chemoreceptors. *Am J Physiol*. 1990;259(3 Pt 2):H932–H939.
58. Orliaguet GA, Catoire P, Liu N, Beydon L, Bonnet F. Transesophageal echocardiographic assessment of left ventricular function during apnea testing for brain death. *Transplantation*. 1994;58(6):655–658.
59. Tzou WS, Korcarz CE, Aeschlimann SE, Morgan BJ, Skatrud JB, Stein JH. Coronary flow velocity changes in response to hypercapnia: assessment by transthoracic Doppler echocardiography. *J Am Soc Echocardiogr*. 2007;20(4):421–426.
60. Euler USV, Liljestrand G. Observations on the pulmonary arterial blood pressure in the cat. *Acta Physiol Scand*. 1946;12(4):301–320.
61. Greyson CR. The right ventricle and pulmonary circulation: basic concepts. *Rev Esp Cardiol*. 2010;63(1):81–95.
62. Netzer NC, Strohl KP, Högel J, Gatterer H, Schilz R. Right ventricle dimensions and function in response to acute hypoxia in healthy human subjects. *Acta Physiol (Oxf)*. 2017;219(2):478–485.
63. Pavelescu A, Naeije R. Effects of epoprostenol and sildenafil on right ventricular function in hypoxic volunteers: a tissue Doppler imaging study. *Eur J Appl Physiol*. 2012;112(4):1285–1294.
64. Boussuges A, Molenat F, Burnet H, Operation Everest III, et al. (Comex '97): modifications of cardiac function secondary to altitude-induced hypoxia. An echocardiographic and Doppler study. *Am J Respir Crit Care Med*. 2000;161(1):264–270.
65. Reichenberger F, Kohstall MG, Seeger T, et al. Effect of sildenafil on hypoxia-induced changes in pulmonary circulation and right ventricular function. *Respir Physiol Neurobiol*. 2007;159(2):196–201.
66. Sørensen AH, Wemmelund KB, Møller-Helgestad OK, Sloth E, Juhl-Olsen P. Asphyxia causes ultrasonographic D-shaping of the left ventricle–an experimental porcine study. *Acta Anaesthesiol Scand*. 2016;60(2):203–212.
67. Ringgård VK, Sørensen AH, Wemmelund KB, Sloth E, Juhl-Olsen P. Effects of progressive hypoventilation on left ventricular appearance: an alternative etiology of acute sonographic short-axis D-shaping. *J Ultrasound Med*. 2017;36(7):1321–1328.
68. Balanos GM, Talbot NP, Dorrington KL, Robbins PA. Human pulmonary vascular response to 4 h of hypercapnia and hypocapnia measured using Doppler echocardiography. *J Appl Physiol*. 2003;94(4):1543–1551.
69. Croft QPP, Formenti F, Talbot NP, Lunn D, Robbins PA, Dorrington KL. Variations in alveolar partial pressure for carbon dioxide and oxygen have additive not synergistic acute effects on human pulmonary vasoconstriction. *PLoS ONE*. 2013;8(7):e67886.
70. Jardin F, Delorme G, Hardy A, Auvert B, Beauchet A, Bourdarias JP. Reevaluation of hemodynamic consequences of positive pressure ventilation: emphasis on cyclic right ventricular afterloading by mechanical lung inflation. *Anesthesiology*. 1990;72(6):966–970.
71. Jardin F, Farcot JC, Guéret P, Prost JF, Ozier Y, Bourdarias JP. Echocardiographic evaluation of ventricles during continuous positive airway pressure breathing. *J Appl Physiol Respir Environ Exerc Physiol*. 1984;56(3):619–627.
72. Orde SR, Behfar A, Stalboerger PG, Barros-Gomes S, Kane GC, Oh JK. Effect of positive end-expiratory pressure on porcine right ventricle function assessed by speckle tracking echocardiography. *BMC Anesthesiol*. 2015;15:49.
73. Franchi F, Faltoni A, Cameli M, et al. Influence of positive end-expiratory pressure on myocardial strain assessed by speckle tracking echocardiography in mechanically ventilated patients. *Biomed Res Int*. 2013;2013:918548.
74. Cheatham ML, Nelson LD, Chang MC, Safcsak K. Right ventricular end-diastolic volume index as a predictor of preload status in patients on positive end-expiratory pressure. *Crit Care Med*. 1998;26(11):1801–1806.
75. Vieillard-Baron A, Schmitt JM, Augarde R, et al. Acute cor pulmonale in acute respiratory distress syndrome submitted to protective ventilation: incidence, clinical implications, and prognosis. *Crit Care Med* 2001;29(8):1551–1555.
76. Luecke T, Roth H, Herrmann P, et al. Assessment of cardiac preload and left ventricular function under increasing levels of positive end-expiratory pressure. *Intensive Care Med*. 2004;30(1):119–126.
77. Whittenberger JL, McGREGOR M, Berglund E, Borst HG. Influence of state of inflation of the lung on pulmonary vascular resistance. *J Appl Physiol*. 1960;15:878–882.
78. Canada E, Benumof JL, Tousdale FR. Pulmonary vascular resistance correlates in intact normal and abnormal canine lungs. *Crit Care Med*. 1982;10(11):719–723.
79. West JB, Dollery CT, Naimark A. Distribution of blood flow in isolated lung; relation to vascular and alveolar pressures. *J Appl Physiol*. 1964;19:713–724.
80. Luecke T, Pelosi P. Clinical review: positive end-expiratory pressure and cardiac output. *Crit Care*. 2005;9(6):607–621.
81. Juhl-Olsen P, Hermansen JF, Frederiksen CA, Rasmussen LA, Jakobsen C-J, Sloth E. Positive end-expiratory pressure influences echocardiographic measures of diastolic function: a randomized, crossover study in cardiac surgery patients. *Anesthesiology*. 2013;119(5):1078–1086.
82. Chin JH, Lee EH, Kim WJ, et al. Positive end-expiratory pressure aggravates left ventricular diastolic relaxation further in patients with pre-existing relaxation abnormality. *Br J Anaesth*. 2013;111(3):368–373.
83. Pinsky MR, Matuschak GM, Klain M. Determinants of cardiac augmentation by elevations in intrathoracic pressure. *J Appl Physiol*. 1985;58(4):1189–1198.
84. Arcasoy SM, Christie JD, Ferrari VA, et al. Echocardiographic assessment of pulmonary hypertension in patients with advanced lung disease. *Am J Respir Crit Care Med*. 2003;167(5):735–740.
85. McCullough PA, Hollander JE, Nowak RM, et al. Uncovering heart failure in patients with a history of pulmonary disease: rationale for the early use of B-type natriuretic peptide in the emergency department. *Acad Emerg Med*. 2003;10(3):198–204.
86. Rutten FH, Moons KGM, Cramer M-JM, et al. Recognising heart failure in elderly patients with stable chronic obstructive pulmonary disease in primary care: cross sectional diagnostic study. *BMJ*. 2005;331(7529):1379.
87. Wheeldon NM, MacDonald TM, Flucker CJ, McKendrick AD, McDevitt DG, Struthers AD. Echocardiography in chronic heart failure in the community. *Q J Med*. 1993;86(1):17–23.
88. Boussuges A, Pinet C, Molenat F, et al. Left atrial and ventricular filling in chronic obstructive pulmonary disease. An echocardiographic and Doppler study. *Am J Respir Crit Care Med*. 2000;162(2 Pt 1):670–675.

89. Fartoukh M, Humbert M, Capron F, et al. Severe pulmonary hypertension in histiocytosis X. *Am J Respir Crit Care Med*. 2000;161(1):216–223.
90. Mukerjee D, St George D, Coleiro B, et al. Prevalence and outcome in systemic sclerosis associated pulmonary arterial hypertension: application of a registry approach. *Ann Rheum Dis*. 2003;62(11):1088–1093.
91. Handa T, Nagai S, Miki S, et al. Incidence of pulmonary hypertension and its clinical relevance in patients with sarcoidosis. *Chest*. 2006;129(5):1246–1252.
92. D'Alto M, Romeo E, Argiento P, et al. Accuracy and precision of echocardiography versus right heart catheterization for the assessment of pulmonary hypertension. *Int J Cardiol*. 2013;168(4):4058–4062.
93. Wilkins LW. Chronic cor pulmonale: report of an expert committee. *Circulation*. 1963;27(4):594–615.
94. Himelman RB, Struve SN, Brown JK, Namnum P, Schiller NB. Improved recognition of cor pulmonale in patients with severe chronic obstructive pulmonary disease. *Am J Med*. 1988;84(5):891–898.
95. Hilde JM, Skjørten I, Grøtta OJ, et al. Right ventricular dysfunction and remodeling in chronic obstructive pulmonary disease without pulmonary hypertension. *J Am Coll Cardiol*. 2013;62(12):1103–1111.
96. Adler Y, Charron P, Imazio M, et al. 2015 ESC Guidelines for the diagnosis and management of pericardial diseases: the Task Force for the Diagnosis and Management of Pericardial Diseases of the European Society of Cardiology (ESC)Endorsed by: the European Association for Cardio-Thoracic Surgery (EACTS). *Eur Heart J*. 2015;36(42):2921–2964.
97. Klein AL, Abbara S, Agler DA, et al. American Society of Echocardiography clinical recommendations for multimodality cardiovascular imaging of patients with pericardial disease: endorsed by the Society for Cardiovascular Magnetic Resonance and Society of Cardiovascular Computed Tomography. *J Am Soc Echocardiogr*. 2013;26(9):965–1012. e15.
98. Cosyns B, Plein S, Nihoyanopoulos P, et al. European Association of Cardiovascular Imaging (EACVI) position paper: multimodality imaging in pericardial disease. *Eur Heart J Cardiovasc Imaging*. 2015;16(1):12–31.
99. Burn S, Barnes PC. Non-Hodgkins lymphoma presenting with evidence of right ventricular outflow tract obstruction. *Br J Clin Pract*. 1994;48(2):73–74.
100. Ren J, Rich MW, Makan M. Right ventricular outflow tract obstruction by lymphoma: case series and review of the literature. *Echocardiography*. 2011;28(10):1164–1167.
101. Konstandin MH, Korosoglou G, Hosch W, Hardt SE, Katus HA, Mereles D. Severe right ventricular outflow tract obstruction caused by non-hodgkin lymphoma: complete regression after one course of bendamustine/rituximab therapy. *J Am Soc Echocardiogr*. 2011;24(7):818. e1–4.
102. Wolfgang R, Lee JG. Endoscopic treatment of acute gastric volvulus causing cardiac tamponade. *J Clin Gastroenterol*. 2001;32(4):336–339.
103. Kariya N, Shindoh M, Nakatani K, Asada A, Nishi S, Kurita S. Echocardiographic diagnosis of extrapericardial tamponade due to dilated gastric roll following oesophagectomy. *Anaesth Intensive Care*. 2001;29(6):634–637.
104. Moore JPR, Fraser JF. Outside the box: extra-pericardial tamponade due to acute recurrence of hiatus hernia. *Ann Thorac Surg*. 2010;89(5):1654–1656.
105. Blanco P, Volpicelli G. Common pitfalls in point-of-care ultrasound: a practical guide for emergency and critical care physicians. *Crit Ultrasound J*. 2016;8(1):15.
106. Strony R, Linkenheil E. How to delineate pericardial effusion from pleural effusion on bedside ultrasound. *J Emerg Med*. 2016;50(3):495–496.
107. Giraud R, Banfi C, Bendjelid K. Large pleural effusion leading to cardiac tamponade. *Intensive Care Med*. 2015;41(12):2191–2192.
108. Kaplan LM, Epstein SK, Schwartz SL, Cao QL, Pandian NG. Clinical, echocardiographic, and hemodynamic evidence of cardiac tamponade caused by large pleural effusions. *Am J Respir Crit Care Med*. 1995;151(3 Pt 1):904–908.
109. Kopterides P, Lignos M, Papanikolaou S, et al. Pleural effusion causing cardiac tamponade: report of two cases and review of the literature. *Heart Lung*. 2006;35(1):66–67.
110. Sadaniantz A, Anastacio R, Verma V, Aprahamian N. The incidence of diastolic right atrial collapse in patients with pleural effusion in the absence of pericardial effusion. *Echocardiography*. 2003;20(3):211–215.
111. Gillam LD, Guyer DE, Gibson TC, King ME, Marshall JE, Weyman AE. Hydrodynamic compression of the right atrium: a new echocardiographic sign of cardiac tamponade. *Circulation*. 1983;68(2):294–301.
112. Chidambaram S, Sangareddi V, Ganesan G, et al. An echocardiographic assessment of cardiovascular hemodynamics in patients with large pleural effusion. *Indian Heart J*. 2013;65(6):666–670.
113. Gámez JM, Forteza JF, Gámez JM, Forteza JF. Cardiac tamponade secondary to pleural effusion in hepatopulmonary syndrome. *Rev Esp Cardiol*. 2008;61(12):1358–1360.
114. Hermansen JF, Juhl-Olsen P, Frederiksen CA, Christiansen LK, Hørlyck A, Sloth E. Drainage of large pleural effusions increases left ventricular preload. *J Cardiothorac Vasc Anesth*. 2014;28(4):885–889.
115. Vaska K, Wann LS, Sagar K, Klopfenstein HS. Pleural effusion as a cause of right ventricular diastolic collapse. *Circulation*. 1992;86(2):609–617.
116. Wemmelund KB, Lie RH, Juhl-Olsen P, Frederiksen CA, Hermansen JF, Sloth E. Pleural effusion decreases left ventricular pre-load and causes haemodynamic compromise: an experimental porcine study. *Acta Anaesthesiol Scand*. 2012;56(7):833–839.
117. Traylor JJ, Chan K, Wong I, Roxas JN, Chandraratna PAN. Large pleural effusions producing signs of cardiac tamponade resolved by thoracentesis. *Am J Cardiol*. 2002;89(1):106–108.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Movie S1 for Figure 1.
Movie S2. Parasternal short-axis view. Bouncing of the interventricular septum into the left ventricle during early diastole.
Movie S3 for Figure 3.
Movie S4 for Figure 4.
Movie S5 for Figure 5.

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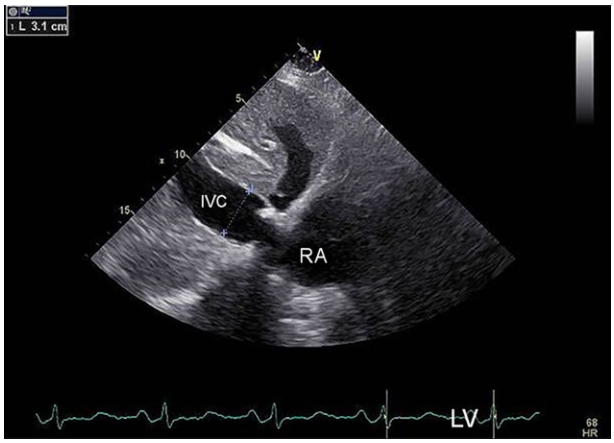
APPENDIX A



Subcostal view. The inferior vena cava and hepatic veins are distended due to pulmonary hypertension and consequently right ventricular failure IVC: inferior vena cava, RA: right atrium