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PICTORIAL ESSAY

All B-lines are equal, but some B-lines are more equal than others

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Abstract
In this pictorial essay the theme of the differential diagnosis between the different causes of lung interstitial disease will be discussed, which can be detected on lung ultrasound as B lines. In particular, from the experience obtained during the covid-19 pandemic, the term B line may appear too simplified, and new data in the literature show that it is necessary to update the terminology and the differential diagnosis of this ultrasound sign.

Keywords Lung · B-line · Artifact · Pneumonia · Ultrasound

The SARS-CoV-2 pandemic enhanced the role of lung ultrasound [1–4]. Particularly, since SARS-CoV-2 induces an interstitial viral pneumonia affecting the peripheral areas of the lung (at least in the first phase), lung ultrasound proved to be a useful and easy to apply method by detecting subpleural lung changes, based on the detection of a specific sign of interstitial disease called B line [1–4].

The "official" definition of B line dates back to a consensus published in 2012, where they were defined as "laser-like vertical hyperechoic reverberation artifacts arising from the pleural line are called B-lines ("comet tails"), extending to the bottom of the screen without fading and moving synchronously with lung sliding" [5].

Several works and data in the literature have focused on the evaluation of B lines in cardiology field [6–9] (Fig. 1). Therefore, the B lines, as defined in the consensus, were proved to be a sign characterized by excellent statistical accuracy in the differential diagnosis of cardiogenic pulmonary edema in patients with dyspnoea and acute respiratory failure, in particular versus COPD [6]; they have also been shown to be useful in monitoring the clinical response to pharmacological and ventilation therapy (eg continuos positive airway pressure) [7–9]. Moreover, their use has also been tested as outpatient monitoring of patients with chronic heart failure [7–9].

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In addition to cardiogenic pulmonary edema, the B lines can be found in other forms of non-cardiogenic, inflammatory pulmonary edema, ie acute respiratory distress syndrome (ARDS) [10]. The distribution of the B lines could distinguish cardiogenic pulmonary edema from ARDS; indeed, in cardiogenic edema there is a typical pulmonary base-apex gradient, whereas the distribution is typically irregular and non-homogeneous in patients with ARDS [10, 11].

Moreover, some works tested the usefulness of lung ultrasound in the diagnosis of chronic fibrosing interstitial diseases. The main signs of those diseases were the presence of B lines, but with specific features; indeed, they present a non-homogeneous distribution (variable according to the main pathology), the pleural line is irregular, thickened and often interrupted by small subpleural consolidations [12, 13]. Furthermore, B lines are more thickened and irregular than those found in cardiogenic pulmonary edema [12, 13] (Fig. 2).

A similar experience was performed on patients with rheumatic diseases, in which the execution of a lung ultrasound with detection of B lines, could show early lung involvement of the disease [14–16].

Furthermore, we must not forget focal interstitial syndrome such as contusion, bronchopneumonia and finally cancer [13].

The SARS-CoV-2 pandemic underlined the features of viral pneumonia: interstitium-alveolar pneumonia which can be detected by finding B lines, consolidations and in some rare cases pleural effusion on ultrasound [1–5]. In particular, SARS-CoV-2 pneumonia showed some specific features; the

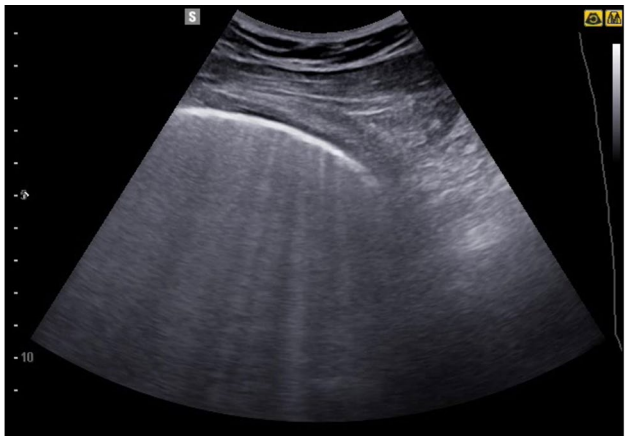

Fig. 1 Convex probe scan performed on patient with cardiogenic pulmonary edema. The image shows a regular pleural line, from which multiple vertical hyperechoic artifacts originate, of equal size, which reach the bottom of the image, without losing intensity

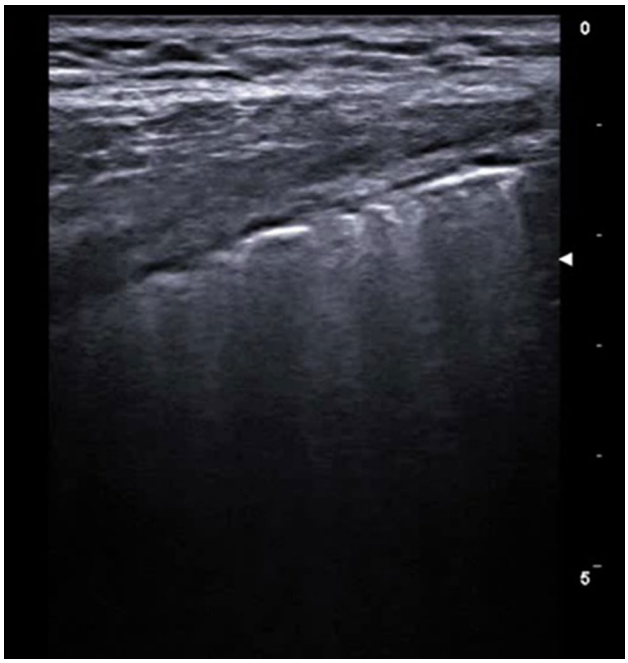

Fig. 2 Intercostal scan by linear probe on a patient affected by chronic interstitial disease: a clear irregularity of the pleural line is highlighted, which is interrupted by small subpleural hypoechoic consolidations. Vertical hyperechoic artifacts originating from interruptions in the pleural line are also evident. The artifacts are different from each other for their thickness

pleural line is almost irregular, jagged, sometimes thickened and with small subcentimetric subpleural consolidations of a hypoechoic appearance [1–5].

Furthermore, the B lines have specific features not only in their distribution (irregular with saving areas) but also in their appearance: they are often different from each other, with a different ultrasound beam width; some of them do not reach the bottom of the image; some seem to have a more demarcated and hyperechoic internal layer (Figs. 3, 4, 5 and 6). Furthermore, some authors evaluated the sign of the so-called "light beam", ie that of an echogenic front (probably formed the confluent B lines) that appears and disappears with the acts of breath (Figs. 7, 8). According to a study conducted by Volpicelli and colleagues, this sign is a typical feature of the LUS pattern in COVID-19 pneumonia, and its presence during a pandemic surge should prompt high suspicion for COVID-19 pulmonary involvement [1].

In last years, some works attempted to find physical bases for the genesis of B lines. In particular, a first work by Mento et al. published in 2020 showed that B-lines can be clearly visualized only within a specific frequency range on an engineering model [17]. The frequency response of these bubbly structures is more likely associated to specific resonance phenomena. A subsequent work [18] by the same group tested the genesis of the artifacts on a laboratory model by reproducing the alveoli shape with the alveolar interstitium level, with known dimensions; the authors showed that low imaging frequencies (i.e., f 2 MHz) generally do not allow the generation of consistent artifacts, regardless of the alveolar diameter choice. Only when the alveolar spacing assumes the largest investigated value (i.e., s 395 lm) do the lowest frequencies start to enable the B-lines' formation.

Therefore, the final representation of the vertical artifact on B-mode ultrasound seems to strongly depend on the frequency of the ultrasounds employed by the probe (therefore on the setting of the machine), and on the three-dimensional

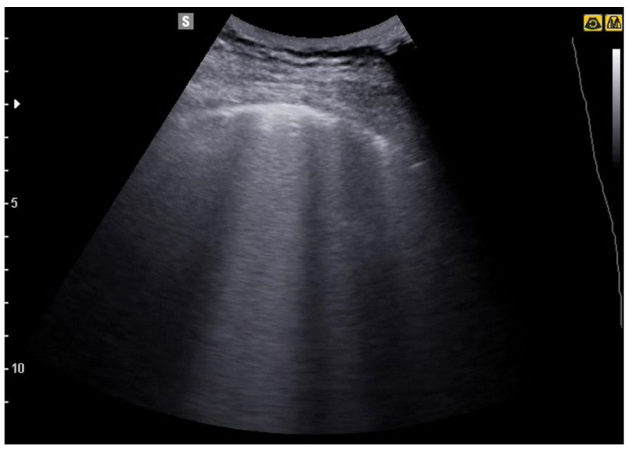

Fig. 3 Lung ultrasound scan performed with a convex probe on a patient with COVID-19 pneumonia: the image shows an irregularity of the pleural line that appears thickened in the middle part of the image. At that level, a vertical echogenic front arises widening in depth reaching the distal part of the image, with a maximum thickness of about 2 cm. Nearby, there are other vertical hyperechoic artifacts that are isolated and with significantly less thickness. There are also sparing lung fields

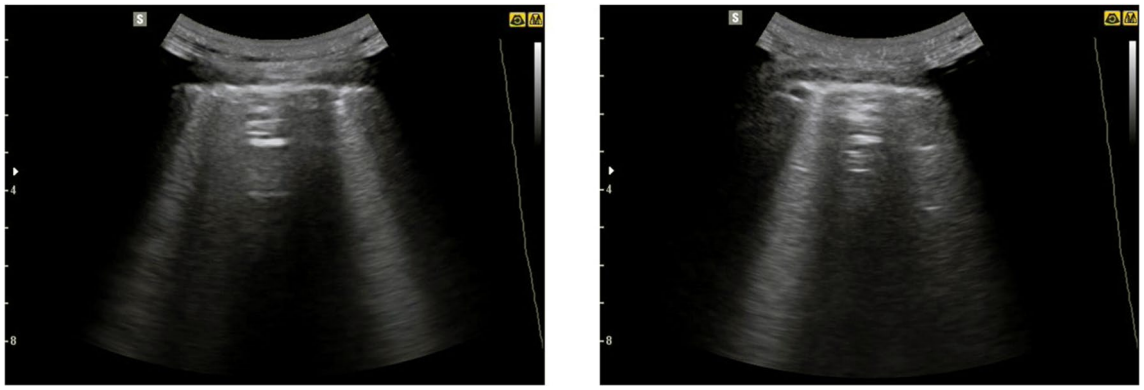

Fig. 4 Ultrasound images of the same lung field on a patient affected by COVID-19 pneumonia within a few frames. The images show that there are vertical echogenic artifacts arising from the pleural line that appear and disappear after a few frames, corresponding with the different phases of the breath. This type of artifact has been called «light beam» and some works have shown good specificity for the diagnosis of COVID-19 pneumonia

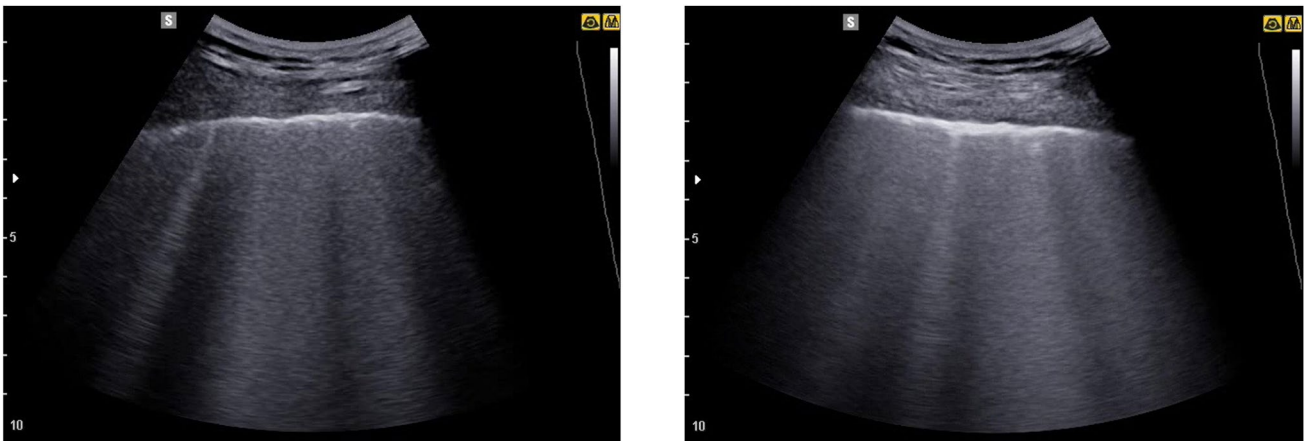

Fig. 5 Convex probe scan in patient affected by COVID-19 pneumonia. It is evident an irregularity of the pleural line which appears jagged. Vertical artifacts arise from the pleural line that appear both unique both confluent with greater thickness in the same scan

Fig. 6 Convex probe scan in patient affected by COVID-19 pneumonia. In this image, a clear irregularity of the pleural line is evident, which is thickened in the central portion. Vertical echogenic artifacts arise from the pleura line, but each is different from the other for its thickness

structure of the interstitium-alveolar spaces. The authors argued that those factors can affect the representation of the artifacts on the ultrasound image, and in the near future it will be possible to differentiate different pictures of different diseases (with alveolar interstitium involvement) on the basis of the iconographic representation of the vertical artifacts [17, 18]. The frequency characterization of vertical artifacts can be used as an indirect measure of the state of the lung, i.e., the lower the frequency at which B lines are visualized, the larger the channels formed between the alveoli and the more severe the lung condition [17, 18].

In the midst of the SARS-CoV-2 pandemic, a consensus of experts published a document suggesting the differentiation of vertical artifacts into B lines (BLA) or comet tail artifacts (CTA) [19]. The reverberation artefact (evaluated by low frequency transducer < 5 MHz without interfering presets) is called BLA if arising from a smooth pleural line (evaluated by high frequency transducer ≥ 10 MHz) [19]. The BLA arises from edema within the interstitium, is well defined with stable width, hyperechoic and extending indefinitely (the entire depth, at least 10 cm), erasing A-lines and moving with lung sliding [19]. The reverberation artefact is called CTA if arising from an irregular (or fragmented) pleural line (evaluated by high frequency transducer ≥ 10 MHz), changes in width (such as e a comet with narrow head and wide tail), is well defined, hyperechoic, and extending definitely (< 10 cm in depth) (evaluated by low frequency transducer < 5 MHz without interfering presets) [19].

Therefore, the vertical artifacts typically found in COVID-19 pneumonia seem to fall within the definition of

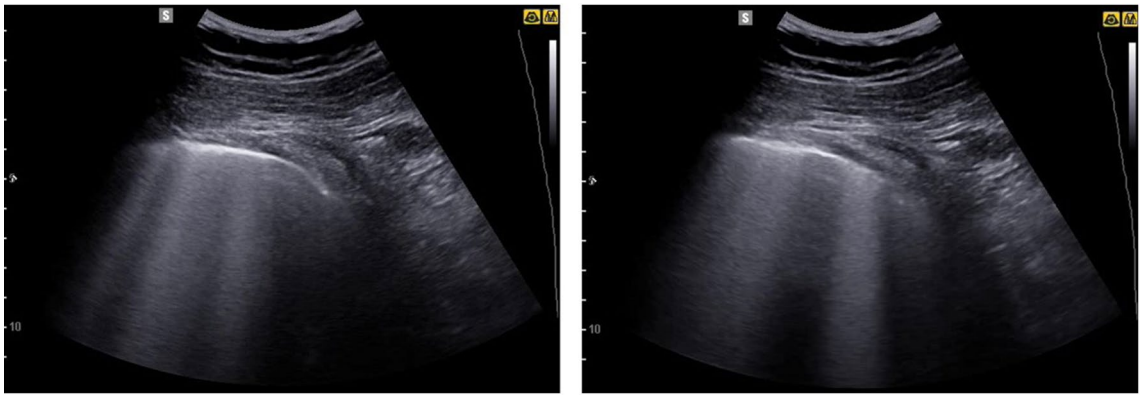

Fig. 7 The figures highlight the presence of vertical echogenic artifacts; sparing areas are evident among the artifacts, that are characterized by a normal A pattern (only horizontal artifacts). The presence of sparing areas in the context of interstitial disease is one of the typical feature of COVID-19 pneumonia. Vertical artifacts have some peculiarities: they originate from a small interruption of the pleural line (viewable as a small rounded anechoic space), they tend to widen in depth and appear to have a more echogenic central portion than the edges of the same artifact

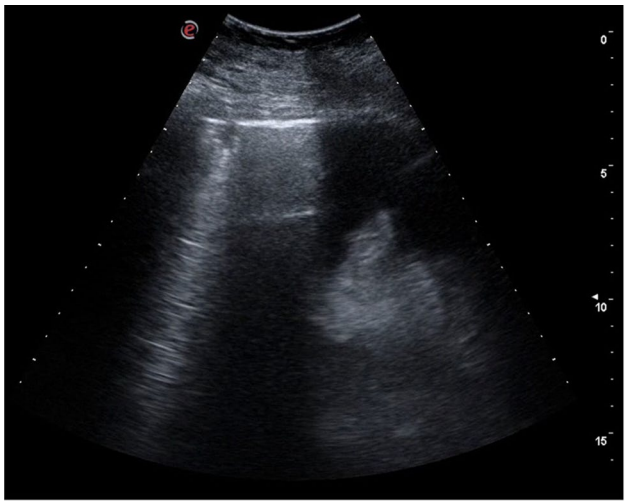

Fig. 8 Patient affected by chronic heart failure with known pleural effusion and superimposed COVID-19 pneumonia. On the left side of the image an anechoic fluid layer is evident, compatible with the known effusion. In the right part of the image, in the context of a normal pattern A, a focal interruption of the pleural line is outlined from which a vertical artifact originates displaying an internal portion more echogenic than its lateral portions. Furthermore, the artifact seems to widen in depth after its origin

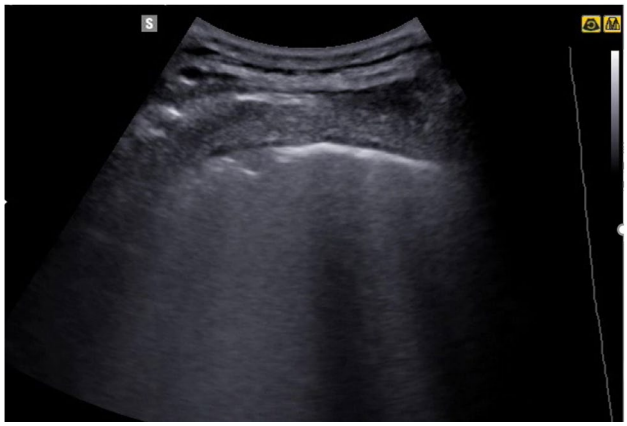

Fig. 9 Ultrasound scan performed on a basal lung field of a patient with COVID-19 pneumonia. The lung field is almost completely "subverted" by vertical echogenic artifacts confluent with each other, leaving only a small area with A pattern (sparing area). In the area of greatest density of the vertical artifacts, a small subpleural consolidation is formed, thus confirming the severe deconstruction of the pulmonary parenchyma and therefore inducing a consolidation pattern

CTA, as well as those found in chronic interstitial pneumonia (Fig. 9).

Nowadays, those are only early and preliminar data. Certainly, COVID-19 pandemic is taking shape as a watershed in the history of lung ultrasound. Nowadays, the "simple" ultrasound finding of B lines seems to be limiting as compared to a wide range of differential diagnoses in the field of interstitial diseases (Fig. 10). In our opinion, in the near future we will have to make a differetial diagnosis not by single signs detection, but by ultrasound patterns, with more ultrasound signs that combined with the clinical context can lead to an etiologically more specific diagnosis. Furthermore, the use of software and machines with diversified physical characteristics (use of different frequencies) will allow a further step towards a more accurate diagnosis.

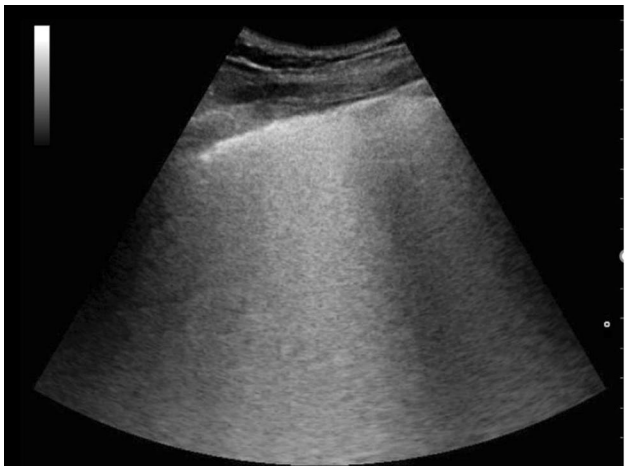

Fig. 10 Ultrasound image representing the so-called "white lung" pattern; the lung field is occupied by a single hyperechoic front, and the A lines are not longer evaluable. The term "white lung" has been usually employed to indicate a pattern suggestive for acute cardiogenic pulmonary edema; otherwise, that ultrasound finding can be detected in several clinical conditions leading to severe alveolar deaeration such as severe interstitial pneumonia, ARDS and focal forms such as pulmonary contusion. The evaluation of the distribution of that ultrasound finding allows to distinguish the different forms; the ultrasound artifact itself does not allow a clear differential diagnosis, if not integrated into a clinical context

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Declarations

Conflict of interest Authors declare no conflict of interest and no founding sources.

Ethical approval The work complies with the ethical guidelines of the 1975 Helsinki Declaration; since it is not a research work, a priori approval by the institution's human research committee was not necessary.

Informed consent Informed consent was obtained from all patients.

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