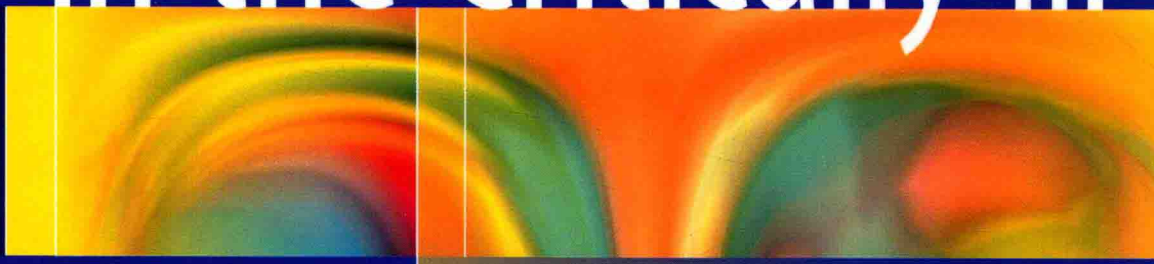
Daniel A. Lichtenstein

Lung Ultrasound in the Critically Ill



The BLUE Protocol

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"The lung: a major hindrance for the use of ultrasound at the thoracic level."

TR Harrison
Principles of Internal Medicine, 1992, p. 1043

"Ultrasound imaging: not useful for evaluation of the pulmonary parenchyma."

TR Harrison
Principles of Internal Medicine, 2011, p. 2098

"Most of the essential ideas in sciences are fundamentally simple and can, in general, be explained in a language which can be understood by everybody."

Albert Einstein
The evolution of physics, 1937

"Le poumon..., vous dis-je !" (The lung... I tell you!)

Molière, 1637

(continued)

These extracts were introducing the Chapter on lung ultrasound of our 2005 Edition.

The present textbook is fully devoted to this application.

A ma famille, mes enfants, le temps que je leur ai consacré était en concurrence avec ces livres qui ont aussi été ma vie. Trouver l'équilibre entre une vie de famille idéale et la productivité scientifique a été un défi permanent. Les défauts qu'on pourra trouver dans le présent ouvrage ne seront dûs qu'à une faiblesse dans la délicate gestion de cet équilibre. Mon père n'aurait pas cru, en 1992, époque de la première édition, qu'il verrait celle-ci; cet ouvrage lui est dédié. Ma mère sera heureuse de voir d'en haut cet achèvement d'une vie.

A Joëlle

Our life is a gift from God; what we do with that life is our gift to God.

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Note several points. Note that the filter "SCC" has been optimized, i.e., suppressed (position 4). Imagine that, if not, the real time should have never shown this minimal lung sliding. Note, at the bottom of the M-mode image, some sand is displayed (not exactly the Peyrouset phenomenon); this sand is far from the pleural line (unknown meaning, minor event). A comprehensive analysis would show the same pattern through the whole chest wall and above all no lung point. This additional detail prevents to wrongly evoke a pneumothorax. To summarize here: no pneumothorax

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Lung Ultrasound in the Critically Ill (LUCI) and Critical Ultrasound: How Did All This Happen? A (Not So) Short Introduction

It was a sunny afternoon after a pleasant night shift, May 1996, Café Danton, Boulevard Saint-Germain (Paris 6th). Sitting at a cozy table, we opened our vintage computer and created a file, the first of a series of patients investigated for acute respiratory failure. A canvas was initiated. Case after case, it was modified: complexified here, simplified there. The BLUE-protocol was coming to life. Time passed and a number of cases were gathered, the manuscript was submitted, the manuscript was rejected, and then rejected again and again before finally being accepted 12 years later. And that sunny day in 1996 was preceded by 11 other years.

We now write a book fully devoted to the most vital organ, unlike our 1992, 2002, 2005, 2010, and 2011 editions. From general ultrasound to whole-body ultrasound, we come now to lung ultrasound in the critically ill, or LUCI. So how did this happen? And how could one imagine, long before it became a standard of care, the story of lung ultrasound in the critically ill?

Lung ultrasound?

Imagine human beings with transparent lungs.

Imagine a lung accessible to ultrasound. Could we see fluid (alveolar, interstitial) inside this fluid-free organ? Could we monitor fluid therapy at the bedside, in harmony with cardiac data?

We don't need to imagine any longer. Since its advent in the 1950s, ultrasound has been able to make the lung transparent. With the development of the real-time ultrasound scanner in 1974, we have been able to do it even better.

The integration of the lung changes almost every step of traditional ultrasound: from the choice of equipment, probe, applications, disciplines, and training priorities to its very philosophy. This is the paradox of LUCI.

A Brief History of Critical and Lung Ultrasound: The Birth of a New Discipline

One hundred and eighteen years after Lazzaro Spallanzani's study on bats, the wreckage of the *Titanic* initiated the birth of ultrasound. Paul Langevin created a type of sonar in 1915 for detecting icebergs. It was used in the 1920s by fishermen (to detect whales), by the military (to detect submarines), and by industry in the 1930s in the manufacture of metals and tires. Eventually, in

the 1940s, physicians considered a possible extension. The father of medical ultrasound (if we choose to omit Karl Dussik, who studied human skulls in Austria in 1942, dark times for medical research, and described as brain structures what appeared to be simple reverberation artifacts) seems to be André Dénier, a modest man who published in *la Presse Médicale* in 1946. From the 1950s on, ultrasound use made great strides in obstetrics (Ian Donald) and cardiology (Inge Edler), and the field was established. The heart was the domain of cardiologists; the uterus, obstetricians; and the rest was for the radiologists. Technological advances lead to improvements, such as real-time scanning in 1974 (Walter Henry and James Griffith). Critically ill patients, however, remained forgotten, in a no-man's land.

So when was *critical ultrasound* created? It is surprising to see that, even today, a number of doctors are persuaded that it came along the advent of the laptop machines (this textbook quietly invalidates this myth). It is true that a commercial revolution made ultrasound suddenly appear in emergency and intensive care rooms. This "new" technology was adopted rapidly, as if physicians were ashamed not to have had this simple idea before. Ironically, a piece, and not just any piece, was missing. In this frenzy of self-appropriating the technique, the most important organ was skipped: the lung. This is the paradox of LUCI.

We do not know who discovered critical ultrasound. In our 1993 article, submitted in 1991, we described a whole-body use, including the lung (a critical organ like any other), by the intensivist in charge of the patient, for critical or routine needs, followed by immediate therapeutic or diagnostic changes; a "24/7/365" use in a field where each minute matters, where there is not always time to call a specialist. Likewise, we don't know who brought first this concept into a clinical practice. Our own small story began in 1983.

1983. Hospital Laënnec, Paris, a sunny Saturday morning. We were kindly asked to bring a woman to the radiology department for an ultrasound test. A student, we had no choice but to agree. The radiologist quietly proceeded, and, so simply, we saw the *inside* of the belly. This was a thunderbolt, a *coup de foudre*. We realized, this is a visual tool for doctors. We also believed that ultrasound should go to the patient, not the other way around.

1984. We learned ultrasound's very basis in a standard radiology department, while initiating an intensivist career.

1985. We worked our first night shifts as an intensivist at François Fraisse ICU, Hospital Delafontaine, Saint-Denis. The responsibility was huge and heavy. This was our challenge: to decrease the risk of erroneously managing these very sick patients. The radiology department was not far from our ICU. Was completely desert after 11 PM. We were tempted to approach one of the machines, discreetly unplug it, and take it to the ICU (these heavy units had wheels!). The transgression was committed, and, little by little, the "monster" was clandestinely domesticated.

1986. We had become familiar with the habit of "borrowing" the machine. It was a night in March, and one of our patients was not well and was not benefitting from our care. It was midnight, and, thinking fast, we crept to the radiology department. All was quiet, not a noise (just the rain outside), nobody was there. We unplugged the machine and brought it to the ICU, Bed 1.

There was supposedly no fluid in the thorax, but there actually was! Action was necessary, there was simply no choice (there was no local computed tomography in 1986, and, even so, our patient was too unstable). In spite of the rules, a needle was inserted in the thorax. Amounts of purulent pleural effusion were withdrawn. The obstacle to the venous return decreases, the signs of circulatory failure seem to improve. The ultimate rendez-vous is not for this night. We bring the machine back to the radiology dept, clean the finger prints, replug it back in. Perhaps, on this dark night in 1986, a new standard of care was born. If similar acts were performed in the same setting (full night, bedside use, etc.) by some other doctor, we would love to shake his or her hand.

1989. We saw that ultrasound could impact critical medicine, but we could not continue "stealing" a unit from the radiology department. Where could we find a suitable ICU with *on-site* ultrasound? There was no need to move across the Atlantic; it was within biking distance at Boulogne (Paris-West). The road to discovery was made by successive encounters. Jean-François Lagoueyte helped us to discover medicine. William Loewenstein gave us the "fatal" taste of critical care. At François Fraisse ICU, we met Bruno Verdière, who introduced us to Alain Bernard, through whom we met Gil Roudy. He helped us by opening the doors of Ambroise-Paré's ICU, where François Jardin developed this pioneering vision: on-site ultrasound for cardiac assessment. There, in our day-and-night research, feeling free to apply the probe everywhere, we discovered, one after another, the countless applications that changed the approach to the critically ill.

1992. The field and limits of critical ultrasound were described in our first textbook (since we did not find any, we simply wrote our own). Today, you find these applications in all courses. Some were classical but did not really benefit the time-dependent patient (e.g., finding free abdominal blood). Some were specific to the critically ill (subclavian vein cannulation). Some were modern (optic nerve). Some were "fantasy" (lung). Some were futuristic (mingling lung with heart). There was no secret to writing our book. The inspiration came by simply always asking, "How can this tool be of help to the patients?" Instead of going to bed on these hot nights, there was endless work in building our research. Thanks to the ideas of Paul Langevin, André Dénier, and François Jardin, the father of echocardiography in the ICU, a discipline was born, the basis humbly gathered in 160 pages, one application or more per page ("1,001 Reasons of Practicing Critical Ultrasound" was the malicious label of Young-Rock Ha in his Korean translation).

Scared was the right word: managing a patient based on what these strange images told, or seemed to tell, was not insignificant. Mainly, we were scared to realize how much this visual tool could impact so many areas of medicine. Yet we did not care about the numerous obstacles. To begin with, there were human factors: the concept sounded so *weird* to our colleagues (mostly academicians). Time was lost. They were intrigued (or another word, maybe) to see an intensivist borrowing the tool of "specialist." And when they saw this person applying the probe at the *lung*, making it a priority target, they were … a little more intrigued (to not use a much worse word). Every time we proudly showed them our "baby," no one had time, or they used the indisput-

able argument: "If this were possible, it should long have been known." That being said, they found the solution and returned, reassured, to their daily routine. Critical time was lost. Ultrasound was reserved for radiologists (to count gallstones) or cardiologists (to assess complex valvular diseases), making two opposing worlds, both very far from ours. Only a few pragmatic (not academic) colleagues, such as Gilbert Mezière, Agnès Gepner, Eryk Eisenberg, and Philippe Biderman, immediately saw the potential and used it. Remember that, at the time, CT was a rarity and D-dimers did not exist. This was the time for an absolute revolution, and we (our small group) were the "kings of the night," but outlaws at daylight. Just the price to pay when you innovate.

Because ultrasound generates *images*, it was "logically" placed (with the exception of the heart and fetus) in the hands of radiologists: they were experts, but not accustomed to *touching* patients (especially in the night or on weekends), nor were they trained to make diagnoses based on artifacts, that is, undesirable parasites. Consequently, this elegant tool was used for almost all organs, *lung excluded*. An issue? Not at all! In the 1980s, CT appeared, and they found a serious tool, keeping ultrasound as a minor discipline, used to see gallstones during office hours. These experts had decreed lung ultrasound's unfeasibility in the most prestigious textbooks, burying it alive! And the following generations quietly followed. This mistake will possibly seem funny (using temperate words) in the history of medicine. We don't blame them; they had so many things to do. But they also succeeded in slowing down publications able to remedy this mistake (once the tool was in the right hands), and this caused more harm.

Before dealing with this harm. How did ultrasound of the lung happen? Initially, it is true, we saw only "snow" or "fog," like on an old TV at night. Yet we had the leisure to spend days and nights on it. This was just (insatiable) curiosity, wondering why these futile parasites were sometimes horizontal, sometimes vertical, until the day when, scanning a young patient with an acute interstitial pneumonia, we had a revelation. Maybe these "parasites" were a language. A language that we just did not understand. In our quest to define critical ultrasound, it appeared that the lung would be the major part. These ultrasound beams were so smart and also able to "cross" the lung. With observations, assessments, time for hope and disillusions, then simplifications, nomenclatures, standardization, we arrived at the point where a simple approach using a simple machine, a simple probe, and simple signs was legitimate. This initiated a work of endless submissions. We aimed at rapidly publishing the lung first, the absolute priority. This was a mistake.

This mistake (*defining* critical ultrasound before widespreading it) prevented us from popularizing nonpolemic fields since 1985 (like peritoneal blood detection – without acronym). Discovering was rather easy, but publishing was almost impossible. We did not publish the majority of our discoveries in the peer review literature. Our reviewers were cautious. We have always respected their work, even if it resulted in breaking our research. Countless teams throughout the world can thank them: while we were stuck with this impossible to publish work on the lung, these authors were able to

quietly publish and publish some more. Leaderships emerged here and there in emergency ultrasound. We are glad for them: our "cake" was too big for one mouth. What remains today from this cake is a minute part – just the lung! This is good as it is. Too many papers in too few hands is probably not good. We are glad to have made so many doctors happy and famous (far more than the number of patients we have saved!). We have now brothers and sisters all over the world who all "think ultrasound." This is great, let us not be too demanding! We know how pleasant it is to publish. In addition, we see the endless work (invitations, etc.) generated by the few articles we were able to publish. For this, also, we thank those who published our discoveries.

The dark consequences of our countless rejections were that mainly laptop machines were invading our hospitals. These machines were chosen by experts, while researchers in the shadows (those who created the field) were judged unworthy of this responsibility. Emergency doctors discovered the worst aspects of the tool: the appearance of being small, a complicated knobology, poor resolution, endless start-up time, cost, "facilities" such as harmonics, and time lag – the worst for lung ultrasound! This revolution was a poor copy and paste of radiologic and cardiologic cultures. Since 1992 and even 1982, we had in hand a tool that could make this revolution really *disruptive*, using a holistic philosophy. Our simple, beloved Japanese unit was more suitable than these laptops. To begin with, it was just slimmer! This is another incredible paradox of critical and lung ultrasound. In parallel, many misconceptions became common (e.g., today, for many emergency physicians, the definition of interstitial syndrome is based on the detection of more than three B-lines). Such distorsions may be spread widely and quickly via the Internet, but are here... *wrong*. This situation created the conditions for writing our textbook, devoted to giving to experts support to be even better. This means for us, instead of a good nap, an endless work in the times to come.

This textbook comes at a convenient time. The words "lung ultrasound" are no longer scary. The previous dogma resulted in disastrous effects on choices of equipment. How can one explain the weird delay in the recognition of critical and lung ultrasound? The human factor possibly explains everything: a doctor who thinks he is good does not need to invest in a new field, especially if it comes from the mist. We give a piece of advice to researchers: begin young! Our story illustrates the words of Max Planck, who said, "an idea wins, not because its detractors are convinced, but because they eventually... die" and Stuart Mill, who stated that "all innovators had to pass through three steps: ridicule; observation; application".

How Does LUCI Make Critical Ultrasound a Holistic Discipline

We did not create lung ultrasound but a holistic ultrasound, with the lung at the center. We may provocatively assert that there is no lung ultrasound, there is just critical ultrasound, integrating the lungs. Lung ultrasound comes in harmony within critical ultrasound. LUCI encompasses more than just the

lung. Integrated with simple cardiac data, it provides answers in the hemodynamic field (FALLS-protocol). Some even think that those who come to CEURF (Le Cercle des Echographistes d'Urgence et de Réanimation Francophones) sessions should forget their previous culture (from Rafik Bekka). This is a bit strong, but we do ask them to temporarily put aside all their knowledge (Doppler, cardiac output, etc.) to catch the spirit of the FALLS-protocol, integrate it, and then return to their previous habits with a bit or more of the CEURF vision.

The challenge in creating a truly holistic innovation was to transform a scary machine into a simple clinical tool, used 24/7/365 by simple clinicians. We used not only science but tools such as a piece of cardboard with holes to hide the useless buttons and highlight the *three* useful ones (i.e., creating, 25 years earlier, the innovation recently developed by a popular Dutch brand: a magic button with two levels: expert and basic). Button or cardboard, never mind, the expert knobology of ultrasound could be skipped. Far from daring any comparison with René Laënnec, simply inspired by his great work, we built our instrument. Laënnec was the father of the stethoscope, of course, but mostly of a new science based on observation. It was the step before the modern era initiated by Claude Bernard. Laënnec had a difficult life, and he began from nothing, which is an impossible task for those who change something in medicine (such a serious profession). With lung ultrasound, the work had to begin from less than nothing. There "was no lung ultrasound." It developed against a dogma; this was another challenge.

Some precious colleagues from various centers, including Raul Laguarda in Boston, Beth Powell and Jeff Handler in Toronto, Mike Welsh in Indianapolis, and German Moreno-Aguilar in Colombia, have efficiently transmitted the holistic spirit of lung ultrasound in the manner of CEURF.

LUCI: A Tool for Whom?

We have never designed who had to hold the probe. It was more important to show what was possible to see; for example, the lung. The historical experts (the radiologists) had a major opportunity, which they did not take advantage of in time. This is a pity because, knowing the basis, they could transmit the method immediately. These times are passed, and now the tool is in the hands of clinicians. We hope that LUCI will be used by all physicians dealing with the lung. This means, as an utmost priority, intensivists, pediatricians (neonatologists, PICUs, etc.), and pre-hospital doctors. Next is anesthesiology, emergency medicine, pulmonology, cardiology, and many others (see Chap. 33). This change will impact a number of unexpected disciplines.

Still a Single-Author Textbook?

Luciano Gattinoni told us of his preference for these books. It means more work for the author, but provides a homogeneous content, avoiding repetitions (or worse, contradictions). The coordination is optimized, as well as the

thickness: a maximal quantity of information in a minimal volume. The writing by a single author was the key for reaching this target.

Of interest, our specific equipment allows an approach based on absolute simplicity. One of our challenges was to change ultrasound into a clinical tool, making each step easier for non-"experts." This textbook shows a winning combination (machine, probe, signs, etc.). Simple machines, available as early as 1982, and a different distribution of priorities (lung first) allowed more than just a transfer of "competencies." Self-taught in critical ultrasound (because nothing existed), free of any influence, we had a major privilege: creating signs as we saw them, for example, not defining pleural effusions as "anechoic collections." When all teams have our equipment and protocols, then many expert multi-author books, similar to this one, will be available.

This book contains unpublished material, that is, "ideas" for other teams. Why? There are roughly three ideas per page, which is not far from 1,000 in a single textbook. We have succeeded in publishing roughly one paper per year (a mini-disaster), making for two dozen papers, or roughly 2.5 % of our goal. Make a calculation: send out 1,000 manuscripts (with five anticipated rejections for each, i.e., 5,000 mailings) or just one textbook. What would *you* do? We chose to write, all in one, the ideas that we will never publish. The readers have a choice: read our non-peer-reviewed experience, tested by 30 years of full-time intensive experience, with permanent confrontations with reality, acceptance of failures, and pertinent criticisms; or wait for each article to be published. The lucid author offers these applications to keep in mind the most important: we deal with patients. This is our small gift to the community. Interested teams will just have to randomly open the book and begin a clinical study; we are ready to help them.

All authors have always, without exception, only one unique target: being useful to the patients. This is true for all. Most are great, most publish good articles, some publish amazing quantities, even if we could see in some a subtle art of visibility, or some curious cases of self-proclamation, sometimes again the art of pushing open doors. We were unable to comprehensively quote all authors, and we deeply apologize for this. In our first underground period, we had plenty of time but nothing to read. Now, publications are countless, to the point that we have only time to read their titles. Just note:

1. An explosive number of papers were the result of the recent (and unnecessary) intrusion of the laptop machines in emergency rooms. These publications usually show that emergency physicians can do as radiologists, after a defined number of examinations. Such articles are laudable, but this has nothing to do with the present textbook. Some are quoted.
2. Works that confirm published points are reassuring but will not modify the content of this textbook. Similarly, articles showing that a sign that worked in 100 patients works in 1,000 or 10,000 won't add anything new. They just confirm that it works. Some are quoted anyway.
3. Many articles extensively develop points that were found in modest textbooks in one simple sentence (e.g., the diagnosis of hemoperitoneum, not far from a religion for many emergency physicians, was dealt with in 12 lines in our 1992 textbook). Some are quoted.