Chapter 3

Lung Ultrasound Comet Tails — Technique and Clinical Significance

Douglas T. Summerfield and Bruce D. Johnson

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/56198

1. Introduction

While often overlooked by traditional echocardiography, the lungs and evaluation of extravascular lung water (EVLW) can be assessed by direct visualization with relatively simple ultrasonographic techniques. The results can help guide clinicians towards the cause of a patient's dyspnea and in the case of pulmonary edema even semi-quantitatively asses EVLW. Additionally the exam can be repeated as often as necessary to monitor response to treatment without fear of subjecting the patient to ionizing radiation associated with conventional chest radiography.

Advancing technology has allowed for increasingly miniaturized and portable ultrasound systems to the point where exams can be performed quickly at the bedside, often by the rounding physician. The more common standard of care for quantifying pulmonary edema has been a chest radiograph which, depending on the institution, may require more time to perform and a more formal interpretation than a portable ultrasound [1]. Even when it is obtained, chest radiograph can have a low sensitivity for common causes of dyspnea such as pulmonary edema [2, 3]. This may be due in part to poor radiographic windows of the patient or the intraobserver variability and skills of those interpreting the x-ray [4, 5]. In the case of acute pulmonary edema, the practitioner using techniques of lung ultrasound, can actually visualize the edema, classify it semi-quantitatively, and prescribe interventions before other traditional diagnostic techniques such as chest radiograph can even occur.

The lung ultrasound finding of "Comet Tails" has been well studied in how it relates to alveolar-interstitial syndromes. These syndromes include conditions with diffuse involvement of the pulmonary interstitium which lead to respiratory distress through impairment of alveolar-capillary exchange. Chronic conditions include pulmonary fibrosis, whereas acute entities are acute respiratory distress syndrome (ARDS), interstitial pneumonia, and acute pulmonary edema [5]. With careful attention paid by the examiner at the bedside to the patient's history and monitoring the response to treatment, the ultrasonographic finding of comet tails can be extremely useful in narrowing the differential diagnosis.

2. Definitions

"A-lines and B-lines" are two separate and distinct ultrasonographic images which may be seen during examination of the lungs by ultrasound (See Figures 1 &2). Their presence is not mutually exclusive, but the formation of each arises from a different underlying structure.

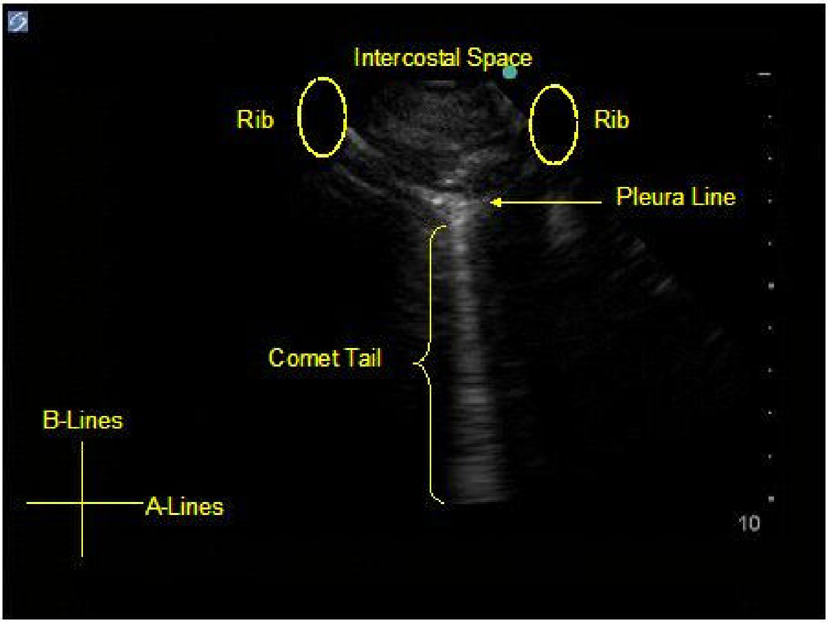


Figure 1. Image of comet tail "B-lines"

Comet-tails or "B-lines" are defined as hyperechoic reflections which originate only from and travel roughly perpendicular to the pleural line of the lung. They have a narrow base and form a ray spreading away from the transducer towards the bottom of the screen and synchronously move with lung respiration. All ultrasound images are formed when a reflection occurs at the interface of two regions with differing acoustic impedance [6]. In the case of comet tails this impedance occurs between fluid filled interlobular septa, with the acoustic impedance of water being 1.48x10^5gp/cm^2 and that of an air filled lung with the acoustic impedance of air being of 0.0004x10^5gp/cm^2. Interlobular septa are structures within the lung containing lymphatic vessels. These septa are below the resolution of the ultrasound beam, which can only detect

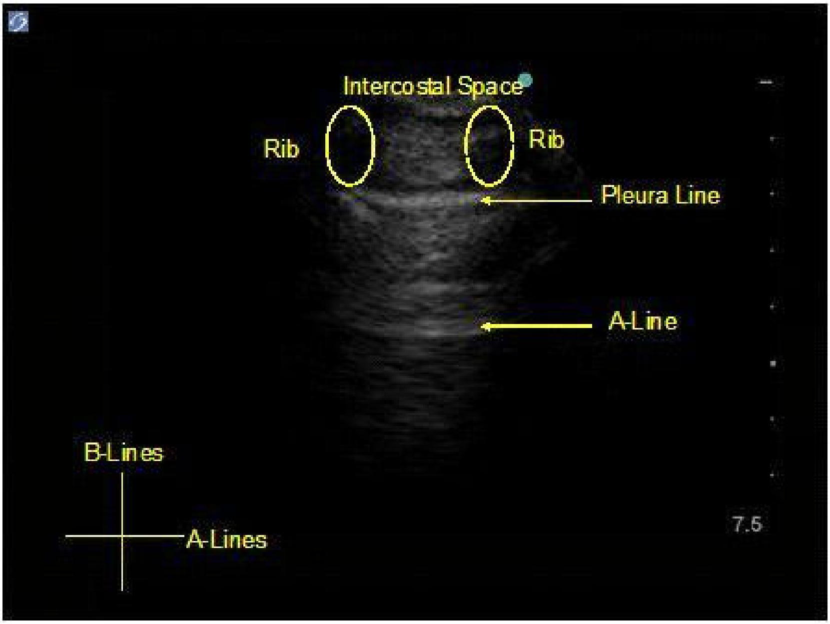


Figure 2. Image of pleural "A-lines."

objects larger than 1 mm. Instead of showing up as a distinct structure, in the right circumstances the areas of highly different acoustic impedance show up as a comet tail [7,8].

Under normal (non-edematous or fibrotic) conditions comet tails are absent because no acoustic mismatch occurs as the beam passes through the subpleural space. However, in conditions known as alveolar-interstitial syndromes an area of high acoustic mismatch occurs at the subpleural space were interlobular septa are in contact with the pleural lining. In the case of pulmonary edema this mismatch occurs between the differing impedances of air and water, however it can also occur anytime there is an area of differing impedances at the surface of the lungs such as pleuritis, fibrosis, or even chronic obstructive pulmonary disease [9].

Even though these structures are smaller than the resolution of the ultrasound beam, the reflections cans still be generated and sent back to the ultrasound probe. Continued reflections set up the phenomenon of reverberation which acts as a continued source of reflections back to the piezoelectric crystal. Since the ultrasound interprets time as distance, and each successive echo or return to the transducer occurs over a more distant time than the original signal, the ultrasound interprets these signals as reflections from a structure more distal from the ultrasound probe [6]. In this way a "beam" or comet tail image is created on the echo screen. (See Figure 3) Histologically the interlobular septa are 7 mm apart when they reach the sub pleural space and this is roughly the distance between the origins of individual comet tails at the pleural line [7].

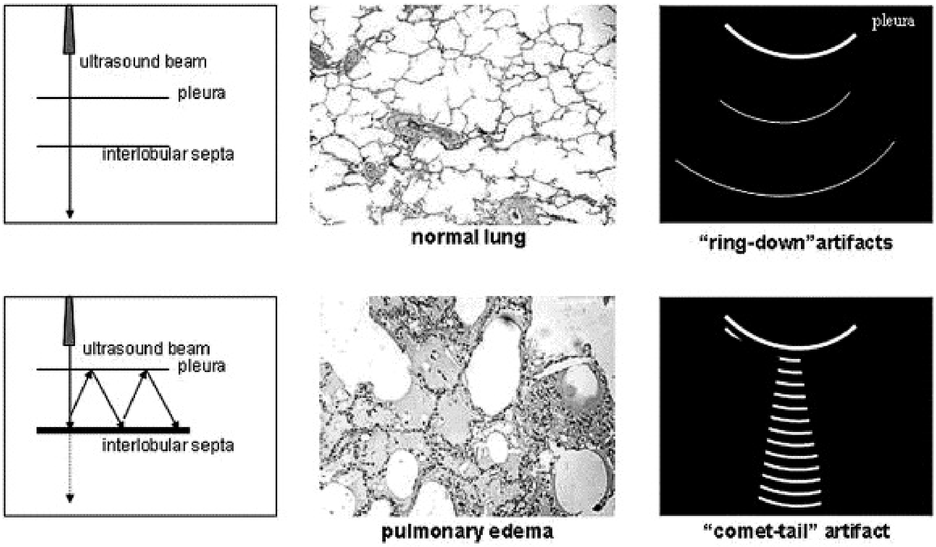
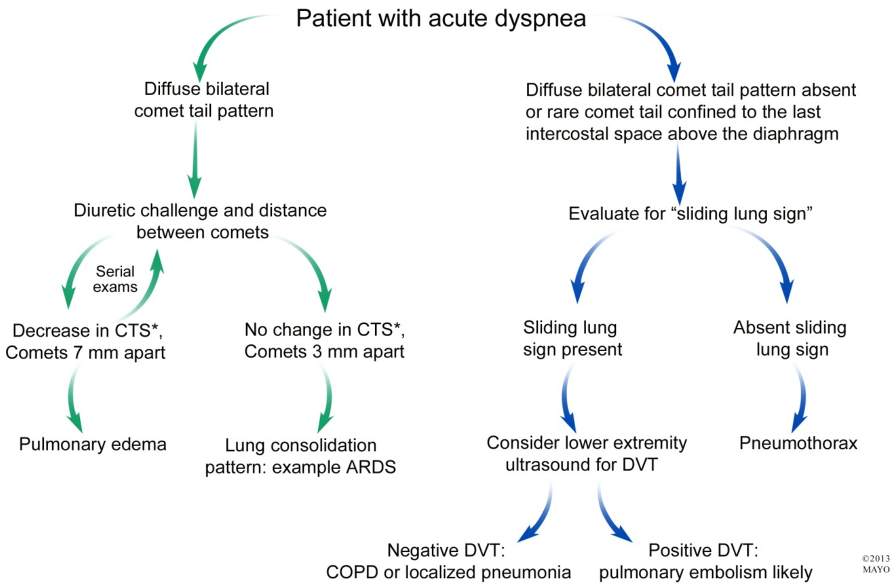


Figure 3. The hypothesized physical and anatomic basis of echocardiographic lung comet tails. Reflections of the ultrasound beam between thickened interlobular septa and the pleura generate a resonance signal over a prolonged time. The increased return over time is interpreted by the ultrasound machine as a hyperechoic structure originating deeper in the tissue and is displayed as a comet-tail on the ultrasound screen. (Illustrations and images 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.)

For the comet tail image to form, these thickened intralobular septa must be in contact with the sub pleural space as any air between them and the transducer has such a low acoustic impedance that the echo return takes too long and is simply "cancelled out" by the machine. (This is the reason lung comets are not seen in pneumothorax and can aid in the diagnosis of that condition.) [6] In a traditional chest radiograph these septa thickened by pulmonary edema are termed "Kerley B-lines" [10, 11].

A-Lines are another distinct ultrasonographic entity separate from the "B-line" comet tails. A-lines are hyperechoic lines which run roughly horizontal across the ultrasound screen and are parallel to the pleural line. These lines are equidistant to each other and are the same distance from each other as the pleural line is from the skin because they are reverberations of the pleural line. Again the ultrasound machine interprets the signals it receives temporally from the reverberations as depth. Hence the reflections are seen as lines deeper on the screen. The presence of A-lines, and absence of B-lines indicates the presence of "dry" intralobular septa and is a strong predictor of a normal capillary wedge pressure [12].



*CTS: Comet Tail Score.

Figure 4. Proposed algorithm for use of lung comet tails in the evaluation of patients with acute dyspnea. In the case of pulmonary edema, serial ultrasonographic exams performed after therapeutic intervention(s) will reveal a diminishing number of comet tails. This algorithm is suggested as a possible supplement for typical clinical assessment in the decision making process.

3. History and origins

The “comet-tail” ultrasonographic sign was first described by Ziskin and colleagues in 1982 when an intrahepatic shotgun pellet was observed to create an artifact similar to what is seen in lung comets [8]. Other conditions affecting the pleura of the lung were later noted to create a similar pattern [9]. However it was not until 1997 when Daniel Lichtenstein, a French critical care physician, described lung comet tails as an ultrasonographic sign of alveolar-interstitial syndrome. In his paper he examined 250 patients, 121 with evidence of either wide-spread (N=92) or localized (N=29) evidence of alveolar-interstitial syndrome on chest x-ray and 129 patients with a normal chest radiograph. He found the sensitivity of ultrasound in detecting this pattern was 93.4% with a specificity of 93.0% in patients who did not have evidence for this on chest x-ray [7].

When Lichtenstein compared chest computerized tomography (CT) to the ultrasound findings on 29 of his 250 patients, he found comet tails were generated diffusely across the lungs from two distinct sources. Both of these sources were lesions associated with acute pulmonary edema, thickened sub-pleural interlobular septa and ground-glass regions. Occasionally even “normal” subjects registered the rare comet tail in the diaphragmatic regions of the lung, and this was detected in both x-ray and CT scan [7].

Clinical applications of comet tails began after Jambrik and colleagues evaluated 121 hospitalized patients with lung ultrasound (see technique below) and compared the findings to chest x-ray. They found a significant linear correlation between a comet tail score (CTS) and x-ray ($r=0.78$, $p<.01$). When patients were examined multiple times, an even higher intrapatient correlation was seen ($r=0.89$; $p<0.01$). [13]

Lichtenstein and Jambrik’s observations were expanded to the medical in-patient setting by Tsereva who validated the technique in patients with diastolic heart failure [14] and by Volpicelli, who validated the use of ultrasound in diagnosis alveolar interstitial syndrome with a 85.7% sensitivity and 97.7% specificity. The lower sensitivity in the later study can be explained by the timing of the x-ray and the ultrasounds. The chest radiographs which the ultrasounds were compared to were taken at admission and guided the treatment given, whereas the lung ultrasounds were done after the initiation of therapy. Thus for some patients the lack of comet tails was merely the resolution of pulmonary edema, but in the analysis resulted in a lower sensitivity of the ultrasound technique [5]. Other researchers further validated lung ultrasound and have suggested that it is superior to chest x-ray with sensitivities similar to Nt-proBNP levels [15]. Nt-proBNP (N-terminal probrain type natriuretic peptide) has become a common biomarker for fluid overload and tracking health status in heart failure patients. However, fluid overload may not always correlate with interstitial pulmonary edema and thus may be a marker primarily of vascular fluid overload.

In an effort to help quantify the number of comet tails seen on exam, Agricola et al. evaluated post-cardiac surgery patients. They devised a relatively simple definition for a positive or negative comet tail exam. A positive comet tail test was simply multiple bilateral comet tails seen over the whole lung surface. A negative test was with the rare occasional comet tail, the absence of comet tails, or comet tails confined to the last intercostals space. They then compared the patient’s comet tail test to the amount of extravascular lung water (EVLW) determined by Pulse Contour Cardiac Output (PiCCO - is an invasive technique requiring catheters and uses principals of transpulmonary thermodilution and arterial pulse contour analysis in order to estimate extravascular lung water), to the patient’s wedge pressure, and to their radiologic score as determined by chest x-ray. Again good correlation was seen between the radiologic assessment of EVLW and comet tails ($r=0.60$, $p<0.0001$) and also when compared to wedge pressure ($r=0.48$, $p<0.0001$). Most useful was the comparison to EVLW. Normal EVLW is <500 mL with alveolar flooding occurring when EVLW reaches more than 75% above its normal limit [16, 17]. With this in mind, the negative test had a 90% sensitivity and 89% specificity of accurately detecting an EVLW volume <500 mL. Likewise a positive test had a 90% and 86% sensitivity and specificity of detecting EVLW >500 mL. When comparing the comet tail test to chest radiographs and PiCCO, they found they were even able to detect excess EVLW below the threshold which would cause alveolar edema (sub clinical or early stages of pulmonary edema) with 87% and 89% sensitivity and specificity [11].

Monitoring EVLW through the formation of lung comet tails was shown to be even more important than knowing a patients overall volume status. Using bioelectric impedance

http://dx.doi.org/10.5772/56198

Mallamaci demonstrated that in dialysis patients, overall volume status was not linked to pulmonary congestion and the formation of comet tails. Rather Comet tails, and pulmonary congestion, had more to do with a patient's left ventricular function. They also demonstrated the ability of comet tails to detect patient who were asymptomatic as 57% of patients had moderate to severe pulmonary congestion but did not have symptoms suggesting such [18]. This is in keeping with Lichtenstein's original paper which discussed a patient with a fat embolism who had the sonographic sign of comet tails three days before symptoms occurred [7] and in older literature which argued that alveolar edema, which would lead to symptoms, is preceded by interstitial edema (which may or may not cause symptoms but can now be detected by ultrasound) [19].

4. Technique

The standard technique for quantification of comet tails has been reported in a number of studies and was pioneered by Picano and colleagues [9,13, 11]. This technique has shown its utility clinically as used by the Himalayan Rescue Association to help diagnose and monitor the degree of pulmonary edema in high-altitude pulmonary edema (HAPE). [20]

The exam is performed using any commercially available portable ultrasound device which has a 1-7 MHz phased array probe. We recommend the use of the 1-5 MHz cardiac probe as it is ideal for viewing between rib spaces and still allows deep enough penetration of the ultrasound beam to view distal structures. Other groups have also found adequate views with the high frequency linear probes as well as the abdominal probes as well [21].

The patient is placed in a supine or near supine position with the anterior chest wall exposed. Each intercostals space from the second to the fifth on the right and the second to the fourth on the left is scanned in four different positions. These are para-sternal, midclavicular, anterior axillary, and mid-axillary. This gives the examiner a total of 28 different windows to examine, 16 on the right and 12 on the left (See graphic representation Table 1).

Right Hemithorax					**Left Hemithorax**			
Mid-Axillary	Anterior axillary	Mid-clavicular	Para-Sternal	Inter-costal space	Para-Sternal	Mid-clavicular	Anterior axillary	Mid-axillary

Table 1. Diagram of the ultrasound windows used to obtain the Comet Tail Score (CTS). This technique was proposed by Jambrik at al. and used by Jambrik, Fagenholtz, Pratali, Agricola, Picano, Mallamaci. Each window is evaluated for comet tails, and the number present is added to form a cumulative score.

Within each window, comet tails as defined above are counted. The sum of the comet tails seen can then be compiled for a comet tail score (CTS). The intra- and interobserver variability using this method has been reported as 5.1% and 7.4% respectively [13]. For clinical purposes Picano and colleges report the comet tail score in a semiquantitative manner for patients in pulmonary edema (Table 2).

Score	Number of Comet Tails	EVLW
0	<5	No Signs
1	5-15	Mild
2	15-30	Moderate
3	"/>30	Severe

Table 2. Semiquantitive classification of the Comet Tail Score (CTS)as proposed by Picano and colleagues.

4.1. Other techniques

Simpler less quantitative techniques have also been described with good prediction of pulmonary edema. Volpicelli and colleagues described a technique where each hemithorax is divided into four quadrants (8 total), upper and lower anterior and upper and lower lateral divided longitudinally by the anterior axillary line and transversely by the 2^{nd} intercostal space. An exam was considered abnormal (positive for edema) if it had all of the following features:

1. At least three comet tails per scan.

2. Diffusely positive with more than one scan per side containing comet tails.

3. Bilateral presence of comet tails.

By using these criteria this group found a 85.7% sensitivity and 97.7% specificity when compared to chest x-ray for detecting the presence of pulmonary edema [5].

5. Application and differential diagnosis

The presence of occasional sporadic comet tails can be a normal finding. Typically these are limited to the last lateral intercostals space above the diaphragm with a hot spot often seen on the right most caudal anterior axillary window [22, 9]. Care must be taken, however, in attributing a hot spot in the lower lateral windows to a benign finding, as local lung consolidation from diseases such as ARDS, atelectasis, or pneumonia can exhibit this pattern. [22, 11]. In those cases, the clinical presentation of dyspnea with other physical signs and symptoms such as low oxygen saturations and fever should be used to help differentiate “normal” from diseased state. With the case of patients presenting with dyspnea, the pathologic state should be considered present until "ruled out" with other diagnostic modalities. However in the research arena where "healthy" subjects may be tested, the pre-test probability that comet tails localized to the last lateral intercostals spaces are normal, is high.

A diffuse bilateral comet tail pattern is not considered normal and is indicative of alveolar-interstitial syndromes (AIS). These can be brought about by a number of disease entities including chronic conditions such as pulmonary fibrosis, and acute entities such as acute respiratory distress syndrome (ARDS), interstitial pneumonia, and acute pulmonary edema [5]. Different clinical presentations can help elucidate the etiology of these different diseases which have the same comet tail pattern. The time course of the illness can differentiate chronic causes such as pulmonary fibrosis and acute causes such as pulmonary edema. Additionally slight variations in the pattern of comet tails are noted. In the case of a fibrotic lung, the comet tails are equal in both hemi thoraces, whereas in cardiac pulmonary edema they are bilateral but with a predilection for the right hemi-thorax. Also in the fibrotic lung comet tails are more patchy than in pulmonary edema, and are stable with diuretic therapy [9].

Highly dense entities such as ARDS typically give rise to comet tails only in regions where the diseased lung is in contact with the sub-pleural space. These highly dense areas give rise to multiple comet tails less than 3 mm apart, whereas comet tails arising from thickened inter-lobular septa are 7 mm apart [23]. Additionally an ARDS pattern also gives rise to comet tails in focal areas which coalesce together and form comet tails of differing lengths and multiple irregular comet tails [7, 23, 1].

Importantly comet tails which arise from pulmonary edema should respond to treatment and disappear as interventions are made [18]. If they do not, then an alternate diagnosis should be sought. This reenforces the need for serial exams many authors encourage repeat exams to monitor response to therapy.

Since the presence of the occasional comet tail is considered normal, the lack of comet tails can be diagnostic as well. Comet tail formation requires an area of differing acoustic impedances, when this is not present no comet tails are created. Such is the case of a pneumothorax. In examining for this potential emergent condition, an additional ultrasonographic sign must be viewed, that of the "sliding lung sign." This is the hyperechoic line which is the interface between the visceral and parietal pleura. This line will slide back and forth with respiration. When there is no sliding of this line, and an absence of comet tails, a pneumothorax should be suspected [24]. The is particularly helpful when some studies show that standard chest x-ray, in addition to taking longer, misses 30% of cases [25-27]. This is contrasted to the lung ultrasound which in a large meta-analysis and systematic review looked at 8 studies representing 1,048 patients. When using both the absence of lung comet tails and sliding lung sign ultrasound was 90.9% sensitive and 98.2% specific in making the diagnosis of pneumothorax. In the same analysis chest radiograph was only 50.2% sensitive, but with a similar specificity of 99.4% [28].

In patients with minimal comet tails confined to the intercostal space above the diaphragm, or no comet tails present on lung ultrasound, but who otherwise present with dyspnea, other common diagnoses should be considered. These include COPD, acute bronchitis, and pulmonary embolism [1]. The issue of COPD is a special consideration which has been studied by at least three groups. In the initial comet tail paper, Lichtenstein observed that COPD could give rise to a fibrotic pattern, bilateral comet tails [7]. However later work performed by the same author comparing ultrasound to x-ray diagnosis suggested that the presence of diffuse bilateral comet tails was absent in 92% of patient with COPD (N=26) and absent or confined only to the laster intercostal space in 98.75% of patients without respiratory disorder (N=80). The two patients in the COPD group who had a positive test (the false positives) had pneumonia in the regions viewed as positive on ultrasound. In the patients without respiratory symptoms, one patient demonstrated a positive test. Interestingly even though he did not have any symptoms, that one patient was admitted for acute renal failure requiring urgent dialysis, again supporting the idea that ultrasound findings occur before symptoms [22]. Additional studies also support the lack of findings of comet tails in COPD exacerbations. In fact in one study looking at the presence of comet tails in patients with acute shortness of breath, the most common discharge diagnosis of patients who did not exhibit bilateral diffuse comet tails was COPD [1, 18, 21].

Overall this technique allows for the rapid assessment of patients in respiratory distress and can take less than three minutes [9, 15]. When used for detecting pulmonary edema, it has nearly a 95% concordance with chest radiographs [1] and, as discussed above, may be more sensitive than chest radiograph for this diagnosis [15]. A gross recognition of the comet tail pattern present, as well as the patient's history and response to treatment can guide the clinician to the correct diagnosis. In terms of application, bedside ultrasound in many emergency departments and intensive care units is readily available.

6. Special situations

Due to its ease of use, portability and relative low cost, this technology is ideally suited for remote research and clinical applications. In fact a bedside ultrasound is the only diagnostic imaging currently used on the International Space Station.

Research applications have used the ultrasonographic finding of comet tails to monitor pulmonary edema in healthy volunteers subjected to extreme environments. These include ironman athletes, breath-hold deep divers, and mountain climbers [29]. Due to the remote nature of the conditions, ultrasound is especially useful in mountaineering where up to 10% of climbers above 4,000 M develop the life-threatening condition known as High Altitude Pulmonary Edema [30]. (See Figure 5) At an altitude of 4,240 M Fagenholz, using the CTS technique described in this chapter, showed that a CTS score of 35 +/- 11 corresponded to patients suffering from HAPE which differed from those who were short of breath from other causes who had a CTS of 12 +/-6.8 [20]. Others have shown that in the presence of normal left ventricular function and normal pulmonary artery pressures, sojourners above 4790 m can develop pulmonary edema with a corresponding decrease in oxygen saturation. The comet tails describe in these studies had right lung predominance [31]. When used in the high altitude environment, care should be taken to ensure that the device employed uses solid state storage.

This is found on most modern portable ultrasounds. Non-solid state devices cool using fans which will over heat at extreme altitudes.

Figure 5. Author (DS) demonstrating the ease of use and portability of modern ultrasound systems by performing an assessment of EVLW at the base camp of Mt Everest, ele 5,364 M, on an elite climber.

7. Conclusion

Although dyspnea is a leading cause of hospital admission, determining its etiology and subsequent treatment remains one of the greatest diagnostic challenges a clinicians faces. While many have lamented the perceived loss of physical exam skills amongst practitioners, the traditional lung exam and classic findings heard on auscultation are often difficult to hear in a noisy intensive care unit or emergency department [32, 33]. Even in ideal circumstances, there is abundant literature to suggest that the physical exam may be inaccurate [14, 15]. This leads the clinician to rely on adjuncts to aid in diagnosis.

In the case of dyspnea, chest radiograph are typically employed to help narrow the differential diagnosis. However even these can be fraught with difficulties including time to obtain, and read the x-ray. Fortunately the field of ultrasound and echocardiography has greatly expanded in the past 20 years. The lung ultrasound finding of comet tails can help guide therapeutic interventions, and unlike chest radiograph, the exam can be repeated without fear of increased radiation exposure.

With the advent of small bedside machines, lung ultrasound techniques can become an extension of the physical exam. These exams can be repeated as often as necessary in response to changing clinical conditions. In this way ultrasonographers can guide real-time decision making for patient care.

Acknowledgements

Funded by grants from NIH HL71478, Mayo Clinic and The North Face Company.

Author details

Douglas T. Summerfield and Bruce D. Johnson*

*Address all correspondence to: Johnson.bruce@mayo.edu

Divisions of Pulmonary and Critical Care Medicine and Cardiovascular Diseases, Mayo Clinic Rochester, USA

References

[1] Zanobetti, Maurizia, et alCan chest ultrasonography replace standard chest radiography for evaluation of acute dyspnea in the ED?" Chest. (2011). , 139, 1140-1147.

[2] Wang, C. S, et al. Does this dyspneic patient in the emergency department have congestive heart failure?" JAMA. (2005). , 294, 1944-1956.

[3] Cremona, G, et al. Pulmonary extravascular fluid accumulation in recreational climbers: a prospective study." Lancet (2002). , 359, 303-309.

[4] Milne, E. N. et. al. "The radiologic distinction of cardiogenic and noncardiogenic edema." AJR Am J Roentgenol. (1985). , 144, 879-894.

[5] Volpicelli, Giovanni, et alBedside lung ultrasound in the assessment of alveolar-interstitial syndrome." American Journal of Emergency Medicine. (2006). , 24, 689-696.

[6] Levitov, A. Critical Care Ultrasonography. (2009). New York, New York: McGraw-Hill

[7] Lichtenstein, Daniel et alThe Comet-tail Artifact." Am J Respir Crit Care Med. (1997). , 156, 1640-1646.

[8] Ziskin, M. C, et al. The comet tail artifact." J Ultrasound Med. (1982). , 1, 1-7.

[9] Picano, E, et al. Ultrasound lung comets: A clinically useful sign of extravascular lung water." J Am Soc Echocardiography. (2006). , 19(3), 356-363.

[10] Kerley, P. Radiology in heart disease. BMJ (1933).

[11] Agricola, Eustachio, et alUltrasound Comet-tail images: A Marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water." Chest. (2005). , 127, 1690-1695.

[12] Lichtenstein, D. A, 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(4), 1014-1020.

[13] Jambrik, Z, et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water." Am J Cardiology. (2004).

[14] Tsverava, M, & Tsverava, D. Comet tail artefact in diagnosis of pulmonary congestion in patients with diastolic heart failure." Georgian Medical News. (2010). , 10(187), 28-35.

[15] Vitturi, N, et al. Thoracic ultrasonography: A new method for the work-up of patients with dyspnea." Journal of Ultrasound. (2011). , 14, 147-151.

[16] Stapczynski, J. S, et al. Congestive heart failure and pulmonary edema." Emergency medicine: a comprehensive study guide. New York: McGraw-Hill; (1992). , 216-219.

[17] Lange, N. R, & Schuster, D. P. The measurement of lung water." Crit Care. (1999). RR24., 19.

[18] Mallamaci, F, et al. Detection of pulmonary congestion by chest ultrasound in dialysis patients." JACC:Cardiovascular Imagin. (2010). , 3(6), 586-594.

[19] Staub, N. C. Pulmonary edema." Physiol Rev. (1974). , 54, 678-811.

[20] Fagenholz, P. J, et al. Chest ultrasonography for the diagnosis and monitoring of high altitude pulmonary edema." Chest. , 131(4), 1013-1018.

[21] Volpicelli, G, et al. Usefulness of lung ultrasound in the bedside distinction between pulmonary edema and exacerbation of COPD." Emerg Radiol. (2008). , 15(3), 145-151.

[22] Lichtenstein, D, & Mezière, G. A lung ultrasound sign allowing bedside distinction between pulmonary edema and COPD: the comet-tail artifact." Intesive Care Med. (1998). , 24(12), 1331-1334.

[23] Lichtenstein, D, et al. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome." Anesthesiology. (2004). , 100, 9-15.

[24] Lichtenstein, D, & Menu, Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung Sliding." Chest. (1995). , 108(5), 1345-1348.

[25] Tocino, I. M, et al. Distribution of pneumothorax in the supine and semirecumbent critically ill adult." AJR Am J Roentgenol. (1985). , 144(5), 901-905.

[26] Chiles, C, & Ravin, C. E. Radiographic recognition of pneumothorax in the intensive care unit." Crit Care Med. (1986). , 14(8), 677-680.

[27] Ball, C. G, et al. Factors related to the failure of radiographic recognition of occult posttraumatic pneumothoraces." Am J Surg. (2005). , 189(5), 541-546.

[28] Alrajhi, K. Test characteristics of ultrasonography for the detection of pneumothorax: A systematic review and meta-analysis." Chest. (2012). , 141(3), 703-708.

[29] Garbella, E, et al. Pulmonary edema in healthy subjects in extreme conditions." Pulm Med. (2011).

[30] Bärtsch, P, et al. Respiratory symptoms, radiographic and physiologic correlations at high altitude." In: Sutton JR, Coates G, Remmers JE, editors. Hypoxia: the adaptations. Toronto: B.C. Decker;(1990). , 241-245.

[31] Pratali, L, et al. Frequent subclinical high-altitude pulmonary edema detected by chest sonography as ultrasound lung comets in recreational climbers." Crit Care Med. (2010). , 38(9), 1818-1823.

[32] Mccullough, P. A. 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, 198-204.

[33] Remes, J. Validity of clinical diagnosis of heart failure in primary health care." Eur Heart J. (1991). , 12, 315-321.