Role and importance of ultrasound lung comets in acute cardiac care

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Review

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Abstract

Lung ultrasonography is an emerging, user-friendly and easy-to-use technique that can be performed quickly at the patient's bedside to evaluate several pathologic conditions affecting the lung. Ultrasound lung comets (ULCs) are an echographic sign of uncertain biophysical characterisation mostly attributed to water-thickened subpleural interlobular septa, but invariably associated with increased extravascular lung water. ULCs have thus been proposed as a complementary tool for the assessment and monitoring of acute heart failure and are now entering into statements in international recommendation documents. Adding lung ultrasonography to conventional echocardiography allows for performing an integrated cardiopulmonary ultrasound examination, and this is an important opportunity for the cardiologist. The technique allows the simultaneous gathering of considerable information about the heart and the lungs to investigate acute and chronic cardio-pulmonary conditions within a non-invasive, radiation-free, single-probe, all-in-one examination. We have here reviewed the pertinent literature on the physical origin of ULCs and on their role and importance in intensive and acute cardiac care settings. We also here propose a new algorithm aimed at implementing evaluation in the diagnostic work-up of patients with suspected acute heart failure.

Keywords

Ultrasound lung examination, ultrasound lung comets, pulmonary oedema, acute heart failure, acute cardiac care

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Introduction

Once upon a time, examinations of the lungs were considered a taboo by ultrasound specialists and echocardiographists, with air considered the worst enemy of ultrasounds. Because of their acoustic transmission properties, the lungs have for a long time been considered a compartment not amenable to ultrasonography. In the 15th edition of the *Harrison's manual of internal medicine*, it was clearly stated that 'ultrasound imaging is not useful for evaluation of the pulmonary parenchyma'.[1] In opposition to the dogma, nowadays the literature concerning lung ultrasonography is rapidly growing and opening up new diagnostic opportunities.[2] Due to the intrinsic high attenuation and acoustic impedance of high air-to-soft-tissue gradients, ultrasound energy cannot penetrate healthy lung tissue, with the normal pleura acting as an almost complete reflective surface,[2,3] with the production of transversal reverberation artefacts, called A-lines, as the ultrasonic pulse which is reflected by the lung surface.[4,5] Anecdotally, in 1982 Wendell and Athey first described the unexpected echographic appearance of an intrahepatic shotgun bullet, giving rise to a roughly vertical narrow-based artefact spreading in the shape of a dense tapering trail of echoes up to the edge of the screen, a kind of laser-ray simulating a comet tail.[6] Subsequently, such aspects were observed at the lung surface in normal or pathological conditions, including lung sarcoidosis.[7,8] This comet-tail artefact

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was shown to be a type of reverberation phenomenon fanning out from the lung surface, originating from volumetric changes in the relationship between the air-filled and tissue-fluid parts of the lung.[9,10] Later on, Lichtenstein et al., a group of French intensive care specialists, first described the relationship between alveolar-interstitial syndrome and the generation of multiple and bilateral comet-tail artefacts also known as B-lines or ultrasound lung comets (ULCs), thus laying the foundations for the clinical development of pulmonary ultrasonography.[11] Since the publication of the first articles showing the usefulness and high accuracy of lung ultrasound in the diagnosis of interstitial syndromes in critically ill and emergency medicine patients, other reports have followed.[12] Two other studies conducted in the cardiothoracic surgery setting showed a positive and significant correlation of B-lines with the amount of extravascular lung water, as assessed by means of semi-quantitative chest X-ray[13] and invasive thermodilution methods.[14] From a cardiological perspective, these latter evidences paved the way for testing ULCs as a tool to assess and monitor cardiogenic pulmonary congestion, optimise the treatment of chronic heart failure) HF, detect impending episodes of HF decompensation, and differentiate cardiac-related acute dyspnoea from that due to lung diseases in intensive and acute cardiac care settings.

Fundamentals of lung ultrasonography

Lung ultrasonography is one of the easiest applications of echography, requiring minimal technical skills, very simple equipment and only a few minutes of time to be performed. Lung ultrasonography is performed using any commercially available 2-D scanner, also with portable apparata, with any transducer frequency (from 1.6–5 MHz), with no need for a second harmonic or Doppler imaging mode.[8] The lung ultrasonography examination is performed using natural images, avoiding filters, especially those designed to suppress artefacts.[15] A micro-convex probe can be easily adapted to any equipment, providing good image quality from the skin surfaces deep into the tissues, both in the adults and in the neonates. Phased array, low-frequency probes with a high degree of penetration are the best option for evaluating extravascular lung water, pleura-pericardial effusions and deep consolidations. Conversely, linear, high-frequency probes provide a great deal of details, but with low penetration, thus being best suited for the analysis of pleural gliding, ruling out a pneumothorax, or for the real-time guidance of percutaneous procedures. Lung ultrasonography deals with non-anatomic, artefact-driven images, and allows a very dynamic interpretation of changes occurring in the lung.[16] Indeed, gas and fluids in the thorax are spatially largely segregated in normal conditions, but such a selective distribution becomes blended in the presence of pathologic processes, which generate artefacts. The set of ultrasonographic images in the lung found to be useful in formulating diagnostic hypothesis of lung diseases has been defined in a series of at least 10 signs[15,17] (Table 1). These arise from the mingling of air and fluids within the chest, spreading from the visceral-parietal pleural interface (VPPI). By placing the probe on the thorax between the ribs in a longitudinal view, it is possible to recognise the VPII (or pleural line) –the primary landmark in lung ultrasonography, as a horizontal echogenic line behind the costal level. The simultaneous presence – within the acoustic window of exploration – or the ribs and of the visceral-parietal pleural interface generates a standardised and permanent ultrasound pattern called the 'bat sign', since it is reminiscent of the wings and the body of a bat (indeed a long-time passionate user of ultrasounds).[15,18] Physiologically, the pleural line has a gliding to-and-fro movement (the gliding sign) due to the sliding of the parietal and visceral serous membranes on each other during the respiratory cycle. The normal lung surface, because of the lung sliding, generates horizontal isometric repetitions of the pleural line, called A-lines, which indicate the physiological or pathologically free presence of gas within the organ.[15,18] In pathological conditions, when the lung is injured and some changes of acoustic impedances and density of the lung occur, increases in lung tissue density and pleural abnormalities can be detected by a variety of artefactual lung signs, points and patterns, with the progressive disappearance of the A-lines.[15–20]

The ultrasound lung comets

B-lines, better known as ULCs or lung rockets, are discrete, laser-like, vertical, hyperechoic artefacts, that arise from the pleural line extending to the bottom of the screen without fading, erasing the A-lines and moving in concert with lung sliding[21] (Figure 1). The presence and/or confluence of B-lines defines a 'break' of the pleural reflecting mirror, and is pathognomonic of the presence of an interstitial lung syndrome, the number of B-lines increasing along with the reduction in air content. Computerised tomography data showed that the number of B-lines correlated, with excellent accuracy, with the thickening of subpleural interlobular septa in pulmonary interstitial oedema and with the fibrotic thickening in pulmonary fibrosis.[11] Two types of B-lines have been described: septal rockets and ground-glass rockets.[18] Septal rockets are scattered, and likely represent thickened, high-impedance, reverberating subpleural interlobular septa, typically distributed at about 7 mm apart, which is roughly the distance between the origins of individual rockets at the pleural line.[17] Septal rockets are the ultrasound equivalent of radiological Kerley B-lines.[22] Ground-glass rockets are confluent or imaged with a 3 mm spacing interval. They are representative of alveolar flooding, and considered equivalent to areas of ground-glass computerised tomography attenuation. They are an expression of a more severe form of interstitial lung syndromes, with extensive involvement of interlobular and interalveolar septa. The interstitial lung syndrome should

Table 1. Lung ultrasonography glossary and clinical significance of findings.

Finding	Definition	Clinical use
A-lines	Horizontal reverberation artefacts appearing as isometric and parallel repetitions of the VPPI	Normal lung
Lung pulse	VPPI movements synchronous to heart activity	Atelectasis if lung sliding absent, rule-out pneumothorax
B-lines	Vertical artefacts arising from the VPPI (shaped by numerous small horizontal J-lines) extending to the far-field, moving synchronously to lung sliding, erasing A-lines	Number-correlated with increased EVLW, ILS, HF
Seashore sign (lung sliding)	B-mode: To-and-fro movement of the pleural line M-mode: sandy, granular pattern arising from the VPPI	Pneumothorax
Stratosphere (barcode) sign	B-mode: abolition of lung sliding, no B-lines M-mode: full-screen barcode pattern	Pneumothorax, pleural adhesions, mainstem intubation, atelectasis
Lung point	Alternating absence and presence of lung sliding and barcode sign	Anatomic border of pneumothorax
Quad and sinusoid signs	B-mode: anechoic quad delineated by VPPI, shadow of ribs and lung line M-mode: sinusoidal movement of lung line towards the VPPI on inspiration	Pleural effusion
Shred sign	Real, tissue-like image, mimicking quad sign but with a shredded, irregular lung line	Lung consolidation
E-lines	Vertical artefacts arising from the subcutaneous tissue	Subcutaneous emphysema
Z-lines	Vertical ill-defined artefacts, vanishing in the far-field, do not erase A-lines	Unknown

B-mode: brightness mode; EVLW: extravascular lung water; HF: heart failure; ILS: interstitial lung syndromes; M-mode: time-motion mode.

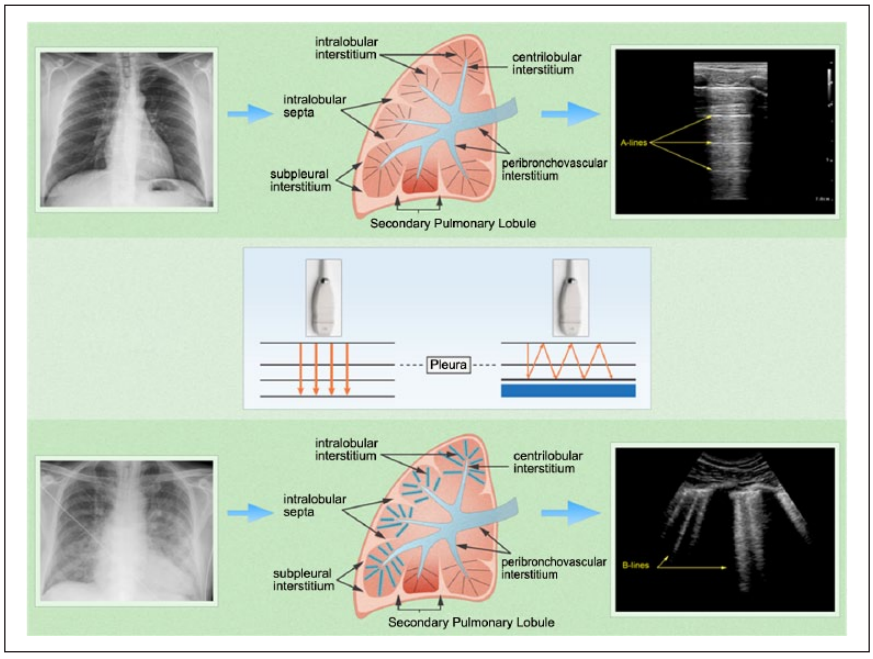

Figure 1. Physical and anatomic basis of echographic pulmonary A-lines and B-lines (see text for details and further explanations).

not be confused with the presence of multiple reverberation artefacts of varying morphology that originate from subcutaneous emphysema and lie external to the pleural line, which is masked by them, as is the costal plane. These artefacts are known as E-lines. It is also important to mention the presence of another similar comet-tail artefact that should not be interpreted as a B-line. It is a vertical ill-defined artefact, called the Z-line, that also arises from the pleural line, briefly

vanishing within a few cm, and with unknown clinical use. Such an image is not synchronised with lung sliding, and does not erase A-lines.

ULCs have been defined as the 'kindergarten' of echocardiography: very easy to obtain with very limited training and optimal precision, and speedily found with very basic and unsophisticated technology.[23]

The biophysical basis of ultrasound lung comets

ULCs are defined as linear vertical artefacts due to reverberation, arising from the VPII and extending through the entire lung field. This definition of B-lines has remained the same for many years in that their physical origin is pretty much unknown. What is a vertical artefact and what do we really know about the biophysical basis of ultrasonographic artefact formation in interstitial lung disease? The B-line is an artefact simply because it cannot represent any anatomic structure in the lung, but also because it can be reproduced in vitro, scanning various phantoms in which linear structures are not present.[16,24] From a methodological perspective ULCs have been evaluated in several studies with different probes and frequencies. As a consequence, what has been imaged with one probe and with a certain frequency is not the same as what shows up using another type of equipment.[16] It has been demonstrated that both phantoms and healthy lung, when artificially deflated to a level considered no longer physiological, can produce vertical artefacts.[16,24] Hence, the increased density (or reduction in 'porosity') of the organ would cause an acoustic interruption of the pleural line. The inherent limit of B-line production is the critical lung density that generates consolidations, ranging from values of 0.15 g/ml of a normally aerated and healthy lung, up to 1 g/ml of a consolidation process, with a progressive increase in concentrations of B-lines before reaching the critical density for producing clear images of consolidation. No matter how attractive such a unifying hypothesis of increased density is, it cannot be accepted in all cases, as not all vertical artefacts are equal and behave in the same way. It is therefore likely that diverse simultaneous and interacting phenomena are responsible for the production of such vertical artefacts, with a concrete limit in the overall definition of these artefacts as B-lines.[10,16] From a physical point of view, ULCs represent superficial, artefactual, density- and geometry-correlated phenomena due to the acoustic permeability of a broken specular reflector, i.e. the pleural line.[24,25] Better physical knowledge of the acoustic phenomena produced by porous and aerated tissues is a major unmet need for a correct interpretation of images of lung disease, which are in reality nothing more than 'errors' of ultrasound machines that interpret acoustic interactions 'in their own manner'.[16,25]

Clinical research and applications of ultrasound lung comets in acute cardiac care

Acute heart failure (AHF)

AHF is defined as the new-onset or rapid worsening of signs and symptoms of HF due to acute elevation of the pulmonary capillary wedge pressure, requiring urgent therapy, most commonly in the hospital setting.[26,27] The diagnosis of AHF is based on the evaluation of clinical findings supported by appropriate investigations, such as the electrocardiogram (ECG), laboratory investigations, echocardiography and chest X-ray. Given the infrequent occurrence of low cardiac output syndromes, the main reason for hospitalisation is related to the symptoms and signs of congestion, which is associated with a poor prognosis and is an important target for therapy.[26,28–30] Clinical congestion in HF is defined as a high left ventricular diastolic pressure (LVDP) associated with signs and symptoms of HF, such dyspnoea, rales and oedema.[26] AHF can be preceded by days or even weeks of haemodynamic congestion with subclinical elevation of the LVDP. Conversely, pulmonary congestion defines a situation of fluids extravasation into the pulmonary interstitium, regardless of the presence or absence of signs and symptoms of HF. The opportunity for early detection and non-invasive bedside monitoring of both haemodynamic and pulmonary congestion, even in their subclinical state, by means of sufficiently sensitive and accurate techniques is an unmet clinical need, and is so intuitively attractive that efforts to develop and validate such technique still continues after many years.[21,31] Prompt diagnosis is key to effective management, and requires at least two essential pieces of clinical information: the status of extravascular lung water and LVDP.

The extravascular lung water is a relatively small but fundamental component of the body fluids volume, and is the water content of the lung interstitium. It is strictly dependent on LV filling pressure, which is considered the most reliable haemodynamic parameter for guiding fluid therapy in critical care.[32–34] Normal extravascular lung water is <500 ml, with alveolar flooding occurring when it overcomes a threshold of more than 75% above its normal limit.[31] At present, the chest X-ray is the clinical standard for assessing extravascular lung water, since more accurate and reproducible methods are also much more expensive and difficult to be implemented for purposes of routine clinical practice. The chest X-ray, however, has its own limitations, which raise non-trivial concerns: it requires radiological equipment and involves radiation exposure; it is operator-dependent, with a substantial inter-observer variability in interpretation, and detects only the most extreme change in fluid status.[35–37] Remarkably, the absence of chest X-ray findings of HF does not exclude a high pulmonary capillary wedge pressure (PCWP). It has been observed that radiographic signs of pulmonary congestion are indeed

absent in more than 50% of the patients with PCWP of 16–29 mm Hg and in almost 40% of patients with PCWP of ≥30 mm Hg.[26,38] Furthermore, according to the latest European Society of Cardiology guidelines for the diagnosis and treatment of acute and chronic HF, the chest X-ray is considered of limited use in the diagnostic work-up of patients with suspected HF (class of recommendation IIa, level of evidence C), its usefulness being aimed at identifying pulmonary congestion/oedema only in the acute setting and detect or rule out certain lung disease, e.g. cancer.[39]

B-lines have been proposed as a reliable alternative diagnostic tool for the assessment and grading of pulmonary congestion in acute HF patients[8,11,21] and lung ultrasonography is now entering European recommendation statements.[26,40] Older studies had shown that B-lines are a cost-effective, bedside, radiation-free, appealing and easy-to-perform technique providing accurate and reproducible estimates of extravascular lung water,[8,32] which in turn may predict adverse prognosis.[41] Compared with the other methods for assessing abnormal increases in lung water in the clinical setting – essentially the chest X-ray, computerised tomography (CT), and catheter-based thermodilution techniques – the assessment of ULCs provides high diagnostic accuracy.[13,35,42,43] Interestingly, when comparing ULCs to transpulmonary thermodilution, i.e. the pulse contour cardiac output technique (PiCCO), it was found that an assessment of ULCs could also detect excess extravascular lung water below the threshold causing alveolar flooding, and therefore subclinical stages of pulmonary congestion.[44,45]

Monitoring extravascular lung water with B-lines was shown to be even more important than knowing total body water volume by using bioelectrical impedance analysis. Mallamaci et al. indeed demonstrated that, in patients undergoing chronic haemodialysis, pulmonary congestion was related neither to the overall hydration status before dialysis nor to the volume of fluids removed with dialysis.[32] Notably, in a series of 102 mechanically ventilated patients who all underwent pulmonary artery catheterisation, A-lines predominance was an excellent and highly specific predictor of a PCWP≤18 mm Hg, while B-lines predominance was observed in a wide range of PCWP levels, thus implying low specificity and positive predictive value for this latter.[46] In another study of patients with preserved left ventricular ejection fraction (LVEF) undergoing cardiac surgery, Agricola and co-workers reported a positive linear correlation between ULCs and both PCWP and systolic pulmonary artery pressure invasively recorded.[42] The correlation between implantable cardioverter defibrillator (ICD)-measured intra-thoracic impedance and PCWP has been previously described in HF patients,[41] and the possibility of monitoring thoracic fluid status measuring the intra-thoracic impedance (the Optivol algorithm) has been therefore implemented in some modern ICDs.[47–49] Recent data have shown a good agreement between an ICD warning for intra-thoracic fluid increase and the number of ULCs at lung ultrasonography. Here the detection of ULCs after an Optivol alert was found to be extremely predictive and sensitive for detecting impending HF decompensation, thus highlighting the possibility of discriminating between true and false-positive impedance alerts in patients with an ICD.[48]

The non-invasive monitoring of LVDP is another important clinical tool for the diagnosis and management of HF patients. In this setting, natriuretic peptides (NPs) and echocardiographic evaluation of diastolic dysfunction have attracted a great deal of attention.[39,50,51] NPs (brain natriuretic peptide (BNP) and N-terminal portion of the prohormone BNP (N-terminal-NT-proBNP) are neurohormones specifically secreted by the heart in response to volume and pressure overload, and leading to increased wall tension. As an index of activation of the neuroendocrine system, they are a sensitive predictor of elevated LV filling pressure and a powerful prognostic marker in HF.[52,53] NPs can be used to rule out dyspnoea of cardiogenic origin and to titrate diuretic therapy.[39,53] B-lines and their changes after therapy measured by lung ultrasonography were well correlated with serum levels of NP[53–55] although the concordance of such measurements was not perfect.[53,54] To better understand this finding, it is important to recall the Starling equation,[56] formulated in 1896 by the British physiologist Ernest Starling and illustrating the role of hydrostatic and oncotic forces in regulating the net fluid movement across capillary membranes:

$$J_v = K_f [(P_c - P_i) - \sigma (\pi_c - \pi_i)]$$

where J_v *is* net fluid movement between compartments or extravascular lung water, P_c is the capillary hydrostatic pressure, P_i is the interstitial hydrostatic pressure, π_c is the capillary oncotic pressure, π_i is the interstitial oncotic pressure, K_f is the filtration coefficient—a constant of proportionality, and σ is the reflection coefficient, a correction factor. The presence of ULCs identifies an excess of extravascular lung water, which defines pulmonary congestion/oedema. The latter can be broadly classified into two main types, based on pathogenetic considerations: (a) hydrostatic or cardiogenic oedema; and (b) hyperpermeability oedema, also termed 'non-cardiogenic' oedema, predominantly encompassing the acute respiratory distress syndrome (ARDS) and acute lung injury (ALI). Increased left ventricular (LV) filling pressure, or P_c, is only one of the Starling forces playing a role in water extravasation, and represents the common haemodynamic trigger for both natriuretic peptides and ULCs. These two, however, evaluate different pathophysiological events, i.e. haemodynamic forces in one case, and pulmonary congestion in the other.[53,57] These basic concepts largely explain the discordant findings in dyspnoeic patients with high NP levels and absence of ULCs or vice versa, identifying a sort of 'grey zone' for the diagnosis of decompensation.[53] Indeed echocardiography is the mainstay imaging modality to evaluate

Table 2. Pros and cons of tissue Doppler-derived early diastolic velocity to early diastolic annular velocity ratio (E/e') and B-type natriuretic peptides for the estimation of left ventricular diastolic pressure..

Natriuretic peptides	E/e'
Pros	
Point-of-care	High specificity
Inexpensive	Can be used in obese patients
Rapid result	Rapidly changes in response to volume changes
Excellent negative predictive value	Validated in multiple studies and patient populations
Well validated for clinical congestive heart failure,	Synchronous E/E'index reliable in atrial fibrillation
Cons	
'Gray zone'	'Grey zone'
Gender differences	In general, not point-of-care
Low specificity in renal failure	More expensive
Unclear use in obese patients	Can be unclear in patients with poor echocardiographic windows
Cannot distinguish among causes of heart failure	Not well validated in mitral valve disease (stenosis, regurgitation, prosthesis)
Unclear use in atrial fibrillation	Not well validated in non-sinus rhythm
NPs memory - may not respond rapidly to volume changes	E/e' is more accurate in estimating LVDP in patients with depressed EF

LVDP: left ventricular diastolic pressure.
Modified from Dokainsh,[50] with permission from the publisher.

patients with suspected HF, providing immediate and crucial data to make the diagnosis of HF, in determining and monitoring appropriate treatment and to obtain prognostic information.[39] Compared with NPs, LVEF, as assessed by echocardiography, is a poor predictor of prognosis; however other echocardiographic parameters may be here used to estimate the severity of congestion.[58,59] It is indeed well established that echocardiographic Doppler-derived indices of LV diastolic dysfunction are non-invasive markers of high left atrial pressure (haemodynamic congestion), and strongly correlated with the haemodynamic and prognostic severity of HF.[35,57] LV diastolic dysfunction is considered to be the underlying pathophysiological abnormality in patients with HF with preserved LVEF, nevertheless the most common cause of diastolic dysfunction is the presence of systolic dysfunction. Thus almost all acute and chronic HF patients have some degree of LV diastolic filling impairment. Of note, no single echocardiographic parameter is sufficiently accurate and reproducible to be used alone to make a diagnosis of LV diastolic dysfunction.[60] Therefore, a comprehensive echocardiographic examination including all relevant bi-dimensional and Doppler-derived indices is highly recommended in such cases.[39,59] Echocardiographic parameters most commonly measured in patients with suspected HF are tissue Doppler imaging (TDI)-derived septal and/or lateral early diastolic velocity of the mitral annulus (e'); the ratio of the early diastolic mitral inflow E wave to e' wave (E/e'); the pulsed-wave (PW) Doppler-derived ratio of early to late mitral inflow waves (E/A) (also during a Valsalva manoeuvre); the left atrial volume index; the mitral E wave deceleration time; and the colour M-mode flow propagation velocity.[39,59] In a single-centre study evaluating clinical and echocardiographic determinants of ULCs, the degree of diastolic dysfunction resulted in the strongest independent predictor of ULCs, followed by NYHA functional class and LVEF.[35] Other studies corroborated this finding and reported a significant linear correlation between B-lines and the E/e' ratio, a well-known surrogate marker for left-sided filling pressures[44] and a powerful predictor of death in patients with HF.[61] The extensive use of NPs and E/e' ratio for the estimation of LV filling pressure and other diagnostic and prognostic purposes requires a careful evaluation of pros and cons (Table 2). Major issues with NPs are obesity, renal failure and an overall low specificity, while appropriate reference values remain a matter of disagreement, thus engendering a diagnostic 'grey zone'.[50,53] Major drawbacks of the E/e' ratio are associated with TDI-related limitations (i.e. Doppler angulation errors), the occurrence of patients with preserved EF; clinical situations in which the E/e' has not been well validated (i.e. mitral valve diseases, atrial fibrillation, paced rhythms); the presence of poor echocardiographic windows; and a 'grey zone' of E/e' ratio values between 11–14, in which case other variables are needed to accurately estimate LV filling pressure.[50,62]

There is a growing interest in defining the diagnostic utility of a complementary evaluation of elevated filling pressure by means of the E/e' ratio, NPs and an estimate of extravascular lung water with lung ultrasonography, as this comprehensive evaluation would allow us to distinguish between haemodynamic congestion – a condition of diastolic dysfunction without damage of the alveolar-capillary membrane – and pulmonary congestion with damage of the

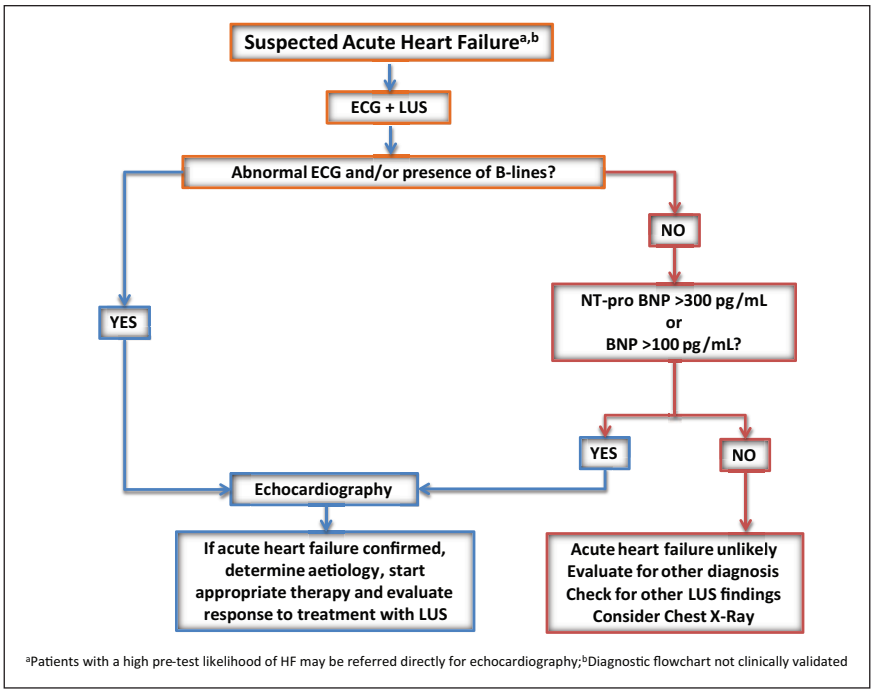

Figure 2. A new algorithm proposed for the use of lung ultrasonography in the diagnosis of acute heart failure. ECG: electrocardiogram; LUS: lung ultrasonography; NT-proBNP: N-terminal portion of the prohormone brain natriuretic peptide.

alveolar-capillary membrane and redistribution of fluids within the lungs, not necessarily related to a high LVDP.[21,53]

Finally, an assessment of B-lines could serve also as a complementary diagnostic and monitoring tool in acute settings to reduce diagnostic lags during evaluation of unstable patients, when NPs levels are in the 'grey zone', or assays are not readily available; and in all those situations where a dynamic evaluation of fluid change is of importance. Indeed, B-lines are extremely dynamic, and fade away in a few minutes after an acute diuretic load, thus representing a unique bedside tool for a quick real-time monitoring of response to diuretic treatment.[18,21]

Differential diagnosis in interstitial lung syndromes

Interstitial lung syndromes may be present segmentally or diffusely in all diseases that change the interstitium-to–air space ratio in favour of the former.[17] This may occur not only in the case of pulmonary oedema, where an acoustic mismatch occurs between the different impedances of air and water, but also anytime there is an area of high acoustic mismatch in the sub-pleural space, where interlobular septa are in contact with the pleural lining, as happens in the case of pleuritis, fibrosis or even chronic obstructive pulmonary disease (COPD).[45] Therefore, the ultrasonographic finding of multiple and diffuse B-lines over the lung fields always deserves careful assessment and attentive clinical contextualisation. Interstitial lung syndromes can be classified, on the basis of their extent, focal or diffuse. Focal interstitial lung syndromes are topographically detectable only in relation to limited zones of pleural-parenchymal changes, i.e. focal interstitial pneumonias, dysventilation areas, pulmonary infarctions and contusions, segments with increased density close to inflammatory or neoplastic consolidations, or pleural-parenchymal scarring. In the case of diffuse interstitial lung syndromes we can distinguish two patterns: type A, with homogeneous distribution of vertical artefacts and a smooth, thin, regular VPII; and type B, characterised by dyshomogeneous distribution of B-lines, with preserved areas and a thickened, coarse VPII.[16] Evaluation of the gradient of concentration of B-lines in the apical-caudal or ventral-dorsal direction can be a further clue to orient differential diagnosis. For example, a type A pattern with a gravitational distribution of ULCs, involving caudal and dorsal regions, especially when associated with bilateral pleural effusions, is highly suggestive of cardiogenic pulmonary oedema, while a type B pattern with an unclear gradient and small sub-pleural consolidations is in general indicative of non-cardiogenic pulmonary oedema (ALI/ARDS).[63–65] Thus, the opportunity to integrate information from lung ultrasonography and echocardiography may allow a complete definition and distinction of cardiogenic and non-cardiogenic acute pulmonary oedema.[16]

Proposal for a new diagnostic algorithm for the use of lung ultrasonography in the diagnosis of AHF

Given these premises, we here propose a new algorithm (Figure 2) to implement the use of B-lines, imaged by lung

ultrasonography, in the diagnostic work-up of patients with suspected AHF. The novelty of this strategy is essentially in the first-step bedside clinical evaluation of the patient with acute onset of signs and/or symptoms suggestive of HF with the ECG and lung ultrasonography, useful to identify patients who most urgently need echocardiography. If the ECG is normal and in the absence of B-lines at lung ultrasonography, an assessment of serum levels of NPs is warranted to guide the differential diagnosis. After this step, serial B-lines evaluation is indicated for the management of diuretic therapy in HF and for reassessing extravascular lung water. A chest X-ray should be considered to detect/exclude certain types of lung disease, e.g. cancer.[39]

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Conflict of interest

The authors declare that there is no conflict of interest.

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References

1. Weinberger SE. Diagnostic procedures in respiratory disease. In: *Harrison's principles of internal medicine*. New York: McGraw-Hill, 2002, pp.145–1456.
2. Soldati G, Sher S and Testa A. Lung and ultrasound: Time to 'reflect'. *Eur Rev Med Pharmacol Sci* 2011; 15: 223–227.
3. O'Brien WD Jr. Ultrasound-biophysics mechanisms. *Prog Biophys Mol Biol* 2007; 93: 212–255.
4. Targhetta R, Chavagneux R, Bourgeois JM, et al. Sonographic approach to diagnosing pulmonary consolidation. *J Ultrasound Med* 1992; 11: 667–672.
5. Reissig A and Kroegel C. Transthoracic sonography of diffuse parenchymal lung disease: The role of comet tail artifacts. *J Ultrasound Med* 2003; 22: 173–180.
6. Wendell BA and Athey PA. Ultrasonic appearance of metallic foreign bodies in parenchymal organs. *J Clin Ultrasound* 1981; 9: 133–135.
7. Thickman DI, Ziskin MC, Goldenberg NJ, et al. Clinical manifestations of the comet tail artifact. *J Ultrasound Med* 1983; 2: 225–230.
8. Picano E, Frassi F, Agricola E, et al. Ultrasound lung comets: A clinically useful sign of extravascular lung water. *J Am Soc Echocardiogr* 2006; 19: 356–363.
9. Ziskin MC, Thickman DI, Goldenberg NJ, et al. The comet tail artifact. *J Ultrasound Med* 1982; 1: 1–7.
10. Soldati G, Copetti R and Sher S. Sonographic interstitial syndrome: The sound of lung water. *J Ultrasound Med* 2009; 28: 163–174.
11. Lichtenstein D, Meziere G, Biderman P, et al. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 1997; 156: 1640–1646.
12. Volpicelli G, Melniker LA, Cardinale L, et al. Lung ultrasound in diagnosing and monitoring pulmonary interstitial fluid. *Radiol Med* 2013; 118: 196–205.
13. Jambrik Z, Monti S, Coppola V, et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. *Am J Cardiol* 2004; 93: 1265–1270.
14. Agricola E, Bove T, Oppizzi M, et al. 'Ultrasound comet-tail images': A marker of pulmonary edema: A comparative study with wedge pressure and extravascular lung water. *Chest* 2005; 127: 1690–1695.
15. Lichtenstein DA and Mauriat P. Lung ultrasound in the critically ill neonate. *Curr Pediatr Rev* 2012; 8: 217–223.
16. Smargiassi A, Inchingolo R, Soldati G, et al. The role of chest ultrasonography in the management of respiratory diseases: Document II. *Multidiscip Respir Med* 2013; 8: 55.
17. Soldati G. Sonographic findings in pulmonary diseases. *Radiol Med* 2006; 111: 507–515.
18. Lichtenstein DA. Lung ultrasound in the critically ill. *Ann Intensive Care* 2014; 4: 1.
19. Stefanidis K, Dimopoulos S and Nanas S. Basic principles and current applications of lung ultrasonography in the intensive care unit. *Respirology* 2011; 16: 249–256.
20. Soldati G, Copetti R and Gargani L. [Lung sonography for the cardiologist]. *G Ital Cardiol (Rome)* 2007; 8: 139–147.
21. Gargani L. Lung ultrasound: A new tool for the cardiologist. *Cardiovasc Ultrasound* 2011; 9: 6.
22. Kerley P. Radiology in heart disease. *Br Med J* 1933; 2: 594–612.
23. Bedetti G, Gargani L, Corbisiero A, et al. Evaluation of ultrasound lung comets by hand-held echocardiography. *Cardiovasc Ultrasound* 2006; 4: 34.
24. Soldati G, Giunta V, Sher S, et al. 'Synthetic' comets: A new look at lung sonography. *Ultrasound Med Biol* 2011; 37: 1762–1770.
25. Soldati G, Copetti R and Sher S. Can lung comets be counted as 'objects'? *JACC Cardiovasc Imaging* 2011; 4: 438–439.
26. Gheorghiade M, Follath F, Ponikowski P, et al.; European Society of C, European Society of Intensive Care M. Assessing and grading congestion in acute heart failure: A scientific statement from the Acute Heart Failure Committee of the Heart Failure Association of the European Society of Cardiology and endorsed by the European Society of Intensive Care Medicine. *Eur J Heart Fail* 2010; 12: 423–433.
27. Antman EM. *Cardiovascular therapeutics: A companion to Braunwald's heart disease*. Philadelphia, PA: Elsevier Saunders, 2007.
28. Gheorghiade M, Abraham WT, Albert NM, et al. Systolic blood pressure at admission, clinical characteristics, and outcomes in patients hospitalized with acute heart failure. *JAMA* 2006; 296: 2217–2226.
29. Tavazzi L, Maggioni AP, Lucci D, et al. Italian survey on acute heart failure I. Nationwide survey on acute heart failure

in cardiology ward services in Italy. *Eur Heart J* 2006; 27: 1207–1215.
30. Drazner MH, Rame JE, Stevenson LW, et al. Prognostic importance of elevated jugular venous pressure and a third heart sound in patients with heart failure. *N Engl J Med* 2001; 345: 574–581.
31. Lange NR and Schuster DP. The measurement of lung water. *Crit Care* 1999; 3: R19–R24.
32. Mallamaci F, Benedetto FA, Tripepi R, et al. Detection of pulmonary congestion by chest ultrasound in dialysis patients. *JACC Cardiovasc Imaging* 2010; 3: 586–594.
33. Staub NC. Pulmonary edema. *Physiol Rev* 1974; 54: 678–811.
34. Crandall ED, Staub NC, Goldberg HS, et al. Recent developments in pulmonary edema. *Ann Intern Med* 1983; 99: 808–822.
35. Frassi F, Gargani L, Gligorova S, et al. Clinical and echocardiographic determinants of ultrasound lung comets. *Eur J Echocardiogr* 2007; 8: 474–479.
36. Collins SP, Lindsell CJ, Storrow AB, et al. Prevalence of negative chest radiography results in the emergency department patient with decompensated heart failure. *Ann Emerg Med* 2006; 47: 13–18.
37. Hunt SA, Abraham WT, Chin MH, et al. ACC/AHA 2005 Guideline update for the diagnosis and management of chronic heart failure in the adult: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Update the 2001 Guidelines for the Evaluation and Management of Heart Failure): developed in collaboration with the American College of Chest Physicians and the International Society for Heart and Lung Transplantation: Endorsed by the Heart Rhythm Society. *Circulation* 2005; 112 : e154–e235.
38. Chakko S, Woska D, Martinez H, et al. Clinical, radiographic, and hemodynamic correlations in chronic congestive heart failure: Conflicting results may lead to inappropriate care. *Am J Med* 1991; 90: 353–359.
39. McMurray JJ, Adamopoulos S, Anker SD, et al. ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure 2012: The Task Force for the Diagnosis and Treatment of Acute and Chronic Heart Failure 2012 of the European Society of Cardiology. Developed in collaboration with the Heart Failure Association (HFA) of the ESC. *Eur Heart J* 2012; 33: 1787–1847.
40. Mayo PH, Beaulieu Y, Doelken P, et al. American College of Chest Physicians/La Societe de Reanimation de Langue Francaise statement on competence in critical care ultrasonography. *Chest* 2009; 135: 1050–1060.
41. Yu CM, Wang L, Chau E, et al. Intrathoracic impedance monitoring in patients with heart failure: Correlation with fluid status and feasibility of early warning preceding hospitalization. *Circulation* 2005; 112: 841–848.
42. Agricola E, Arbelot C, Blaivas M, et al. Ultrasound performs better than radiographs. *Thorax* 2011; 66: 828–829; author reply 829.
43. Sivak ED and Wiedemann HP. Clinical measurement of extravascular lung water. *Crit Care Clin* 1986; 2: 511–526.
44. Agricola E, Picano E, Oppizzi M, et al. Assessment of stress-induced pulmonary interstitial edema by chest ultrasound during exercise echocardiography and its correlation with left ventricular function. *J Am Soc Echocardiogr* 2006; 19: 457–463.
45. Summerfield DT. Lung ultrasound comet tails – technique and clinical significance, hot topics in echocardiography, http://www.intechopen.com/books/hot-topics-in-echocardiography/lung-ultrasound-comet-tails-technique-and-clinical-significance (2013, accessed 25 August 2014).
46. Lichtenstein DA, Meziere GA, Lagoueyte JF, et al. A-lines and B-lines: Lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. *Chest* 2009; 136: 1014–1020.
47. Vollmann D, Nagele H, Schauerte P, et al. Clinical utility of intrathoracic impedance monitoring to alert patients with an implanted device of deteriorating chronic heart failure. *Eur Heart J* 2007; 28: 1835–1840.
48. Maines M, Catanzariti D, Angheben C, et al. Intrathoracic impedance and ultrasound lung comets in heart failure deterioration monitoring. *Pacing Clin Electrophysiol* 2011; 34: 968–974.
49. Wang L. Fundamentals of intrathoracic impedance monitoring in heart failure. *Am J Cardiol* 2007; 99: 3G–10G.
50. Dokainish H. Combining tissue Doppler echocardiography and B-type natriuretic peptide in the evaluation of left ventricular filling pressures: Review of the literature and clinical recommendations. *Can J Cardiol* 2007; 23: 983–989.
51. Hunt SA, American College of C, American Heart Association Task Force on Practice G. ACC/AHA 2005 guideline update for the diagnosis and management of chronic heart failure in the adult: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Update the 2001 Guidelines for the Evaluation and Management of Heart Failure). *J Am Coll Cardiol* 2005; 46: e1–e82.
52. Clerico A, Recchia FA, Passino C, et al. Cardiac endocrine function is an essential component of the homeostatic regulation network: Physiological and clinical implications. *Am J Physiol Heart Circ Physiol* 2006; 290: H17–H29.
53. Miglioranza MH, Gargani L, Sant'Anna RT, et al. Lung ultrasound for the evaluation of pulmonary congestion in outpatients: A comparison with clinical assessment, natriuretic peptides, and echocardiography. *JACC Cardiovasc Imaging* 2013; 6: 1141–1151.
54. Gargani L, Frassi F, Soldati G, et al. Ultrasound lung comets for the differential diagnosis of acute cardiogenic dyspnoea: A comparison with natriuretic peptides. *Eur J Heart Fail* 2008; 10: 70–77.
55. Volpicelli G, Caramello V, Cardinale L, et al. Bedside ultrasound of the lung for the monitoring of acute decompensated heart failure. *Am J Emerg Med* 2008; 26: 585–591.
56. West JB. *Respiratory physiology: The essentials*. Philadelphia, PA: Wolters Kluwer Health/Lippincott Williams & Wilkins, 2012.
57. Tschope C, Kasner M, Westermann D, et al. The role of NT-proBNP in the diagnostics of isolated diastolic dysfunc-

tion: Correlation with echocardiographic and invasive measurements. *Eur Heart J* 2005; 26: 2277–2284.
58. Shah KB, Kop WJ, Christenson RH, et al.Natriuretic peptides and echocardiography in acute dyspnoea: Implication of elevated levels with normal systolic function. *Eur J Heart Fail* 2009; 11: 659–667.
59. Nagueh SF, Appleton CP, Gillebert TC, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *Eur J Echocardiogr* 2009; 10: 165–193.
60. Lester SJ, Tajik AJ, Nishimura RA, et al. Unlocking the mysteries of diastolic function: Deciphering the Rosetta Stone 10 years later. *J Am Coll Cardiol* 2008; 51: 679–689.
61. Mornos C, Petrescu L, Pescariu S, et al. [Prognostic value of septal E/(E'xS') ratio in predicting cardiac death in patients with heart failure]. *Kardiol Pol* 2014; 72: 166–174.
62. Abhayaratna WP, Seward JB, Appleton CP, et al. Left atrial size: Physiologic determinants and clinical applications. *J Am Coll Cardiol* 2006; 47: 2357–2363.
63. Copetti R, Cattarossi L, Macagno F, et al. Lung ultrasound in respiratory distress syndrome: A useful tool for early diagnosis. *Neonatology* 2008; 94: 52–59.
64. Copetti R, Soldati G and Copetti P. Chest sonography: A useful tool to differentiate acute cardiogenic pulmonary edema from acute respiratory distress syndrome. *Cardiovasc Ultrasound* 2008; 6: 6–16.
65. Sartori E, Gadducci A, Landoni F, et al. Clinical behavior of 203 stage II endometrial cancer cases: the impact of primary surgical approach and of adjuvant radiation therapy. *Int J Gynecol Cancer* 2001; 11: 430–437.