The power and limitations of lung ultrasound.

On the Practice of Ultrasound

At first, what little I knew about lung ultrasound seemed to be at variance with what I thought to be appropriate standards of practice in other applications. However, excellent clinical results were claimed, so I went about interviewing practitioners in ICU settings and looked at some of the literature, from peer reviewed, through YouTube videos.

We practice in two realms simultaneously: a global one from our education, literature, meetings, and presentations, and a local one on the individual we are trying to help with our ultrasound diagnostics. A lot of the limitations of ultrasound, arise from a lack of communication between separate sonic fiefdoms. Our common denominator is the equipment we use and therein may be a way to regain something that was diluted after the big bang of subspecialty fragmentation of the last 25 years. Lung ultrasound is a pretty remote tributary from the main stream of practice, so it should make a good practice study example.

A Fetal Preview

I am going to cite a few things I did myself, old articles, included for concept rather than content. I am so glad that I have had the opportunity to collaborate with Elaine Farrell, an awesome neonatologist. One of our joint papers was “Fetal Lung Development: compressibility as a measure of maturity”, which appeared in the November 1985 issue of Radiology. Let me set the stage as I recall it now. Respiratory distress was the leading clinical concern in NICU’s. Artificial surfactants were just being introduced, and obstetrics was resistant to using steroids pre-emptively. Assessing functional maturation of the lungs (ie, the elaboration of surfactants within alveoli) was pretty limited to very few phospholipid assays in amniotic fluid samples.

When surfactants are produced, the lungs soften. We sought to evaluate fetal lung compliance from continuous high speed imaging of a magnified region of interest of the left lung adjacent to the border of the heart. Our visual clue was the old time fluoroscopic (and early liver ultrasound) technique of seeing if the parenchyma of an organ moved en bloc (stiff) or if it squished (soft) after a forceful, rapid surface deformation, like coughing, sneezing, or thumping.

This approach seemed to work excellently; there was an obvious visual cue, plenty of cases, and great statistics. However, this work seemed to drop into a black hole. Of course this might have been deserved, but I have always been suspicious of three factors: it was presented at an RSNA meeting and published in the radiology literature, the concept involved materials science and physiology, not anatomy, and, it demanded a high level of performance for the equipment.

Equipment is Everything (One of the Pillars of Ultrasound)

Magnification was the critical system feature for that (transabdominal) functional fetal lung evaluation. When you write an image onto the memory for the display unit, the echo information is cast onto a fixed number of pixels. If you magnify that image, spatial resolution decreases. The image becomes bigger and fuzzier. This is called ‘read’ magnification, and it has been around since the beginning of ultrasound. The Acuson 128 was a beam forming system that reconstructed images on a point-by-point basis instead of line by line. There was ‘write’ magnification: a region of interest was selected and the entire array insonified and interrogated just that region. Spatial and contrast resolution were enhanced. This is just like zooming from a landscape view of a forest to a telephoto picture of the leaves of one tree. Instead of changing the optics of a zoom lens mechanically, the electrophotonics of the transducer are adjusted via software. This scheme of image formation was computationally intensive to a degree which was not matched by most of the commercial systems in popular use in obstetrics then.

There is one more general concern to be gleaned from some subsequent reports addressing fetal lung maturation. The first report of comparing average reflectivity of lung and liver was likely from...
Heidelberg in 1991 in *Ultrasound in Obstetrics and Gynecology*. The notion is that serial changes in relative reflectivity can be correlated with lung maturation after alveolar development, even though functional competence is not an anatomic feature. This is a little like looking at liver reflectivity versus that of the renal cortex for identifying fat infiltration. Lung/liver reflectivity seems reasonable, but it’s also a really bad idea technically, because it utilizes data samples that are corrupted by a vast amount of noise of various types arising from interactions all along the imaging chain as well as the sound pulses propagating through the body region under study. The consequence is that one facility might get results that they can apply clinically with a particular unit, specific transducer, and a cohesive patient demographic, but the results will be different for any change in operating conditions. The use of a ratio doesn’t do anything for standardization either, being a factor only when the quantities are independent and bear a linear relationship.

The early days of ultrasound were littered with similar false leads in other application areas. There have been about a half a dozen new reports of lung/liver reflectivity approaches in the OB ultrasound literature in the last year, even though we know a lot more about ultrasound now than we did in 1991.

**Claude Joyner’s Brilliant Observation**

I had the great good fortune to present papers or participate in educational courses in the 1970s with the late Claude Joyner. Claude was a cardiologist and a pioneer of echocardiography. He was supportive and smart, a great teacher, and a perfect gentleman who never sought the limelight. The biggest problem then in hospitalized patients was, by far, acute pulmonary embolism. Chest X-rays were typically not helpful, and most of the identified cases were of massive thrombi.

Claude told me that if you scan through an interspace, you should have no signal beyond the pleura, but if there is transmission and reflection, then the lung has to be abnormal, such as a peripheral infarct. It is worthwhile to read this exposition of the concept from 1967. This was elegant in its simplicity, it made sense given what was known then, and it addressed a major problem. However, with the immense area of sonically accessible lung surface, there is a major sampling problem for detecting focal processes.

**Hampton’s Hump and Lung Ultrasound**

In order for ultrasound to visualize any of the lung itself, peripheral alveoli have to be filled with fluid. Lung is like a foam, and its ultrasonic transmission properties are much more complicated than a fluid zone like an organ with blood-filled small vessels, nerves, and a macromolecular collagenous skeleton. Going back to acute pulmonary embolus, there are few X-ray signs, any of which are pretty rare occurrences. One great example is Hampton’s Hump, reported by MGH legends Aubrey Hampton and Benjamin Castleman (Correlation of postmortem chest teleroentgenograms with autopsy findings with special reference to pulmonary embolism and infarction. *AJR Am J Roentgenol.*1940;43:305–326). The ‘hump’ is a peripheral pleural based opacity that occurs in those few cases of pulmonary embolism with lung infarction. This is from an era in radiology in which findings with a distinct pathologic correlation might constitute a sign. The presence of a sign might be a clue, but its absence conveys nothing. This is like saying the specificity is high but the sensitivity is way low. Most imaging findings don’t score too highly in sensitivity or specificity, and clinical utilization revolves around everything else that you know about the patient at the time of the study.

I have tended to avoid ultrasound applications involving the lung. My basic bias is that X-rays are great for lungs, and CT is better, and I have the sonologists’ dislike of anything that blocks ultrasound transmission in spades. I do like pleura, though. I did some A Mode interferometry for measuring pleural thickness in 1973 and I had a short note in 1988 about visualizing the margin of the lung (with a high frequency linear array) in city dwellers and in a patient with scleroderma. Pneumothorax in NICU dwellers is an exception, because this is an ionizing radiation-free way to determine or exclude a critical condition that can be done right at the isolette with a portable or mobile ultrasound unit with a very high frequency linear array with excellent near field viewing. In the case of a pneumothorax, the pleura is the single (parietal) layer. There is also the dynamic backup of failing to see the two layers of pleura slide over each other when they are separated by an air gap. There is less of a sampling problem than in adults because the air pocket will be positioned upmost, the thorax is small, and the pleural space is pristine.

**An Interview with an Intensivist**

From time to time, I’ve seen some papers using ultrasound for various pulmonary conditions, like interstitial fibrosis, mainly from Europe and Asia. It seems that pretty much all of the imaging was done with low frequency convex or sector probes with near field issues, which never made much sense to me technically, although the reports were glowingly positive about findings in carefully
selected study populations. A few confident YouTube videos were made with a linear array, which
was placed across an interspace. There was shadowing from the ribs, taking out about 50% of the
elements from contributing to image formation for the edge of the lung. This is another one of those
inexplicable quirks that makes no sense technically or procedurally.

I happened to mention my interest in this area to an acquaintance who distributes ultrasound
equipment. He put me in touch with an academic internist at one of Chicago’s main teaching
hospitals. I was told that he had seven or eight years’ experience with ultrasound. I e-mailed him,
explained my testing of high performance ultra-portable equipment, expressed a desire to learn
about this application, and stated that I was happy to share anything that I knew about the
applications that I had been doing. A visit was granted.

The intensivist is an attending physician at his hospital’s adult intensive care units. His interest is in
bedside ultrasound that he does himself as an integral part of managing critically ill patients. He said
that he had never consulted with anyone in radiology about lung imaging or about having the service
provided. He was dismissive of portable chest films, despite the technical improvement in that
equipment during the last 20 years. He saw no reason to involve the hospital’s portable ultrasound
service.

I asked him about the administrative part of imaging. My impression was that he made observations
during the exam, but that archiving and reporting were not important. Lung ultrasound was billed as
‘physical exam’ with a note appended in the chart. Procedures had a different protocol, because of
their high reimbursement potential. Thoracentesis and jugular vein catheter insertion were cited. I
asked about platform devices. His response was that these and their various transducers were not of
much value and it was a nuisance to move equipment on an elevator between different units.

It seems that his department had just purchased a hand held portable unit for him. It was a low
frequency, single element, mechanical sector scanner which I had tested and declined to name or
include in my review of portable units, because of an astonishing level of noise. He said that he
really liked having a screen that he could hold close to his eyes when he was doing an exam. He did
not need his left hand for anything else during the study. He seemed to have no interest in other
units or anything technical about ultrasound itself. He did not regret that his diagnostic evaluation
was limited to the lung. We touched on sampling error, and I got the sense that the lung was only
looked at in two or maybe three places on each side. He showed me his copy of Daniel Lichtenstein’s
Blue Protocol, and advised that I read it before calling the interview to the end. I never got to the
ICU.

I have not met Daniel Lichtenstein, but I should like to sometime. I have a real admiration for what
he has accomplished, but I hated the book. The admiration part was that he took a primary
observation that he likely came up with himself in parallel with Claude Joyner and then pursued it
academically and scientifically in his emergency/intensive care area. I would guess that he had no
support from the medical imaging community during his years of establishing his technique. He
developed “signs” of lung disease in several publications and correlated them with macro- and
microscopic pathology.

What I hated was the large amount of editorial content to the effect that the technical part of
ultrasound is irrelevant. I think I recall that his favorite unit is a 1992 Hitachi, that he disapproves of
more modern units with noise and artifact suppression, and that he advises covering over the
controls when the ultrasound system is in use.  
Jason Birnholz, MD

**A and B Lines**

This approach to lung ultrasound does not involve imaging the lung. Instead, information is gleaned from perceived differences in image noise in the far field. There is a definite cleverness in this, making lemonade out of speckle, when all of the progress in every other area of ultrasound has stemmed from noise reduction for improved anatomic fidelity. It does feel like stepping back to classifying states and conditions by their humors.

A lung is said to be “normal” when there are A lines spaced along the depth axis the imaging field. The A lines are multiple reverberations between three big impedance boundaries: skin, the subcutaneous fat/intercostal muscle border, and the smooth pleural/foamy air boundary of the peripheral lung. A lines are generated by interactions outside the lung; they are visible against noise when far gain is very high. If there is anything that interferes with specular scattering at the pleural/air surface, then other forms of noise obscure the A lines implying something amiss in the lung periphery. Two negatives make a positive, I guess.

B lines have been named for the miniscule interlobar septi and/or lymphatics filled with blood, lymph, edema fluid, oriented perpendicular to the lung surface, described (along with A and C lines) by PJ Kerley in his textbook in 1951. The reported ultrasound findings are bright white and dark lines fanning out from the lung surface. These are also called ‘comet tails’. One or two of these is said to be OK; the more there are, the more abnormal the lung is said to be. These are artifacts from scatter at the surface of the lung, when it is roughened.

By the way, if roughness needs to be quantitated, there is an extensive literature on this in the nondestructive testing field. Keeping up with ultrasound in its non-medical applications is very informative about the nature of ultrasound pulse propagation and sensor efficiency, and it has the benefit of providing some ready-made solutions for many of the things we encounter every day and with our existing equipment.

**Prospects for Lung Ultrasound**

At first, I was appalled that any physician would make management decisions for critical care patients based on anything as flimsy and ephemeral as random noise. However, to be fair, patients requiring an ICU are being monitored in a variety of ways all of the time, they are re-evaluated...
multiple times every day by attendings, residents, and nurses, they will likely have had every other kind of imaging and lab procedure used in ICU’s, so that it is easy to conform the ultrasound observation to what is most likely going on. This is a lot different from the usual referral ultrasound in which clinical information for the interpreter is typically minimal or the object is early diagnosis in someone asymptomatic.

I had a tough time during the interview in eliciting what it is that the intensivist really wanted to know, was it distinguishing respiratory from circulatory issues, was it the type of shock? In either case, there are other factors that could be sought ultrasonically, if equipment performance were adequate.

I was not surprised that there had been no exploration of vocal fremitus as a way to tell more about the lung. This is an old time physical exam technique that is easily updated with the energy Doppler which will map the frequency shift in audible sound transmission with consolidation and atelectasis versus normally aerated lung segments. Breast ultrasounders will appreciate this, since this is an additional way to find tumors and distinguish benign from malignant masses. This technique was first described in the same Professor Sohn who we referenced before in the section about fetal lung. This is another example of the interplay between clinical need and adapting what we do to solve that problem. It rarely works the other way: here is an imaging device, what can I do with it at least at this point in time?

Radiologists who have a serious interest in ultrasound can and should function as advisors to less experienced practitioners in any non-imaging field. The problems and solutions will, of course, change in time as everyone learns more and foundation knowledge advances. This brings back the notion of radiology where and when I was educated: we were consultants on imaging matters to our colleagues. It really does not matter who does the exam, as long as it is done properly. Ultrasound is the great example of a field that should have been diffused under radiology guidance into its application areas. Instead, parts of ultrasound were grabbed off by specialties without imaging science knowledge, alienating imaging specialists, who may not have understood what clinical information was really needed for management decisions in those fields. Over time, the general level of ultrasound expertise in radiology has diminished, even as the global daily number and range of exams has increased. The adopters tend to remain at the technical level at the time of their entry into the field.

Let me reinforce the comment: equipment is everything. It is the performance limiting step in data acquisition and the essential need to get that data in the first place. There needs to be a national level resource for evaluating and grading commercial equipment for basic technical specifications and for individual clinical applications. I imagine that there are a lot of people, like the intensivist who have decided that they want to use ultrasound. They do not have the time, education, or inclination to understand the technical aspects of the field. They tend to buy on the basis of cost, and they are unduly influenced by sales efforts that use a bewildering array of technical terms mixed with platitudes about excellence in delivery of service. Our national level practice organizations and colleges have never stepped into this role, preferring to be vendor neutral. The FDA certifies the claims that manufacturers make, which is essential, but off the point of performance in the field. Without intending to step on the toes of the Bureau of Radiologic Health, because I really do not know the missions of ultrasound related government agencies, I would think that the independent, ‘consumer reviewer’ should be the NIBIB. They have an active ultrasound section. They fund ultrasound research in all areas, and they provide expertise and coordinate with other government agencies and the public.

I suppose that this endeavor would require special funding, which might be delayed as priorities are set by emerging public health threats. If it does not conflict with rules, the program should be voluntary with equipment manufacturers of FDA-approved equipment providing units and covering expenses largely themselves. After all, if they believe their equipment to be best for clinical uses, which is to say, to contribute to the responsibility we all feel for individual patient care, then they should be happy to have that reconfirmed independently.

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