Abstract. – Background: Literature concerning lung ultrasonography is largely growing and opening new diagnostic opportunities. The clinical value of the ultrasonographic interstitio-alveolar syndrome, based on artifactual (lung comets or B-lines) rather than real images, in the detection of lung contusion, pneumonia and pulmonary edema, is clearly demonstrated. As clinical echographers, though, we are living the paradox of relying our experience in lung pathology on images whose biophysical and genetic nature is not fully understood.

Objective and Perspectives: A detailed review of the ultimate findings with an analysis of recent and past literature regarding the formation of ultrasonographic artifacts was undertaken with the aim of clarifying what we know and where we are heading in this field. It is important for us to underline how lung ultrasonography is not morphological, as this, along with the study of artifact formation, will be the base for the development of a novel ‘view’ able to take us from artifact to reality in terms of ‘quantification’ of lung disease and damage.

Conclusions: Lung ultrasonographic artifacts need to be read in a new light which will privilege biophysical knowledge and research. In this field a gap of basic knowledge clearly exists. A greater understanding of the formation of acoustic artifacts from ultrasound interference on discretely aerated tissues of variable density, would place the practice of lung “ultrasonography” in the correct technological and clinical position.

Key Words:
Ultrasound, Sonography, Artifacts, Lung, Diagnosis.

Introduction

Study of the lung through ultrasound (US) is a relatively recent acquisition1. In the last few years, the use of lung US has received growing attention in clinical research in intensive care patients and trauma settings, in patients with heart failure, adult respiratory distress syndrome, pneumonia and pneumothorax2-5. More precisely, what is recent, is the study of the partially aerated lung, as both the chest wall and the pathologic pleural cavity have received attention ever since echography began to be used as a diagnostic tool. Although steps ahead have been made, we pay today a cultural debt towards an organ which has always been considered “hostile” to US6.

This concept has important biophysical implications as air is a barrier to the progression of ultrasound. An air collection larger than the ultrasound wavelength used for scanning will specularly reflect the acoustic energy it receives and thus impede an anatomic scan of underlying structures. Smaller and contiguous air collections instead, produce complex phenomena of reflection generating artifactual images7. Different lung diseases, collectively included in the generic term of ‘interstitio-alveolar’ syndrome, are described not anatomically but through the analysis of these phenomena.

Real US Lung Imaging

Normal lung, as well as pathologic lung that is not completely collapsed, does not offer an echo-graphic morphologic representation with usual clinical frequencies (3.5-15 MHz). The presence of air in the normal lung (about 80-85% of its total volume), and that in the pathologic lung up to a density of 0.8-0.9 g/ml, constitutes an acoustic barrier which is inidoneous to the formation of a morphologic echostructure7. The normal pleura acts as an almost complete specular reflector (about 85% of incident acoustic energy does not penetrate the pleural plane). Due to the high acoustic impedance of an elevated air to soft tissue gradient, US energy cannot penetrate lung tissue and it is sent back to the tranducer producing horizontal reverberation phenomena (Figure 1)
seen each time one tries to explore an air collection whether in the pleural cavity, in the abdomen or in a phantom. Table I summarizes examples of impedent interfaces pertinent to lung sonography.

Morphologic lung ultrasonography is, therefore, a real echography of defined “acoustic entities”, as a critical lung mass (with a density close to that of water), pleural thickenings or a pleural effusion. The possibility of seeing these entities through echography is part of radiologists’, pneumologists’ and emergency medicine physicians’ culture and they have long been able to study the thoracic wall, the pleural cavity, pneumonias, superficial lung tumors as well as parts of the mediastinum. Only in the last 10 years has it been observed that a specific, sub-compacting lung pathology is able to generate US images which do not actually represent real structures but artifacts (Figure 2).

Artefactual US Lung Imaging

Most of new diagnostic opportunities in the interstitial pathology of the lung ( extravascular lung water expansion, edema, interstitial inflammation, interstitial fibrosis) are based on sonographic visual artifacts. An artifact is defined as an erroneous interpretation of a signal by the machine. Artifacts are produced in echography when the machine creates acoustic interference signals as images which are not correlated to a real morphologic entity. An interesting family of these artifacts is formed by so called “ring down artifacts”, also known as “lung comets” or “B-lines” (Figure 2). These are defined, in lung US, as linear vertical signals that emerge from the pleural line and extend through the entire lung field. Although well known to all those who use and study lung US in cases of interstitial pathology, their characterization in terms of acoustic interactions has not been fully described. To date, no scientific evidence exists regarding their genesis and whether they are similar in different types of lung pathology, or if instead they may be discerned in terms of number, density, homogeneity, spared areas and so on.

Although their presence in actual US lung images is unequivocally evident, their biophysical

Table I. Reflective properties of acoustic discontinuities in human chest.

<table>
<thead>
<tr>
<th>Interfaces</th>
<th>Reflection coefficients*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat/muscle</td>
<td>0.13</td>
</tr>
<tr>
<td>Muscle/atelectatic lung</td>
<td>-0.01</td>
</tr>
<tr>
<td>Muscle/consolidated lung (pneumonia)</td>
<td>-0.61</td>
</tr>
<tr>
<td>Muscle/deflated lung</td>
<td>-0.72</td>
</tr>
<tr>
<td>Muscle/inflated lung</td>
<td>-0.88</td>
</tr>
<tr>
<td>Muscle/air</td>
<td>-0.99</td>
</tr>
<tr>
<td>Water/air</td>
<td>-0.99</td>
</tr>
</tbody>
</table>

*Acoustic energy reflected back from anatomic interfaces (1 = maximal reflection, 0 = maximal acoustic permeability).
characterization is not so clear at all. We are in the paradoxical situation of being able to understand certain subatomic interactions and at the same time not know what simple acoustic interactions as B-lines or the “white lung” stand for. The few Authors who have intended to study the formation of these artifacts on biologic and non-biologic substrates have been able to classify US artifacts as reverberation and/or resonance phenomena based on limited past scientific evidence. In fact, historically, the only study addressing these artifacts formation was the one carried out by Avruch et al. on the concept of US induced resonance between small air bubbles arranged in tetrahedrons. Although this study leaves several perplexities as a pure in vivo phenomenon, numerous subsequent ones refer to Avruch’s resonant tetrahedrons as the paradigm of a diffuse acoustic phenomenon described prevalently, but confusedly, as “ring down artifacts”. As often happens in science, we may find with surprise that several decades ago certain physicists, and not physicians, had described the acoustic behavior of the lung, not in terms of images but of acoustic interactions and permeability, first admitting and later denying productive interference as all that goes beyond acoustic reverberations on multiple and discrete air collections.

What seems to emerge is that lung tissue permeability to US is correlated to its density or its porosity, in other words to its increase in weight or, furthermore, to its loss of air content or deflation (deflated lung with same weight, isobaric, with no intrinsic pathology). In this context, the “B-lines” in their variable arrangements (but are they really all arrangements of different B-lines?) appear to the machine as “signals” that indicate a physical event corresponding to a physiopathologic lung alteration. And if it is so, the image we create through echography is actually redundant and a simple display showing numbers, perhaps a color map, or Cartesian axes as the results of complex equations and algorithms solved, could be enough for diagnostic purposes.

The Interstitial-Alveolar Syndrome
Sonographic interstitial-alveolar syndrome was first described in 1997. To date, the vast majority of Authors refer to the classical Lichtenstein’s interpretation. This vision emphasizes the role of subpleural interlobular septa for the genesis of lung comets (B-Lines). We believe it is time to reflect on this thesis and comprehend the real and complex nature of ultrasound lung artifacts.

Moreover, in order to see and acquire these interference phenomena, we are using machines that paradoxically consider them as errors and that technology is working to adjust. We are studying phenomena that appear to those who design and build echographic machines as parasites on which to carry out a sort of “electronic cosmesis”.

What occurs is not a purely theoretical or technical problem, it would be so if these effects were only encountered in the laboratory, but actually several clinical studies are based on data regarding pathologic lungs that appear as non-structured fields of B-lines. And how can we deny the value of being able to use these images clinically, for the detection and differentiation of lung disease? How can we deplore the formulation of the echographic interstitial syndrome based on the presence of few to coalescent B-lines? No doubt exists regarding the value of the echographic interstitial syndrome in the detection of lung pathology, what is missing is a thorough understanding of the formation of US artifacts both in terms of biophysical phenomena but especially of anatomic and structural lung alterations.

The interstitial, or interstitio-alveolar syndrome, is an anatomo-pathological entity but, unlike the alveolar syndrome which has its respective echographic anatomy (a lung consolidation), it creates artifacts instead of real images. Evidence shows that what is tagged as echographic interstitial syndrome does not topographically go
beyond the first two millimeters of subpleural lung tissue, although what is seen unequivocally fills the entire display.

In this view, we are building whole chapters of echographic imaging regarding different lung entities, based on signs we do not fully know and which are characterized by an intrinsic elusiveness. This uncertainty derives from the fact that these vertical artifacts, contrary to current opinion, do not appear to correlate with a specific anatomical structure. A recent work on this topic and rare preexisting studies have demonstrated how similar artifacts may be created in proper bubble systems both in vitro and in vivo. There is evidence that analogous signals are produced in jelly systems, in foam systems or on a polyurethane scaffold (Figure 3) (personal unpublished data) independent of a tetrahedric or definite anatomic structure (as interlobular lung septa). It appears ever clearer how signals analogous to B-lines are seen each time the sonated substrate increases its permeability to US due to geometric alterations in its porosity (i.e. density).

**Perspectives and Conclusions**

Lung sonography is an interesting diagnostic method, with a high sensitivity in cases of interstitial lung pathology, in particular located in near subpleural parenchyma. However, we believe that lung US artifacts need to be read in a new perspective which will privilege biophysical research and clarify how this type of echography is not morphological. Although we have demonstrated the link between echographic syndromes and certain lung pathology it does not mean we should still be talking, in these specific cases, of “echography”.

It may seem provocative but if we believe in lung US we should at this point plan a future that considers the relationship between artifactual lung images and lung density. Density will be isobaric when what varies is air extension and relatively isovolumetric when what varies is the interstitial space (or organ weight).

Will it be a radiant future? No data yet allows us to affirm this. If we think, though, about the applications of Computerized Tomography in the quantitative evaluation of subpleural lung density and to the clinical implications this had in terms of pulmonary edema, acute lung injury and adult respiratory distress syndrome, even if the close ideal of lung “echography” was only a discrete, strictly cortical, densitometric model, we could consider ourselves satisfied.

**References**

Lung and ultrasound: time to “reflect”