REVIEW ARTICLE

Ultrasound Lung Comets: A Clinically Useful Sign of Extravascular Lung Water

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Assessment of extravascular lung water is a challenging task for the clinical cardiologist and an elusive target for the echocardiographer. Today chest x-ray is considered the best way to assess extravascular lung water objectively, but this requires radiology facilities and specific reading expertise, uses ionizing energy, and poses a significant logistic burden. Recently, a new method was developed using echocardiography (with cardiac probes) of the lung. An increase in extravascular lung water—as assessed independently by chest computed tomography, chest x-ray, and thermodilution techniques—is mirrored by appearance of ultrasound lung comets (ULCs). ULCs consist of multiple comet tails originating from water-thickened interlobular septa and fanning out from the lung surface. The technique requires ultrasound scanning of the anterior right and left chest, from the second to the fifth intercostal space. It is simple (with a learning curve of < 10 examinations) and fast to perform (requiring < 3 minutes). ULC assessment is independent of the cardiac acoustic window, because the lung on the anterior chest is scanned. It requires very basic 2-D technology imaging, even without a second harmonic or Doppler. ULCs probably represent an ultrasonic equivalent of radiologic Kerley B-lines. On still-frame assessment, cardiogenic watery comets can be difficult to distinguish from pneumogenic fibrotic comets, although the latter are usually more localized and are not dissolved by an acute diuretic challenge. Functionally, ULCs are a sign of distress of the alveolar-capillary membrane, often associated with reduced ejection fraction and increased pulmonary wedge pressure. The ULC sign is quantitative, reproducible, and ideally suited to complement conventional echocardiography in the evaluation of heart failure patients in the emergency department (for the differential diagnosis of dyspnea), in-hospital evaluation (for tailoring diuretic therapy), home care (with portable ultrasound), and stress echocardiography lab (as a sign of acute pulmonary congestion during stress). In conclusion, ULCs represent a useful, practical, and appealingly simple way to image directly extravascular lung water. (J Am Soc Echocardiogr 2006;19:356-363.)

Ultrasound lung comets (ULCs) represent an echocardiographic sign detectable with cardiac ultrasound on the chest and consisting of multiple comet tails fanning out from the lung surface (Figure 1, *B*). ULCs originate from water-thickened interlobular septa[1] and arise from the hyperechoic pleural line, which represents the parietal and visceral layers of the pleura in normal subjects. ULCs must be clearly distinguished from normal artifacts, consisting of 1 or 2 roughly horizontal, parallel lines visible at regular intervals below the pleural line (Figure 1, *A*). The vertical distance between 2 adjacent lines is the same as the distance between the pleural line and the skin (Figure 1, *C*). In ULCs, the horizontal distance between 2 adjacent vertical lines is similar (Fig 1, *D*). ULCs change throughout the respiratory circle, with a to-and-fro movement observed at the level of the pleural line synchronized with respiration.[1]

We prefer the term "ultrasound lung comets" to "comet-tail artifact," because the comet tail has a not totally artifactual origin. The first echo (close to the head of the comet) has a clear physical origin in the thickened interlobular septa, and thus is not a true artifact. Horizontal artifacts are normal findings, whereas vertical ULCs on the anterior chest are always associated with an abnormal condition (Table 1), although they can be found as a normal variant in healthy subjects, confirmed laterally to the last intercostal space above the diaphragm.

HISTORICAL BACKGROUND

The "comet-tail" sign was first described in 1982 concerning an intrahepatic shotgun pellet,[2] giving rise to a roughly vertical narrow-based artifact spreading up to the edge of the screen. Subsequently, it was noted at the lung surface in normal or pathological

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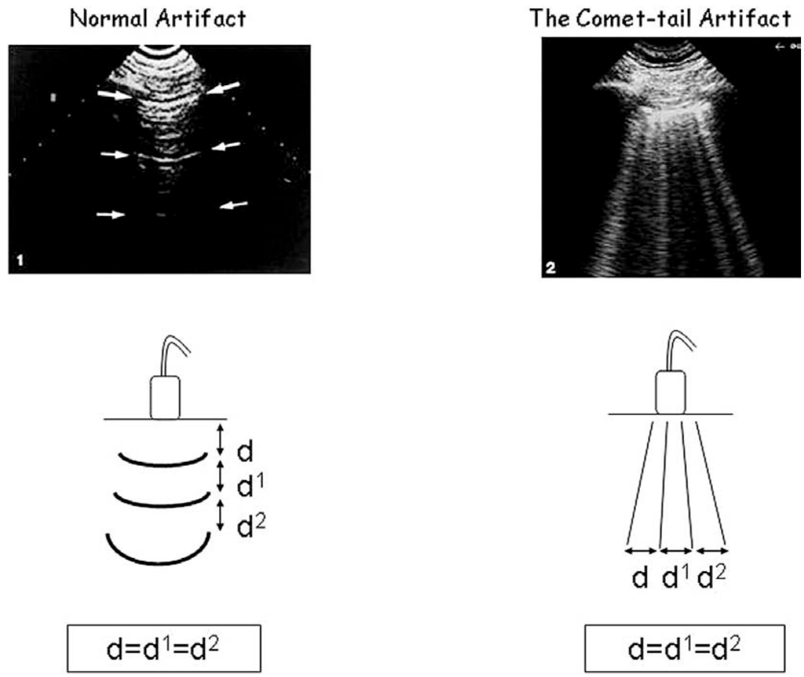

Figure 1 Left column, upper panel: Normal lung appearance with horizontal artifacts originating from the pleural line (parietal and visceral pleura). Left column, lower panel: Schematic drawing showing how horizontal parallel lines are visible at regular intervals as multiples of the skin–pleural line distance. Right column, upper panel: Abnormal ULCs in a patient with heart failure and dyspnea. Between 2 ribs (lateral = acoustic shadows), a hyperechogenic horizontal reflection represents the pleural line. Several vertical comets fan out from the pleural line, spreading like a laser-ray up to the edge of the screen. Right column, lower panel: Schematic drawing showing how the horizontal distance between reflections is consistent. (Reprinted with permission by the American Thoracic Society from Lichtenstein et al. The comet-tail artifact: an ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med 1997;156:1640-6.)

Table 1 Ultrasound lung reflections: normal horizontal artifacts versus ULCs

Definition	Ring-down artifacts	ULCs
Anatomic reflector	Parietal-visceral pleura	Interlobular septa
Orientation	Horizontal	Vertical
Origin	Pleural line	Pleural line
Spatial distribution	Multiples of the skin–pleural line distance	Edge of the screen
Clinical meaning	Normal	Abnormal
Spatial regularity	Vertical	Horizontal

conditions, including lung sarcoidosis.[3] Following these initial ultrasound anecdotes, Lichtenstein et al first described the potential usefulness of comet-tail artifact as a diagnostic marker of alveolar-interstitial syndrome.[1,4-6] Lichtenstein was a French intensivologist who also established for the first time the 2 main structural correlates of the comet-tail sign, through a systematic comparison of ultrasound findings with chest computed tomography (CT).[1] CT data showed that ultrasound was able to detect 2 patterns present in the lung surface: the thickening of the subpleural interlobular septa in pulmonary interstitial and alveolar edema (Figure 2) and the fibrotic thickening in chronic obstructive pulmonary disease (Figure 3). These applications were very interesting but remained strictly confined in the intensivist area for several years. In 2004, Jambrik et al,[7] in our laboratory, described the correlation between extravascular lung water assessed by chest x-ray and the number of comets detected in the chest by echocardiography. In this way, comets entered for the first time the cardiology practice, with an enormous potential to affect the care of patients with chronic heart failure.

PHYSICAL BASIS AND DIFFERENTIAL DIAGNOSIS

All diagnostic ultrasound methods are based on the principle that ultrasound is reflected by an interface between media with different acoustic impedance. In normal conditions, with the transducer positioned on the chest wall, the ultrasound beam finds the lung air

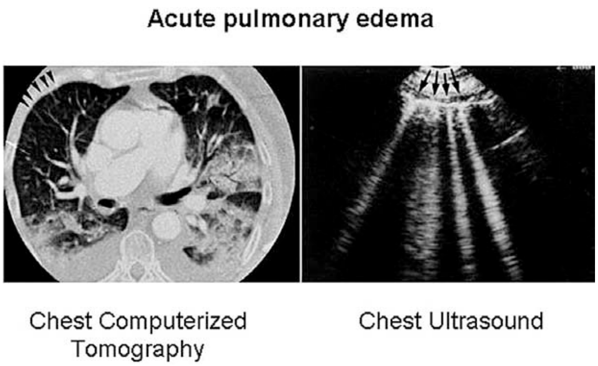

Figure 2 The origin of ULCs from water-thickened interlobular septa. The corresponding CT pattern is shown on the left side. (Reprinted with permission by the American Thoracic Society from Lichtenstein et al. The comet-tail artifact: an ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med 1997;156:1640-6.)

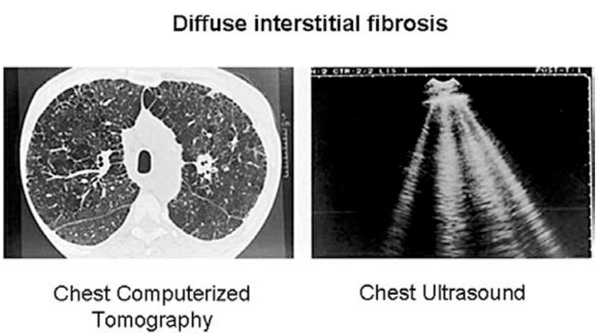

Figure 3 The origin of ULCs from fibrotic interlobular septa. The corresponding CT pattern is shown on the left side. (Reprinted with permission by the American Thoracic Society from Lichtenstein et al. The comet-tail artifact: an ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med 1997;156:1640-6.)

(ie, high impedance and no acoustic mismatch on its pathway through the chest).[1] In the presence of extravascular lung water, the ultrasound beam finds subpleural interlobular septa thickened by edema (ie, a low-impedance structure surrounded by air and with a high acoustic mismatch). The reflection of the beam creates a phenomenon of reverberation (Figure 4). When the beam meets the subpleural end of the thickened septum, the time lag between successive reverberations is interpreted by the transducer as a distance, resulting in a center that behaves like a persistent source, generating a series of very closely spaced pseudointerfaces. The physical basis of the water comets also explains the sources of pneumogenic comets, which were often found in the presence of radiologic alterations, such as pleuritis, bronchiectasia, or chronic obstructive pulmonary disease. In all of these conditions, fibrosis in the parietal pleura or interlobular septa may occur, which can lead to reflection of the ultrasound wave, generating echo comets (Table 2). The physical scatterer is represented by water-thickened interlobular septa with cardiogenic ULCs, and by connective tissue—thickened interlobular septa with pneumogenic ULCs.

The 2 types of ULCs can pose a challenge to differential diagnosis, although some clues may help distinguish the 2 entities. Cardiogenic ULCs occur in greater numbers and are more diffuse in the right lung than in the left lung, with a "hot zone" of higher density in the right anterior-axillary third intercostal space.[7] Cardiogenic ULCs can be dissolved in a few hours by an acute diuretic load.

METHODOLOGY

The echocardiographic examination is performed using any commercially available 2-D scanner, also portable, with any transducer frequency (from 1.6 to 5 MHz). There is no need for a second harmonic or Doppler imaging mode. The echocardiographic examinations are performed with patients in a near-supine or supine position (Figure 5). Ultrasound scanning of the anterior and lateral chest is obtained on the right and left hemithorax, from the second to the fourth (on the right side to the fifth) intercostal spaces, and from the parasternal line to the axillary line.

The comet-tail sign is defined as an echogenic, coherent, wedge-shaped signal with a narrow origin in the near field of the image. In each intercostal space, the number of comet-tail signs is recorded at the parasternal, midclavear, anterior axillary, and midaxillary sites (Figure 5). The sum of the comet-tail signs yields a score denoting the extent of extravascular fluid in the lung. Zero is defined as a complete absence of comet-tail artefacts in the investigated area. ULCs have a very satisfactory intraobserver and interobserver variability, around 5% and 7%, respectively.[7]

EXTRAVASCULAR LUNG WATER: CLINICAL VALIDATION

There are 2 other main methods of assessing extravascular lung water in the clinical setting: chest x-rays (used extensively in the clinical arena) and a catheter-based thermodilution technique (sometimes used in intensive care).[8,9] The ULC sign was compared with each of these 2 gold standards, and results were reassuring.

Nevertheless, each of the 2 standards suffers important limitations. Usually, chest x-ray allows adequate recognition of pulmonary edema, with signs evolving as a function of the wedge pressure.[8] At a pulmonary capillary wedge pressure of < 8 mm Hg, the vasculature pattern is normal. As the pulmonary capillary wedge pressure increases to

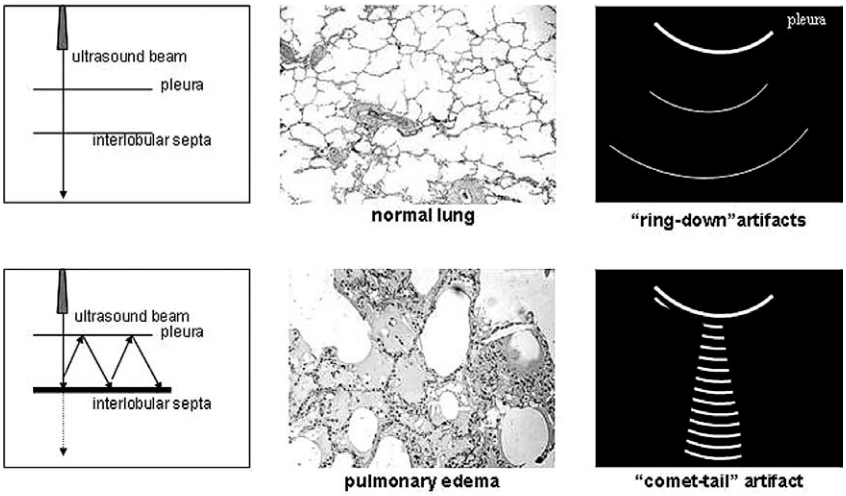

Figure 4 The hypothesized physical and anatomic basis of echocardiographic ULCs. Reflections of the ultrasound beam by the thickened interlobular septa proves "comet-tail" artifact in patients with extravascular lung water. (Reprinted from Jambrik et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. Am J Cardiol 2004;93:1265-1270, with permission from Excerpta Medica, Inc.)

Table 2 Differential diagnosis of ULCs originating from the pleural line

	Cardiogenic	Pneumogenic
Number	High	Low
Lateralization	Right > left lung	Right = left lung
Distribution	More diffuse	More patchy
Hot zone	Right anterior-axillary third space	Variable
Diuretic therapy	Reduction in hours	Stable
Underlying disease	Heart failure	Chronic obstructive pulmonary disease

10-12 mm Hg, the lower-zone vessels appear equal in diameter to or smaller than the upper-zone vessels. At pulmonary capillary wedge pressures of 12-18 mm Hg, the vessel borders become progressively hazier because of increasing extravasation of fluid into the interstitial space. This effect is sometimes evident as Kerley B-lines— horizontal, pleural-based, peripheral linear densities. As pulmonary capillary wedge pressure increases above 18-20 mm Hg, pulmonary edema occurs with interstitial fluid present in sufficient amounts to cause a perihilar "bat wing" appearance. However, full-blown cases of pulmonary edema with high wedge pressure can coexist with a paucity or absence of radiologic signs of pulmonary edema.[10]

In patients with congestive heart failure, chronic changes in pulmonary vascular pattern occur that do not correlate with the changes occurring in patients with normal left ventricular pressure at baseline, and abnormal elevations in left ventricular end-diastolic pressure may coexist with a normal pulmonary vascular pattern. The pulmonary vascular pattern varies with the patient's position (erect vs supine) and is altered substantially by underlying pulmonary disease.[6] Noninterpretable or ambiguous findings are not infrequent in patients with dyspnea. Finally, chest X-ray requires radiology facilities, uses ionizing energy, and poses a significant logistic burden.

Evaluation of the pulmonary vascular pattern is very important, but remains difficult and imprecise.[9] In a head-to-head simultaneous comparison of chest x-ray and ULC, we found a linear correlation between echocardiographic comet score and radiologic lung water score ($r = .78$; $P < .01$) (Figure 6).[7]

Typical examples of patients without and with extravascular lung water are shown in Figures 7 and 8, respectively. In clinical situations when there is time pressure, the chest scan can even be restricted to the "hot spot" of the right third anterior axillary intercostal space, still with a good correlation with radiologically assessed extravascular lung water.[7] Interpatient variations were obtained in 14 patients and showed an even stronger correlation between changes in echocardiographic ULC and radiologic lung water scores ($r = .89$; $P < .01$) (Figure 9).[7] Compared with chest x-ray, ULC assessment is obviously faster and simpler. The clinical impact of ULC is further increased by the nonionizing nature of the examination, which can be performed at bedside with

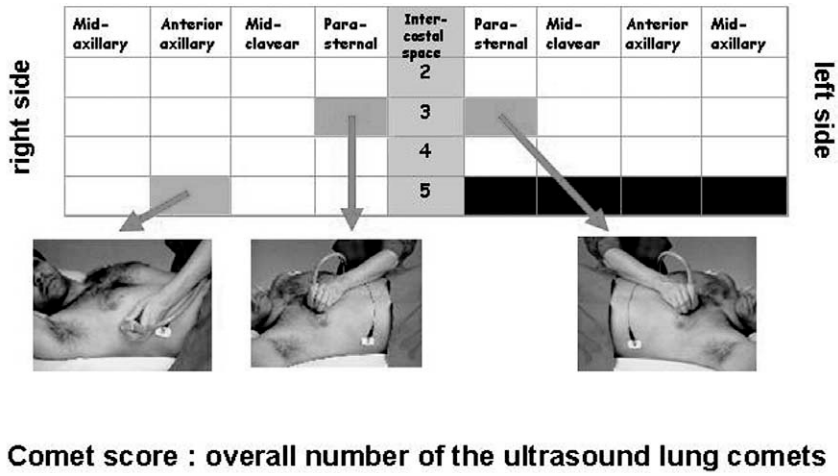

Figure 5 Methodology of echocardiographic lung scanning. (Reprinted from Jambrik et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. Am J Cardiol 2004;93:1265-1270, with permission from Excerpta Medica, Inc.)

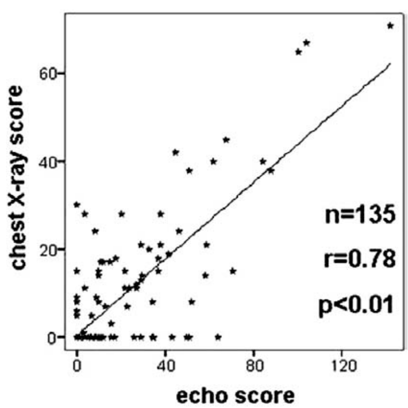

Figure 6 Correlation between radiologic score of extravascular lung water ULC score. (Reprinted from Jambrik et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. Am J Cardiol 2004;93: 1265-1270, with permission from Excerpta Medica, Inc.)

a hand-held device, is easily quantified, and is not dependent on patient decubitus (Table 3).

The indicator dilution method is another approach to assess extravascular lung water in a more direct way by the thermodilution technique, which requires right heart catheterization and arterial puncture.[11] A 10-mL bolus of cold 15% dextrose solution is injected through a central venous catheter, and the thermodilution curve is evaluated with arterial catheter inserted in the femoral artery. From the cardiac output, we can obtain the intrathoracic total volume and the intrathoracic blood volume, and finally from the difference of these 2 parameters, we can obtain the value of extravascular lung water. Normally, extra vascular lung water is < 500 mL; alveolar

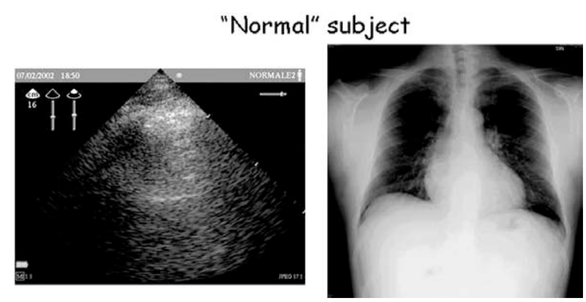

Figure 7 Echocardiographic view of the lung (**A**) and chest X-ray (**B**) in a patient without extravascular lung water. (Reprinted from Jambrik et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. Am J Cardiol 2004;93:1265-1270, with permission from Excerpta Medica, Inc.)

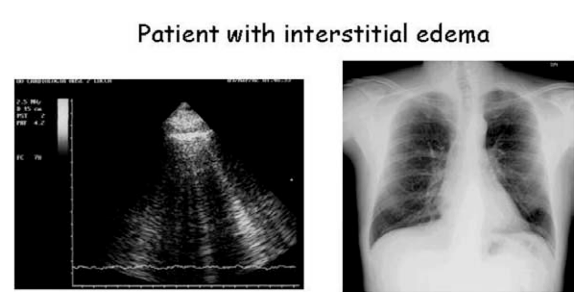

Figure 8 ULCs (**A**) and radiogram (**B**) in a patient with interstitial edema. (Reprinted from Jambrik et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. Am J Cardiol 2004;93:1265-1270, with permission from Excerpta Medica, Inc.)

flooding usually appears when the extravascular lung water is $> 75\%$ above the normal limit.[12]

A significant positive linear correlation was found between ULC score and extravascular lung

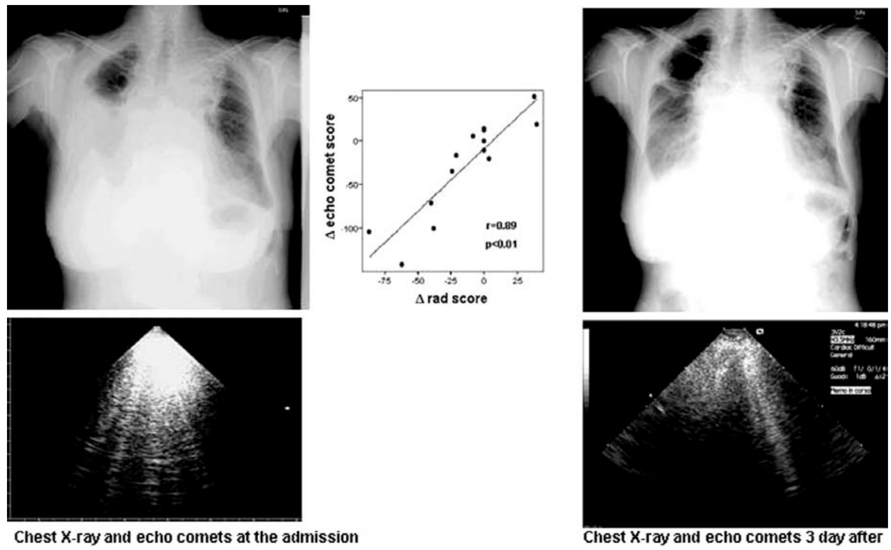

Figure 9 Intrapatient correlation between the changes in the radiologic score of extravascular lung water (*y*-axis) and echographically assessed comet score (*x*-axis). *EVLW*, extravascular lung water. (Reprinted from Jambrik et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. Am J Cardiol 2004;93:1265-1270, with permission from Excerpta Medica, Inc.)

Table 3 Available techniques for assessing extravascular lung water

	ULCs	Chest X-ray	Thermodilution
Portability	+++	+	−
Economic convenience	+++	++	−
Noninvasiveness	+++	+++	−
Nonionizing radiation	+++	−	−
Safety	+++	++	+
Quantitativity	++	+	++
Reproducibility	++	+	++
Accessibility	+++	++	−
Physician-friendly	+++	+	−
Patient-friendly	+++	+	−

+++, Excellent; ++, good; +, sufficient; −, poor.

Table 4 The quantification of ULCs in the echo report

Score	Number of ULCs	Extravascular lung water
0	<5	No signs
1	5–15	Mild degree
2	15–30	Moderate degree
3	>30	Severe degree

Description: Presence of ultrasound lung comets (of mild or moderate or severe degree) consistent with increased extravascular lung water.

water determined by the thermodilution system ($r = .42$; $P = .001$). In these same patients, the correlation was higher between the ULC score and radiologic lung water pressure ($r = .60$; $P < .001$). The indicator dilution method has the advantage of directly measuring extravascular lung water, whereas most imaging methods produce estimates of total water content (ie, vascular and extravascular lung water). However, the method is invasive, technically demanding, and used clinically only in intensive care patients in the cardiac surgery environment, mostly in the postoperative period (Table 3).

ECHOCARDIOGRAPHIC DESCRIPTION

At present, we have incorporated in our laboratory ULC assessment for all patients with dyspnea and with known or suspected heart failure. For clinical and research purposes, the best approach is to describe the "comet score," summing up all scores of all scanned spaces. This requires < 3 minutes and is added to our echo data bank. For clinical purposes, the response in the written report forwarded to the patient and the referring physician can be coded in a semiquantitative fashion (from absent to severe), similar to what is done for most echocardiographic parameters (Table 4). The presence of a few scattered comets can be a normal variant, especially in the lower intercostal spaces. Below the threshold of 5 comets, the signal is considered insignificant clinical noise.

This information could be of great relevance for serial evaluations in the same patient. Especially in heart failure patients, it is a frequent finding that changes in clinical status are possibly better mirrored by changes in ULCs rather than changes in

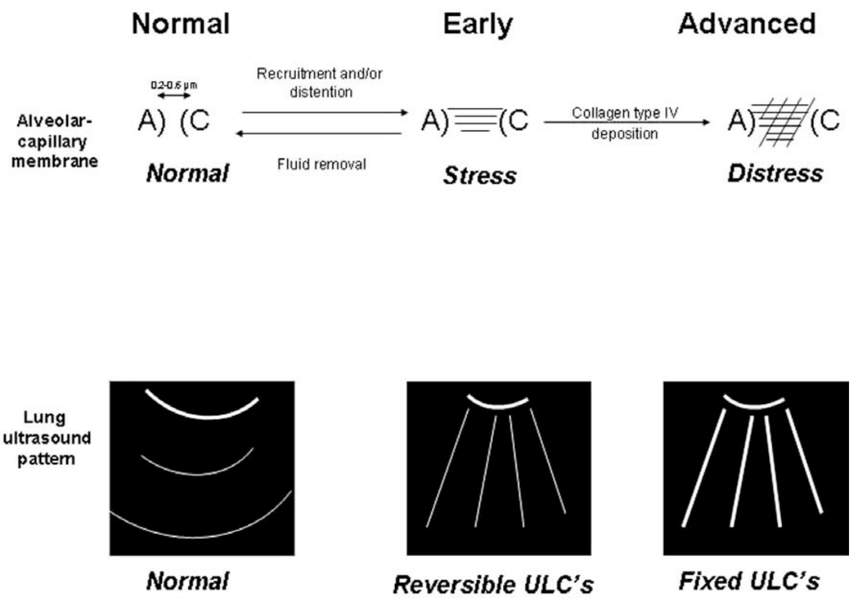

Figure 10 Schematic drawing representing the hypothetical effects of the natural history of heart failure on structural changes of the alveolar-capillary membrane (upper panel) and ultrasound (lower panels). In normal conditions (left side panels), the alveolar-capillary membrane is normal, and only normal ring-down artifact can be detected by ultrasound. During early stages of heart failure (central panels), pulmonary vessel recruitment and/or distension determine thickening of the interstitium and development of ULCs, which can be reversed by fluid removal. At an advanced stage of heart failure (right panels), irreversible structural remodeling of the interstitium is associated with fixed ULCs, which cannot be reversed by therapeutic interventions.

other much more stable and less reproducible parameters, such as ejection fraction.

POTENTIAL CLINICAL IMPACT

At this point, ULCs represent a useful, practical, appealingly simple way to assess extravascular lung water. This sign should be systematically assessed for in the echocardiographic evaluation of patients with dyspnea and/or known or suspected heart failure. Although cardiologic research with ULC has just started, we can already identify some clinically relevant correlates of this sign. It is directly related to radiologically assessed extravascular lung water[7] and is associated with a rise in pulmonary wedge pressure.[13] We can speculate that from a pathophysiologic standpoint, it indicates a condition of reversible stress or irreversible distress of the alveolar-capillary membrane, which may be present at rest in patients with acute or chronic heart failure and also can be elicited transiently by exercise in patients with severe baseline left ventricular dysfunction.[14] Its potential domain of application includes the differential diagnosis of dyspnea in the emergency room, monitoring of therapy in heart failure patients, and prognostic stratification in heart failure patients.

The potential impact of ULCs in the care of patients with heart failure is obvious for epidemiologic, pathophysiologic, and logistic reasons. In 2003, more than 1 million hospitalizations for heart failure occurred in the United States,[15] and a similar number was reported in Europe.[16] European Society of Cardiology guidelines recommend chest x-ray and echocardiography for the evaluation of heart failure patients.[17] In particular, chest x-ray is useful to detect the presence of cardiac enlargement and pulmonary congestion. Echocardiography can certainly do better than chest x-ray for cardiac enlargement, and—with ULC—may also provide direct imaging of pulmonary congestion.

From a pathophysiologic standpoint, ULCs promise to provide an insight onto pulmonary congestion and alveolar–capillary distress, 2 key players in the onset of acute heart failure.[18] In patients with chronic heart failure, alveolar-capillary membrane dysfunction may contribute to symptom exacerbation and exercise intolerance, and may be an independent prognosticator of clinical course.[19] Chronic heart failure increases the resistance to gas transfer across the alveolar–capillary interface. In early stages, an acute pressure (distention) and/or volume overload (recruitment of pulmonary capillaries) indicates a reversible stress failure of the alveolar-capillary membrane, with an increase of thickness due to fluid excess, which can be reversed with fluid removal (Figure 10). At a more advanced (and irreversible) stage, there is a structural remodelling of the alveolar-capillary membrane, with an excess deposition of collagen type IV, possibly triggered by excess neurohumoral activation (including angiotensin II and noradrenaline circulatory levels) and/or cytotoxic stimuli (such as increased tumour necrosis factor α), similar to what happens at the myocardial level.

ULCs provide a simple, user-friendly, radiation-free[20] direct imaging of extravascular lung water and alveolar-capillary distress, possibly useful for gaining insight into the mechanisms of heart failure. Finally, it is logistically important that the ULC information can be obtained with identical accuracy with simple portable units or expensive echocardiographic instruments.

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