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Whole Body Ultrasonography in the Critically Ill

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A ma mère

Preface

Our 1992 volume was a unique opportunity: defining the field of critical ultrasound. Fusing together the idea of Dénier, the father of ultrasound [1], with that of François Jardin, to enrich his ICU with an ultrasound unit [2], we were in a privileged place for achieving this task. At the time it was initiated (1989), this music sounded strange to most ears. Ultrasound was a sophisticated technique reserved for an elite group, for focused fields (gallbladder gallstones at one side, echocardiography at another: two worlds). Our volume aimed at making ultrasound a clinical tool, including classical emergency applications (aortic aneurism, venous thrombosis, free blood) specific applications (venous catheterization, simple cardiac sonography), and new applications (inferior vena cava, optic nerve...) for an *adapted use* to the critically ill. At this basic point and without including basic applications that were not supposed to exist (the lung), the field was so substantial that an on-site role with urgent transfer of competence was imaginable. When we saw the unlimited whole-body potential of such a unit, and searched in vain for a devoted textbook, we wrote our own. This lack in the literature was explained probably because two distant worlds (critical care and imaging) had too distinct traditions and philosophies. The 1992, 2002, and 2005 editions of our book reflect an experience born from a synthesis between these two disciplines.

Many years were lost because not only the concept of critical ultrasound (by a nonexpert physician) initially intrigued the community but also, above all, because the *lung* was advocated as the priority target. Fortunately, the author began as a student – a good idea when you propose something different to the community. Like all new concepts, it needed the usual gestation time before being accepted in people's minds. It is a pleasure to see that, now, these obscure times are behind us. Some doctors believe that critical ultrasound was created by the laptop revolution in the 2000s, but basic chapters will quietly show that the real revolution was fully possible long before.

For Whom Is This Book Intended?

Neither the earlier editions nor the present one designed a specialist for holding the probe (intensivist or radiologist), but rather what could be possible with this probe (lungs, etc.). There was a space for the radiologist, who had the expertise for disseminating the technique immediately. With distance, this space is still available, but we can consider that they let the opportunity escape. Critical ultrasound is now the tool of the intensivist, who has a 24/7 (24 h a day, 7 days a week) need, in a space where speed is life, with no possibility to wait for a specialist.

Suggesting to confine ultrasound to the hands of "nonexperts" was a challenge. Providentially, critical ultrasound is a simple discipline. The following pages aim at demonstrating that simple signs based on a simple technique, simple equipment and simple philosophy make it such a method. The most simple signs are present at most priority targets: lung, deep veins... Even the heart benefits from an emergency sonography based on simplicity. We ask the readers to admit that simple machines (present since 1982, perfect since 1992) and a different distribution of the priorities allow us to benefit, not from a passive competence transfer for studying biliary tract anomalies or complex cardiac Doppler flows, but *really* from a new discipline..

New Points in This Edition

All chapters of this book have been completely rewritten in order to gain clarity, simplicity, and compactness. The rarest situations have been sacrificed again to concentrate on the more common daily ones. The candid questions of the attendees of ICU bedside sessions in France through CEURF, and around the world through countless workshops in many initiatives like WINFOCUS, have all received answers. They are integrated in this book, contributing to making it more comprehensive – but not more complicated. We suppressed old propaganda comments, since now the question is no longer *why*, but rather *how* (i.e., how to practice critical ultrasound).

The user will begin with the abdomen (a traditional field, with adapted use however), slightly leave it with the aorta, then go into the deep matter. A venous approach will initiate the BLUE protocol. Eleven chapters are now devoted to the lung and the BLUE protocol. Chapter 20 assesses acute respiratory failure. Chapter 21 deals with the lung in the neonate. A simple approach for the heart and hemodynamic management, in light of the lung approach, will then be proposed. Chapter 23 gives clues with direct data for hemodynamic assessment of acute circulatory failure.

The new title indicates more specifically its holistic content. We could use the title of the Korean translation of our 2005 edition: "The 1,001 reasons to develop ultrasound in the critically ill patient," but the current title indicates that the *heart* is included in our approach – since 1992.

Intensive care medicine is a complex area. Did we succeed in pushing back the "twilight zone"? In all areas where there is a "gold standard" (such as CT), the reader will find solid ultrasound elements, especially at the respiratory area. In areas where the gold standard is weak, mainly hemodynamic assessment, our progression is slower and our conclusions still cautious, but we humbly propose new references.

Like in the previous editions, the author heartily thanks those colleagues (acknowledged in the text where possible) who indirectly contributed to this book.

What Is Unchanged in This Edition

We kept our vision of simplicity. This precious tool was exploited to its limits without compromise for the patient's safety, since passing years have shown that this is the winning way. Once again, the reader will search in vain for images with Doppler.

Critical ultrasound is a new discipline, with a real adaptation to the critically ill, and not a simple copy-paste of the traditional radiologic (or cardiologic) culture just performed in the emergency room (ER) instead of within the radiology department. Our books only deal with points of immediate clinical relevance for life-threatening situations (most gynecologic situations and minor surgical diseases such as appendicitis are not dealt with).

The homogeneity and coordination have been optimized. In order to have the lightest volume as possible, *essential notions are not repeated*. They are inserted at a logical site, and shortly recalled in other chapters. A maximal quantity of information fits, therefore, in a minimal volume. A single-author redaction was the key for this concept.

As usual, the author apologizes for possible errors or omissions, and will greet with major attention the suggestions of the colleagues who make the effort to open this book. The recent explosion of ultrasound in the ER has given rise to many publications. Papers willing to show the interest of ultrasound, in an evidence-based approach, are basic, but we apologize for not have space for including the numerous references which show that nonradiologists can do what radiologists can, or that nonexperts can become experts after a certain number of examinations. This was not the aim of this textbook. Wanting to keep the size of the book to a minimum, we devote only on what can be done with a probe rather than who can hold it, and after how long training.

For Those Interested in Research

Of the 320 pages of this textbook, the authors had time to publish a minute part (20 publications) in the peer-reviewed international literature in 19 years. With one paper published per year, they have calculated that time would be short for publishing all of them. Dozens of applications that featured in the 1992 edition are now widely in use (venous access, search for free blood in trauma, optic nerve, gastric tube, etc.). This book is an alternative for all ideas that will not be published for lack of time. The reader has just to take those from this textbook which are not yet peer-reviewed, and publish them. This is the modest gift of the lucid authors to the patients from the whole community, from sophisticated sites to sparsely resourced countries.

The Images

Our 1992 edition used 1982 technology images (the ADR-4000 and its mechanical sectorial 3-MHz probe). Our 2002 and 2005 editions combined technologies from 1982 and 1992 (the Hitachi EUB-405 and its electronic 5-MHz microconvex probe). In this 2010 edition, we use the same 1992 technology, because we find it of superior quality to that found in the usual small-height machines.

Some images obtained using 1982 technology have been kept, simply because the clinical information was fully relevant for saving lives. They will be recognized thanks to their dotted (centimetric) lateral borders.

Everybody will agree that the 1951 resolution was a bit weak. The figure enclosed herein, from the historical article of Howry [3], is perhaps the first ultrasound real

image (not dealing with Dussik's images of 1942, which proved to be a mistake, taking artifacts as pathologic structures, nor Dénier's work, since we have no image). The revolution of real time, acquired thanks to the work of Walter Henry and James Griffith in 1974, has been a nice step forward. The 1982 resolution was perfectly suitable for saving lives, decreasing X-rays and CT referrals. The 1992 resolution is even better.

One Last Point

In our 1992 edition, we warned the readers that our policy of trying to decrease irradiation by all available means was a critical aim. Certain uses of ultrasound may have looked excessive for some. Meanwhile, works highlighting the side effects of radiation techniques have at last been published [4–6]. Colleagues who long ago invested in ultrasound made a winning choice and are now one step ahead.

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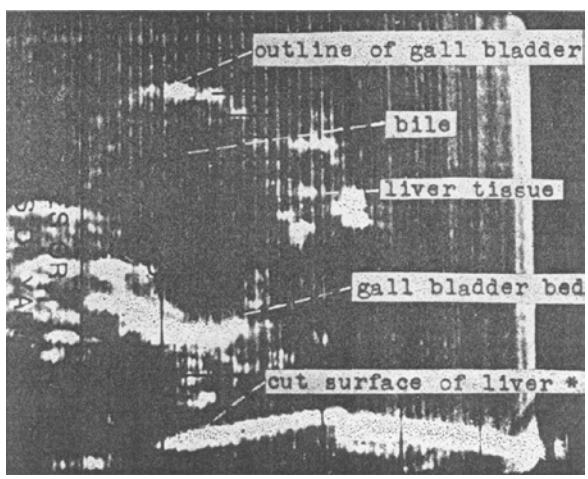

Normal gallbladder, transverse scan. This scan was obtained from the historical article of Howry and Bliss (J Lab Clin Med 40:579–592). We can understand that, from *this* image, ultrasound did not have the immediate success of radiography, CT or MRI... and therefore academicians forgot to acknowledge such a pacific revolution. This image suggests another comment. Even using the pantographic systems of 1970, the sound had the same speed as today, i.e., 1,540 m/s. This means that, theoretically, a scan of the thorax would have been able to display the A-lines and B-lines and even maybe the seashore sign, which are the main tools of lung ultrasound. Maybe a visit to the museum of sonography would reserve some surprises.

Contents

Part I

Introductive Chapters

Basic Notions of Critical Ultrasound

1

Notions of the physical properties of ultrasound are not indispensable for the user (as we wrote in our 1992, 2002 and 2005 editions). If needed, they can be found in any ultrasound textbook.

We will discuss here notions useful for understanding critical ultrasound. Every maneuver that favors simplicity will be exploited. We will explain why only one setting is used, why, at the lung or venous area, only one orientation probe is favored; and how to easily improve the image quality.

Preliminary Note on Knobology

The ideal material is described in Chap. 2. An ultrasound unit includes a number of buttons and cursors. The only functions we deem really useful for critical ultrasound at the beginning are:

1. The switch-on button (which is not always obvious to find)
2. The gain setting
3. The image depth
4. The M-mode (for demonstrating dynamic acquisitions like lung sliding)

The sole use of these four settings converts any complex unit into a simple stethoscope.

We never utilize all of the multiple pre- and postprocessing possibilities: we always use the same, natural image. Annotations are useless when the examination is not made for another doctor: that is the spirit of critical ultrasound. We use once for all a single positive–negative inversion position. We bypass most filters, which distort the reality (see the next chapter).

Opinions about sophisticated modes, harmonics, etc., are available in Chap. 2 and debated in Chap. 30.

The freeze button is apparently insignificant. If one operator (sonographer) provides a static image, and another operator (radiologist) interprets this image (i.e., US used with US habits), the potential of critical ultrasound is not exploited. Our philosophy stems from deactivating the freeze function. Critical ultrasound is a real-time discipline.

Step 1: Learning to Interpret Spatial Dimensions

As opposed to radiography, CT or MRI, the operator creates the image. This weakness is a strength. Spatial learning is the first step and, without doubt, the most delicate to acquire. The rest is easy. Yet, it is possible to make this step easy, using simple rules. Favoring the lung (the easiest since the window is always the same) or the venous network using only cross-sectional scans makes this task easier than traditional ultrasound. The operator must understand how to locate the elements displayed on the four parts of the screen: upper, lower, left and right (Fig. 1.1). Our probe has sectorial scanning, displaying a triangular image, the probe head being on top.

The upper part of the screen shows the superficial areas. The lower part of the screen represents the deep areas. This is not a source of problems.

Interpretation of the left and the right parts of the screen can be simplified by deactivating the left-right inversion button, once set in the optimal position. Immediately things become much easier. The user has just to follow the landmark, easily palpable on any well-designed probe for immediate control.

For transversal scans, the universal convention in imaging (X-rays, CT, etc.) is to see the image as if it

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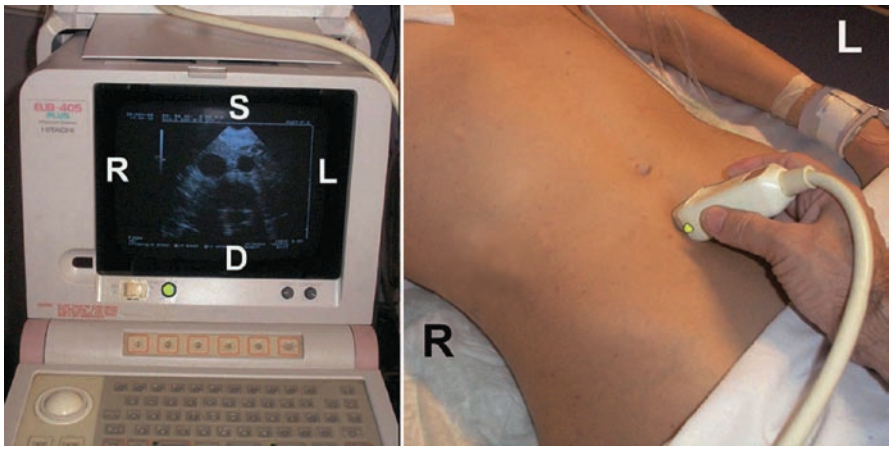

Fig. 1.1 The spatial configurations. The probe is applied transversally on the abdomen. The right structures of the patient are displayed to the left of the screen (*R*). The top of the screen corresponds to the superficial area, i.e., the skin (*S*), the lower part of the screen to deep areas (*D*). This allows (among other criteria) to locate the vessels on the screen as the inferior caval vein (near the *R*) and the aorta (near the *L*). The rachis is deep, located behind the vessels, near *D*. Note the clear *yellow* landmark on the probe side, corresponding to the clear green button on the ultrasound unit

was the patient, i.e., the liver at the left of the screen. This convention serves the purpose of rapid recognition of an image and establishing habits. As a striking example, when a chest radiography is held upside down, the image is unusual and hard to analyze, although nothing has been modified.

For longitudinal scans, the head should be imagined on the left of the screen, the feet on the right. This is a practical convention in imaging, but cardiologists have adopted the opposite convention. To make our practice simpler, we have homogenized ultrasound according to the radiologists' convention, including the heart. In a longitudinal scan, the liver will be seen on the left of the image, the kidney on the right.

How to Hold the Probe: The Elementary Movements

For most parts, i.e., lung, veins, abdomen, head and neck, the probe is perpendicular to the skin (Fig. 1.2). Only for the subcostal heart or the bladder is the probe inclined (see Fig. 9.12 page 72).

The probe is nearly always perpendicular to the skin. Three main movements are visible. The *blue arrows* indicate translation (this movement done from left to right in this longitudinal scan moving the skin on the underskin is the Carmen maneuver). If the probe was transversally applied, the Carmen maneuver would go from head to feet. The *turning arrow* indicates rotation of the probe (like screwdriving). The *black arrows* indicate a scanning that looks like changing the gears of an automobile (this movement has a minor importance through the text but major importance for the trainee to reach the good position).

Critical ultrasound analyzes vital structures, i.e., movements (lung, heart, vessels, GI tract, etc.). The operator's hand must be still (Fig. 1.2), since the

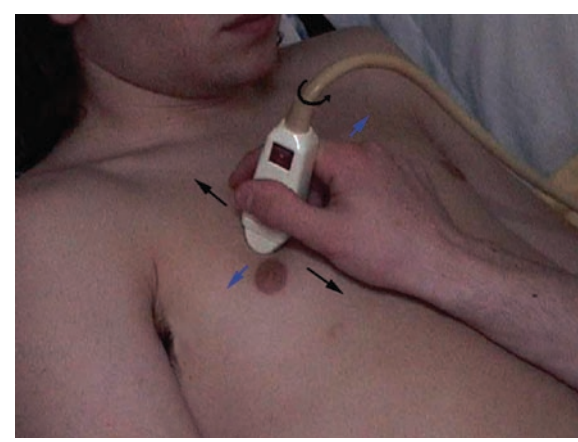

Fig. 1.2 How we hold the probe. Like with a fountain pen, the operator can stay hours without any fatigue, and the image is perfectly stable on the screen. The probe is applied at zero pressure, which is comfortable for the patient and mandatory for any venous analysis, as well as the optic nerve

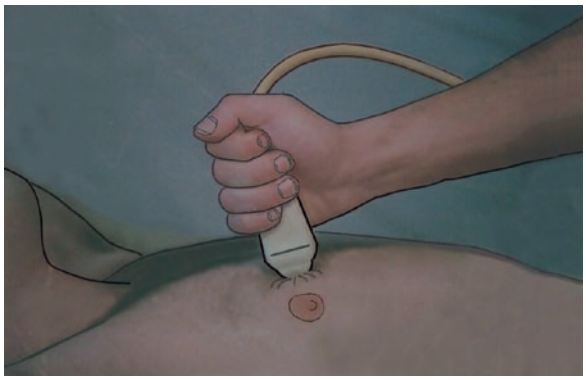

Fig. 1.3 How we do not hold the probe. The pressure is not controlled, and fatigue will generate hand movements which create turbulence on dynamic structures

dynamic should be generated by the patient alone (not the operator's hand). Figure 1.3 shows how we do not hold the probe. Uncontrolled movements of the probe create the "off-plane" effect: a dynamic caused by the movement of the probe alone.

We find it critical to hold the (microconvex) probe like a fountain pen between thumb and index finger, with the operator's hand quietly applied on the patient's skin. For many parts, we work at "zero pressure": the probe is advanced to the skin until an image appears on the screen. This minimal pressure warrants absence of pain (or cardiac trouble when working on the eyelid). In addition, prolonged examinations can be done without fatigue. Veins are squashed, especially at the neck area, when the probe is applied too heavily. Some beginners hold the probe too tight. The operator must take care to not let the probe fall, without additional fatigue. Our criterion of a correctly held probe is the possibility for another operator to withdraw it without effort from the operator's hand. One secret is in the suppleness of the hand. Often, the novice user is discouraged when a suboptimal image is obtained when an experienced user comes nonchalantly behind and obtains a much nicer image. Yet the difference is often due to minimal changes of angulation of the probe. Whereas the probe keeps its mark on the young user's hand (like, almost always, the joystick of a first flight – a sign of intense crispation), the experienced user holds it slightly and is not afraid to move it liberally. The Carmen maneuver (see just below) is to our knowledge the best way to dramatically improve an image.

Three main movements can be described (Fig. 1.2):

1. Scanning, for example, a transverse scan beginning at the epigastrium and ending at the pelvis.

The *Carmen maneuver* is a simple but important elementary movement that we permanently make at many areas. It labels a variant that is the same movement but with the probe nearly standstill, just using the gliding of the skin over the underskin (making a roughly 1-cm amplitude to each side). This subtle maneuver allows immediate control of the image: it helps in optimizing the image quality when scanning an intercostal space or another area. It shows immediately a vascular couple that was not obvious on a static view, making Doppler useless, at least for helping to locate the vessels. At the lung, it makes evident subtle structures that may not be apparent on a motionless approach.

2. Rotation on its main axis (like screwdriving): the study of a vessel on its longitudinal axis and then on its transversal axis.
3. Sliding, for instance, a longitudinal probe in a craniocaudal axis, i.e., from an intercostal space to the upper intercostal space – the hand moves like changing gear in an automobile.

These movements create significant changes on the screen, which can be unsettling at the beginning, perhaps the major difficulty of ultrasound, but also its strength. One travels through the third dimension. These changes will be integrated and become automatic with practice.

The Logic of Longitudinal and Transversal Scans

Critical choices can make ultrasound easy or difficult. The logic of choosing longitudinal or transversal scans is part of them. Strictly, these terms refer to the craniocaudal and left-right locations on the human being. We will refer to axial and cross-sectional scans when referring to structures with one long axis and one short axis (vessels, heart, kidneys, intestines, gallbladder, etc.). Figure 13.1, page 100, shows that most veins are roughly parallel to the longitudinal and transversal axes. For studying a vein, the choice of an axial approach is a bit similar to violin practice, the cross-sectional

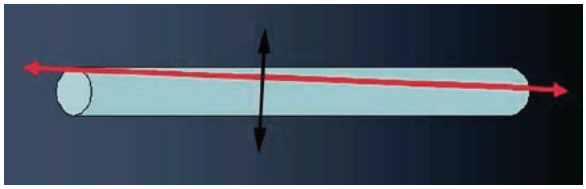

Fig. 1.4 Cross-sectional versus axial scan. This figure shows these two incidences for approaching a tubular structure – with a slight drift (2° or 3°). Whereas the cross-sectional scan (*black*, 3°) is roughly insensitive to this drift, the axial scan (*red*, 2°) is much more affected. Slight movements at this moment can make the vein disappear, simulate a positive compression maneuver, and all in all make ultrasound a more difficult discipline

approach to the guitar (Fig. 1.4). The violin is more demanding than the guitar, where the pitch is self-adjusted (we mean, for the left hand). Studying a vessel through its cross-sectional scan is easy: once the probe is applied, the vascular couple is immediately recognized. If not, the Carmen maneuver makes it. Even if the hand of the operator moves, the vessel remains in the gunsight. Making an axial approach requires millimetric precision, nearly obliging the operator to hold his breath – like a sniper before the shot. At the lung area, the practice of oblique scans (in the rib axis) makes lung ultrasound such a difficult exercise.

An exercise which creates expertise is the pass from cross-sectional to axial scan. Any vessel (abdominal aorta, subclavian vein, etc.) can be used for this exercise. Novice users will be disconcerted by this maneuver. When they try to rotate the probe, they usually lose the target rapidly. We help them by introducing Anke's maneuver, which standardizes the approach. The probe should always remain at the zenith of the target. The probe shows a cross-sectional scan. A rotation is then initiated (as if we had a screwdriver in hand) – a slight, 10° rotation, to begin with. Once this slight rotation is completed, a slight Carmen maneuver brings the target to the middle of the gunsight. The probe must always remain at the zenith, this possibly needing a slight correction. Then 10° again, etc. The rotation changes should increasingly be more subtle when reaching the end of this 90° rotation maneuver, since the vessel will suddenly appear in its axial dimension. During this maneuver, the probe must remain vertical (zenith) to the skin, and at the same point (avoiding gear changes). If the target is lost, it is of critical importance to come back, not forward, in order to find it where it was previously. This is a basic visual flight rule. The Anke maneuver, which combines two kinds of movement, can appear subtle. With experience, it is done with increasing speed, with a permanent, millimetric Carmen maneuver. When the user does it without effort, he or she has become a sonographic expert.

The Second Hand

Critical ultrasound is performed by both hands. The second hand is constantly used to assist in many different ways. It helps in slightly turning the patient's back for prompting a posterior lung analysis (Stage 3, see Fig. 14.5 page 121). It helps the probe's hand to push the gas in an abdominal scan (see Fig. 11.9 page 86). It makes the venous compression possible in areas reputedly noncompressible (see Fig. 13.8 page 104). Last, it keeps the compress soaked with the contact product, making the operator ready to extend the field of investigation.

Step 2: Understanding the Composition of the Image

How does one master the white, gray and black nuances of the images?

Gain

The gain control influences the tones. Optimal control of gain is obtained only with experience. Decreased gain yields a black image, and details are masked. Increased gain yields a white image, and details are saturated (Fig. 1.5). In the units we use, the proximal, distal and global gains can be adjusted. That said, we modify only the global gain, from time to time, and almost never the proximal and distal gains.

Tradition uses a scan of the liver with the gallbladder. The liver must appear gray, the gallbladder (without sludge) black.

Basic Glossary

An anechoic structure yields a black image, since no echo is generated. In the pioneering times of ultrasound,

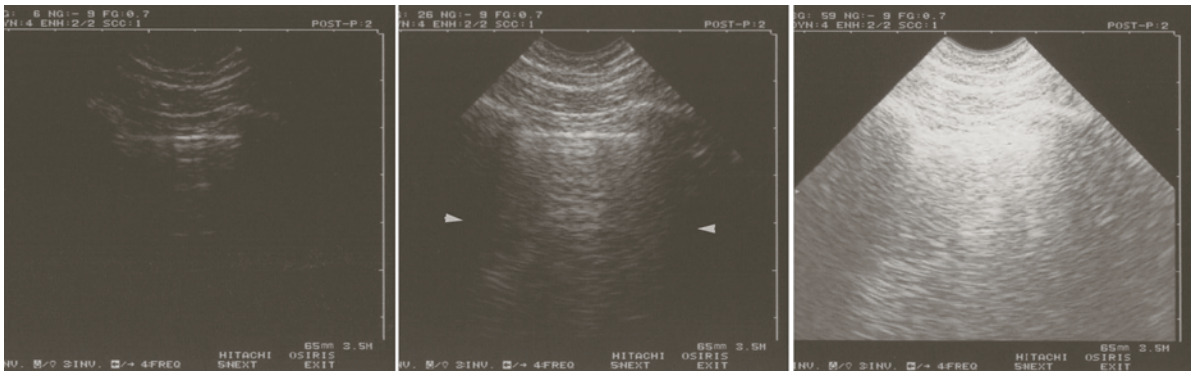

Fig. 1.5 Gains. Longitudinal scan of the lung. *Left*: The gain is too low. Details are lost. *Middle*: The gain is optimal, clearly showing the pleural line. *Right*: The gain is too high: superficial areas are saturated (another illustration of the consequence of too high gain is shown in Fig. 18.4 page 167)

the images were inverted, i.e., anechoic images were represented as white.

Inversely, an echoic structure gives a gray image. It can be more (closer to white) or less (closer to black) echoic.

An image defined as hypoechoic, isoechoic, or hyperechoic assumes that a reference image has been defined, usually the liver.

An acoustic window is a structure that is easily crossed by ultrasound, allowing analysis of deeper structures. This window can be physiological (bladder for the analysis of the uterus) or pathological (pleural effusion used to study the thoracic aorta). The search for an adequate acoustic window can be difficult, especially for detecting the heart. It is never a problem with the lung, which is everywhere, just under the skin. For other areas, countless tricks are available for having a good acoustic window (see within the text).

Artifacts and Real Images

Artifacts are traditionally the poor part of the ultrasound world: structures that spoil the image... Their analysis is the basis of lung ultrasonography, providing life-saving information.

Artifacts are created by the principle of propagation of the ultrasound beam, i.e., stopped by air and bones and facilitated by fluids.

Artifacts are easy to recognize: they have regular, straight, geometric shape, usually vertical or horizontal, more precisely converging to the head of the probe (the top of the screen) like parallels or meridians, i.e., totally different from any anatomical structures. This is the common point for nearly all artifacts. Real images have anatomic shapes, never fully regular, and can be measured (e.g., liver).

An acoustic shadow is an anechoic (echo-free, black) image, which arises from a bony structure (Fig. 1.6). It hides information. The shadow of the ribs makes an important part of lung ultrasound (see about the bat sign, page 123).

A reverberation echo (or repetition echo) is generated by an air structure. A succession of roughly horizontal lines generates a striped pattern, alternating dark and clear lines at regular intervals. They can be large (i.e., on the screen, extending from the left to the right) or very narrow (see Figs. 14.7 page 123, 17.2 page 153, 18.9 page 171). A reverberation echo hides

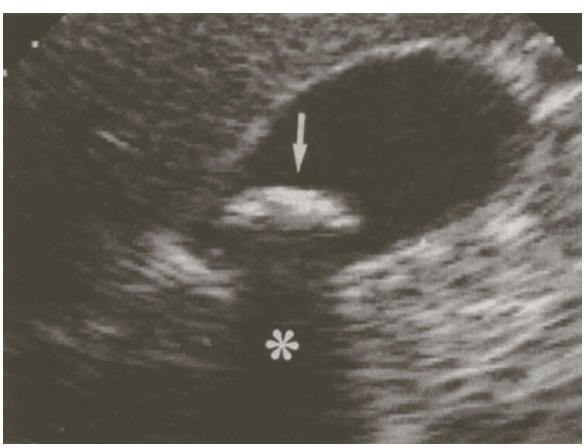

Fig. 1.6 Posterior shadow. This one (*asterisk*) is generated by a large stone (*white arrow*) in the gallbladder. The bile appears anechoic

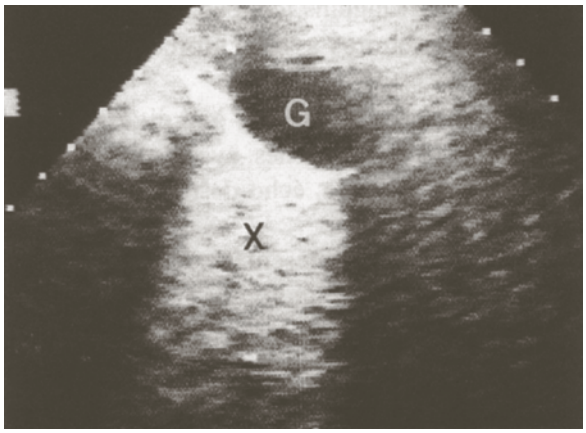

Fig. 1.7 Acoustic enhancement. This one (*X*) arises from the gallbladder (*G*). This sign is of interest when the examined site is poorly defined, since its fluid nature is demonstrated. This is an example of a figure which provides the answer to a clinical question (fluid or solid mass?) in spite of the poor image quality

the information below, as does an acoustic shadow. At the lung level, acoustic shadows of ribs and reverberation echoes of air regularly alternate. Even if these artifacts completely hide the information below, they are the key of lung ultrasound. Their clinical use is dealt with in the Chaps. 14, 17–20, 23, and 29.

Echoic tissues like fat surrounding a blood vessel can create parasite echoes within the lumen of the vessel ("ghosts") (see Figs. 11.5 and 12.7 pages 84, 94). Ghosts are not mandatorily horizontal or vertical: they follow the surrounding bright structures.

Acoustic enhancement is a common artifact, which is useful for indicating the fluid nature of a mass in traditional ultrasound. It creates a more echoic pattern behind a fluid element (Fig. 1.7). The liver parenchyma is more echoic behind the gallbladder than lateral to it. We almost never have to use this artifact in our current practice.

The Dynamic Dimension

Critical ultrasound is mainly devoted to vital organs (lungs, heart, vessels, bowel). A common feature to any vital structure is a permanent dynamic, from birth to death. A vital structure that does not move is *dead,* or dying. The M-mode button allows demonstration on a frozen picture of any dynamic. Figures 5.8 (peritoneal effusion), 5.15 (pneumoperitoneum), 6.16 (mesenteric infarction), 13.10 (floating thrombosis), 14.10 (normal lung), 15.3 (pleural effusion), 16.5 (pneumonia), 16.9 (complete atelectasis), and 18.7 (pneumothorax), among others, demonstrate the relevance of the dynamic dimension.

Elementary Anatomical Images

An approach from the anatomical structure (Table 1.1):

A parenchyma (cardiac muscle, liver) is echoic.

A pathologic tissular mass (thrombosis, alveolar consolidation, or tumor) is echoic.

A pure fluid collection is anechoic (with acoustic enhancement: circulating blood, vesicular bile, urine, pure fluid collections).

A pathological fluid collection can be echoic: abscess, hematoma, thick bile, etc. A collection containing tissular debris (necrosis) or bacterial gas is heterogeneous. Variations in shape, possible acoustic enhancement, detection of a dynamic movement within the mass indicate various fluids.

A gas structure is hyperechoic (with posterior echoes missing if the gas has small volume): air or microbial gas.

Deep fat is hyperechoic, such as mesenteric fat (allowing to perfectly locate the mesenteric artery). We have not invested a lot in this field, but, as clues for those interested, commercial oil is anechoic, and

Table 1.1 Elementary ultrasound images

	Real structure	Artifact
Black tone	Pure fluid	Acoustic shadow
Gray tone	Parenchyma	
	Alveolar consolidation	
	Thick fluid	
	Thrombosis	
White tone	Bone or stone	Comet-tail artifact (B-line first)
	Fat	A-lines (lung)
	Cardiac valve	
	Interface	

commercial butter has a tissular pattern with strong absorption (looking like a liver parenchyma).

A bone (or a large stone) has a hyperechoic surface followed by an acoustic shadow.

An interface between two anatomical structures results in a hyperechoic stripe: pleural layers, diaphragm, cardiac valves, interface between liver and kidney, etc.

An approach from the echostructure:

An anechoic image can be:

- An artifact: the shadow of a bone (rib in particular)
- A real image: pure fluid

An echoic image can be:

- An artifact: acoustic enhancement from a fluid collection
- A real image:
  - Normal
    - Parenchyma
  - Pathological
    - Solid: thrombosis, alveolar consolidation, hematoma, necrosis
    - Fluid: thickened bile, abscess, noncirculating blood

A hyperechoic image can be:

- An artifact: reverberation of gas structure
- An anatomical structure: surface of a bone, surface of a stone, gas bubble, deep fat, cardiac valve, or interface

Note that most hyperechoic structures are rather lines (artifacts or interface).

Step 3: Ultrasound Anatomy – Descriptive Step

One difficulty (and strength) of ultrasound is that anatomy can be studied in three dimensions. The operator's hand must (or can) make rotating, pivoting or scanning movements, and thus creates an image to a certain extent.

The practice, at the beginning, of strictly transverse or longitudinal scans will make the images more quickly familiar. We use exclusive longitudinal scans at the lung area, and exclusive short-axis scans for any vein.

Dimensions can be accurately measured by freezing the image and adjusting electronic landmarks, or calipers. Yet critical ultrasound has not so much interest for measurements (see through this book).

Impediments to Ultrasound Examination

Several factors can lead to something of an esoteric fog, which will give this method an unwarranted sense of inaccessibility, at the beginning of the training.

Gas and ribs interrupt the image. This is one of the rare drawbacks of ultrasound, not found with radiography, CT, and MRI.

Bowel gas is, per se, an inescapable obstacle. However, an acoustic window may exist between two gases. A gas can move, like a cloud previously hiding the sun. Before concluding that an examination is impossible, the approaches must be diversified: one must sometimes wait and try again. The operator's two hands may be able to shift the gas (see Fig. 11.9 page 86). For getting rid of the gas, our maneuver is slight expiratory pressure, maintaining the pressure during next inspiration, then exerting a slightly greater pressure, and so on – with patience and method – this is the most pacific and efficient way.

Air at the lung level is traditionally considered an absolute obstacle. We will see that this dogma is wrong.

Bones are absolute obstacles. The adult brain should, therefore, not be examined with ultrasound. However, fine bones (maxillary bones, scapula) are transparent to the ultrasound beam. Using these windows, ultrasound extends its territory throughout the entire body.

Subcostal organs (liver and spleen) can be entirely hidden by the ribs and cannot be analyzed using the abdominal approach. Our universal probe will scan through the intercostal spaces, creating an incomplete vision – but fully adapted to the information required for a critically ill patient.

Obese patients (the elegant term is "challenging" patients) are traditionally not perfect candidates for ultrasound. The next chapter will show that the problem is balanced since most critical acute disorders are superficial.

A patient covered with extensive dressings is difficult to examine. See Chap. 27.

In daily practice, an examination that contributes nothing is rare. All in all, ultrasound answers a clinical question with a clear analysis in 80–90% of cases, and there is either a doubt or a full impossibility in other cases. At superficial areas (lung, veins, optic nerve, etc.), the answer is nearly always possible.

Step 4: Interpretation of the Image

Only the operator's familiarity with the field, enriched by reading the literature and personal experience, will indicate which conclusions can be drawn from, for instance, a gallbladder wall measured at 9 mm. This operator has carefully learned to choose an appropriate machine and probe, switch on the ultrasound unit, check for the proper gain, bypass useless modes, locate the gallbladder and take an accurate measurement of its wall.

The Ultrasound Equipment

2

With the continued use of complicated machines (even if small in size) with complicated techniques and unsuitable probes, ultrasound will remain the complicated discipline it always has been.

Some readers may be surprised to see described here a technology unit dating from 1992. Since this machine is simply perfect for critical ultrasound, and is still manufactured at the time of the present edition (some regular updates have involved only slight esthetic changes), we will just describe in two steps why we have not felt like changing this basic apparatus. In this chapter, we will simply describe it. In Chap. 30, we will compare it with the recent products in the market. Its main feature is its simplicity, in a field where a simple machine can really optimize the management of the critically ill.

Critical ultrasound heralds a new discipline (that we can temporarily call ultrasound-enhanced critical medicine). The more we can make it simple, the more it will become widespread. In this chapter, we aim at sharing the vision that our unit has given us since 1992. The reader is free to buy any machine – at a time when the possibilities are profuse between the cumbersome sophisticated echocardiography machines and the ultraportable market. These lines are simply our message.

Some doctors are persuaded that the modern up-to-date machines are better than older ones. This is not true if these machines have not been specifically designed for critical care, and for the most vital organ (the lung).

Some doctors are persuaded that the laptop revolution is the factor which initiated the birth of critical ultrasound. The craze without precedent for these machines comes from a slight confusion: a machine which is quite small (i.e., a laptop) is of great interest for those who work outside the hospital, but not necessarily for the majority who work inside. *Smaller* machines existed long before.

A Short Version for the Hurried Reader

We use an intelligent machine, which is still manufactured after its 1992 first version.

The feature we appreciate most about this machine is its small size: a width of 29 cm (and only 33 cm with cart), allowing the physician to pass between patient and ventilator, a critical point in a setting where each centimeter counts.

The image quality comes from a cathode ray tube monitor providing analog resolution (please see the figures in this book).

Its keyboard is flat, its design is compact, allowing efficient cleaning, a critical requirement between two patients.

This machine switches on in 7 s, which is basic for time-dependent situations as well as the multiple daily management of critically ill patients.

The cart is smart, since it fits the machine design with a width now of 33 cm. The cart is very important because it is mounted on wheels, which allow transportation of even heavy apparatus (our machine is 12 kg in weight) without effort from the ICU to the ER.

We use this machine because its 5-MHz microconvex probe is suitable for a whole-body analysis and can be qualified as universal. Having a probe that is small and can be applied anywhere without need for change is critical.

We appreciate the low cost of this system, a basic point since it allows easy purchase by the hospital, i.e., easy saving of lives since 1992.

This machine has advanced esthetics, but this particular point is subjective, as opposed to the seven

D. A. Lichtenstein, *Whole Body Ultrasonography in the Critically Ill,*
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previous ones, which are scientific. Their smart interactions generate a *harmonious* tool.

As a marketing strategy, in light of the field covered by this 300-page book, our summarized position would be: tomorrow's medicine using yesterday's tools.

A Longer Version: The Seven Requirements We Ask of an Ultrasound Machine Devoted to Critical Use

We now go into more detail for the unhurried reader. Ultrasound is reputed to be difficult, and it will remain so if we do not take care to consider seven basic requirements that make critical ultrasound simple.

First Basic Requirement: A (Really) Small Size

It is critical to find a place between the patient and the ventilator. Each centimeter is important. The important dimension (for those who have high ceilings, i.e., those who work in hospitals) is the width. We invite colleagues to measure the width of their machine (using the instrument of Fig. 30.2 page 298). We keep our 1992 machine since it is small: 29-cm wide on its own, 33 cm with our smart cart: it extends from bed to bed without a problem. For doctors working outside the hospital (airplanes, etc.), please see below.

Second Basic Requirement: An Intelligent Image Quality

The reading of most figures featured in this book (which are reprints of reprints...) shows why we respect our 1992 image quality. The analog technology (via a cathode ray tube monitor) gives analog image quality. The weight of the monitor is not a problem, thanks to the wheels. Comments about the resolution quality of the digital technologies are available in Chap. 30.

Figure 2.1 shows our definition of a suitable resolution.

Third Basic Requirement: A Compact Design – for Efficient Cleaning

We respect our patient, but we also respect the next ones. Accordingly, the cleaning of the machine is a critical point in the ER, and even more in the ICU. Our 1992 machine has a *flat* keyboard – efficiently washed in a few seconds. We do not advise the choice of machines with too many nooks and crannies for hospital use. The compact and smooth body of our machine is also rapidly cleaned – if necessary (see Chap. 3). What is mandatory for any patient is even more mandatory for the pediatric ICU.

Fourth Basic Requirement: A Short Start-Up Time

Time is life in the critically ill (plus multiple daily uses for less critical problems). Critical ultrasound

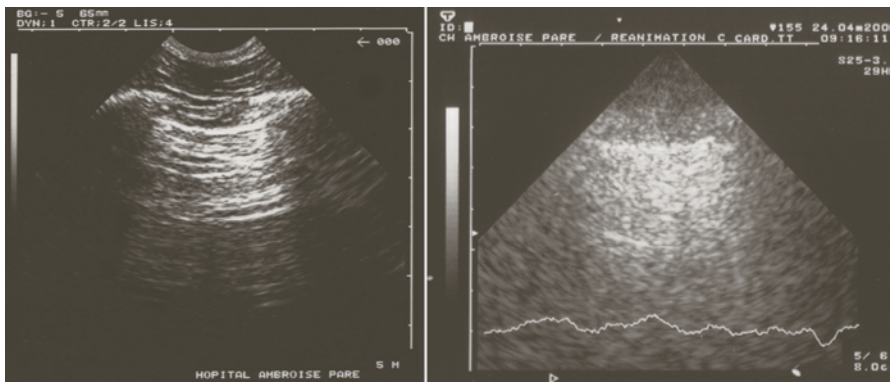

Fig. 2.1 This figure summarizes one of the main dramas in the history of lung ultrasound. The intensivists who had the opportunity to have echo machines had to deal with this kind of resolution (*right image*) – an efficient factor for discouraging from developing lung ultrasound

assumes immediate switch-on. Our 1992 technology has a start-up time of 7 s. Each additional second is an issue.

Fifth Basic Requirement: An Intelligent Cart

We find it important to have small machines: a small size allows the unit to be moved easily from bed to bed. For those who work in hospitals (i.e., more than 95% of us), the cart is more than an accessory. It joins together the ultrasound unit, the probe, the contact product, the procedural material, and the disinfectant (and more) in a compact way, and the screen/keyboard is at ergonomic height. The cart cancels the advantage of miniaturization (which is not a problem if the unit is narrow). The cart is equipped with a major, although old, technology: the *wheel.* The wheel was available roughly 4,000 years ago in Mesopotomic cultures. Thanks to the wheel, heavy machines (and mainly our 12-kg machine) are easily transported from bed to bed, from ICU to ER.

Since 1982, the ADR-4000 has had these wheels, and a 42-cm width (Fig. 2.2). These features have allowed the authors to define critical ultrasound at the point of care [1]. Since the ADR-4000's resolution was suitable for all critical diagnoses (optic nerve apart), we can state that the year 1982 was the point for the ultrasound revolution in the critically ill.

Our intelligent cart fits the unit exactly and does not take up useless place laterally. Figure 2.3 shows how the space is exploited for fixing the main items of equipment and the probe at the top of the monitor.

One role of the cart is to protect the machine. The overall weight and volume (in height) is an invitation to keep the machine within the hospital (i.e., make it difficult to steal).

Those who want to know more about our system should make a rendezvous with the PUMA concept on page 302 of Chap. 30.

Sixth Basic Requirement: The Access to an Intelligent Microconvex Probe

The probe is maybe the most important part of critical ultrasound – the bow of the violin.

Fig. 2.2 The ADR-4000, from ATL: a reference machine. This respectable machine was less cumbersome than some laptops (it was 42 cm wide) and could, thanks to the cart and wheels, go at the bedside and achieve the current critical ultrasound revolution since 1982. Please also see Fig. 30.4 page 300 showing how fine this machine was for developing lung ultrasound

The traditional ultrasound culture requires cardiac phased-array (2.5 MHz) probes for the heart, abdominal (3.5 MHz) probes for the abdomen, vascular (7.5 MHz) probes for the vessels, and endovaginal probes for the vagina.

We use none of these probes.

All are organ-specialized choices, none having been designed for a critical care use. We have benefited since 1992 from a universal microconvex probe able to answer to all immediate problems (Fig. 2.4). Its head has a unique small footprint: 10 × 20 mm, curved in one axis and linear in the other. It can be applied anywhere, on the numerous hard-to-access areas: intercostal spaces first, for the lung, but also supra-clavicular fossa (lung, superior caval vein), suprasternal area (aorta), the posterior parts of the lung in supine, ventilated patients, the subclavian vein, the popliteal area, the calf, and not to forget the heart. As to larger areas (abdomen), they are analyzed as well without compromise.

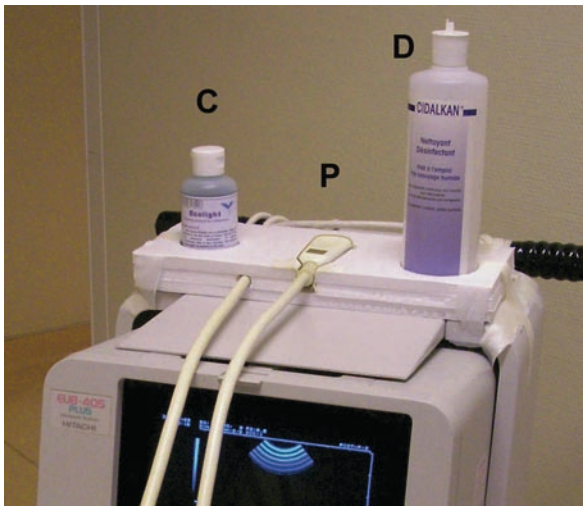

Fig. 2.3 Optimal space management. This view shows how the top of our smart analog machine is exploited. Instead of storing items on lateral extensions, we have inserted them on specifically designed spaces on top. Our microconvex probe (*P*), our contact product (*C*), and the disinfectant product (*D*) are immediately available. Space is optimized in the interesting dimension, simply the height. Featuring, the 2006 version of a 1992 technology (they just added some purple color on the dressing)

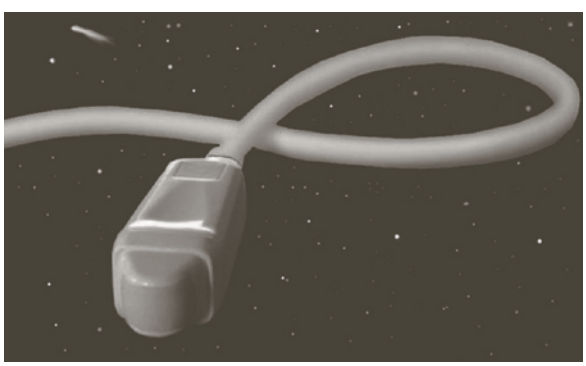

Fig. 2.4 Our universal microconvex probe. This probe is light, is 9 cm long and a 10 × 20-mm surface. The frequency is 5 MHz, but the explored field is 1–17 cm, allowing superficial as well as deep analysis. These features are major weapons for universal use in critical settings

Our smart microconvex probe is short: 9 cm. This makes possible investigation of posterior parts in the supine, ventilated patient, such as the posterior wall of the lung (PLAPS point, see page 118), or the popliteal fossa, etc. without effort. Each additional centimeter makes ultrasound more difficult. The usual 12- to 15-cm-long probes *discourage* the operators from routine lung analysis.

The frequency of our probe is 5 MHz but, more importantly, it provides sufficient image quality, from 1 to 17 cm. This unique range means satisfactory analysis of a subclavian vein as well as the inferior caval vein. Some microconvex probes seen in the recent laptop market have a good intention but have only a 10-cm range, and cannot be considered as universal. Note that a characteristic feature of critical ultrasound is that, apart from abdominal aorta and some veins, the most critical data are extracted from analysis of superficial areas. The lung is the best example. Most of the venous network (internal jugular, subclavian, etc.), peritoneum (pneumoperitoneum), optic nerves are other edifying examples of areas of easy access. As regards the heart, the pericardium is superficial. The ventricules are more superficial than the auricules, which are of lesser importance. In plethoric patients, deep abdominal analysis (pancreas, etc.) is often disappointing, and these patients are eventually referred to CT. Our choice for our single 5-MHz probe has taken this important detail into consideration.

Our probe resolution, slightly similar to an abdominal probe, is far superior to that of cardiac, phased-array probes. Abdominal probes have poor ergonomy. They are useful for measuring the size of a liver – only of interest for the radiologist – but this is not the tool of the intensivist.

The light weight facilitates analysis of the whole body without fatigue (optic nerve, maxillary sinuses, Hunter canal, etc.).

Further discussion about vascular probes is available in Chap. 30. In summary, however, we do not find these probes suitable for use on the human being (they are probably a relic of the industrial, pre-medical era of ultrasound). We use our microconvex probe for all deep veins.

Can one use linear probes for the lungs? This is a fact: lives can certainly be saved using them. The user must just accept to have limited access to the longitudinal approach (that makes lung ultrasound easy), limited criteria for distinguishing B-lines from Z-lines, restricted access to the deep structures, time spent for buying the probe, changing (and therefore disinfecting) probes frequently, and limited access in overly meager patients. Some advocate that lung sliding is easier to detect, but this can be solved simply using M-mode (see page 126).

Using only one probe has several advantages:

1. This allows fast protocols. Once the machine is switched on, the user wastes no time in selecting a probe, or adjusting settings. This is critical for acute respiratory failure, cardiac arrest management, or daily use for any other procedure in the critically ill.
2. It reduces the cost of the equipment and requires buying just one, i.e., saving lives more easily.
3. This is mandatory for performing clean ultrasound. More than one probe, with its cable, is a hindrance for efficient cleaning. When the examiner feels like changing the probe, especially in an emergency, a logical asepsis is quite impossible to achieve (see Chap. 3).
4. This favors simplicity – a golden rule of critical ultrasound.

Seventh Basic Requirement: An Intelligent, Simple Technology

This generates simplicity of use associated with low cost. The low cost is a critical point, since each saved dollar saves additional lives.

Cathode Ray Tube Technology

See above, our second requirement.

The Point About Doppler

We do not use Doppler. This will be a comment throughout this textbook, for each classical application. Additional comments feature in Chap. 30. The main problem with Doppler is the cost (which is triple the cost of a simple machine), having put ultrasound out of the reach of many hospital budgets over the years. This factor has possibly delayed a revolution that could have occurred in 1982 (ADR-4000).

Our daily use is centered around life-saving or very current applications. Observations have showed that Doppler is sometimes required, but on rare occasions for extreme emergency use. We therefore developed the concept of the Doppler Intermittently Asked From Outside: Rare Applications – the DIAFORA concept – for indicating that we are not closed to it. We just ask, from time to time, an outside operator with a complex machine, to come to the bedside. Even more than half the time this is not contributive to the patient (study in process).

We have also envisaged a simple, low-cost alternative: a low-cost continuous Doppler probe, which we arrange to couple with our real-time probe, for having the vessel located, then the Doppler signal. We have not found time to build a serious device for coupling the two probes (indicating that we have not felt an urgent need for using this potential).

Filters

We work on natural images. Filters are good for radiologists, by providing an image nice to look at, but we think that they are a hindrance for critical ultrasound. The profusion of recent modes is maybe a marketing policy, or possibly a necessary adaptation to the poor resolution of the flat-screen technology. We regularly inactivate persistence filters, dynamic noise filters, and average filters, which prevent real-time dynamic analysis of vital organs: lung first, heart, vessels, GI tract. Filters creating a lag are not compatible with dynamic analysis. Some modes try to suppress the artifacts. Multibeam mode is maybe the most destructive filter. We are concerned with the desire of manufacturers to suppress these artifacts. This would simply mean "burying alive" lung ultrasound. We will resist this new fashion by any means. We do not clearly see the interest of harmonics and bypass this function. As a rule, we bypass *all* filters. Critical ultrasound is performed using natural images.

We also consider here the facilities for challenging patients. Some modern modes that advocate making them well echoic should be carefully assessed.

For visual comfort, with increasing experience, smoothing the image can be helpful when studying motionless organs (liver).

Contrast-Enhanced Ultrasound

This mode is possibly interesting, although requiring special software, and is not accessible with our simple

unit. We will examine this mode in the future, when the full potential of a simple critical ultrasound design will be covered.

Computer Technology

This condemns the user to a long switch-on time (far from our 7-s time) and the permanent risk of bugging, for no benefit.

M-Mode

This is an important function, allowing ideal use of lung ultrasound. Our unit aligns the real-time and the M-mode images on a perfect horizontal plane. See Fig. 2.5, and our comments about those which do not, and the consequences on the diagnosis in Chap. 18 page 165.

To Conclude on this Technologic Point

The most sophisticated modes will be useful to some very specialized centers (cardiac surgery ICU, for instance), but bear in mind that they will be unable to cross bones, air or dressings. These are true limitations of ultrasound. Attending countless workshops using modern laptop equipment, we have become accustomed to them little by little, but are left with feeling a difficulty in using them. They are configured in traditional ultrasound, which critical ultrasound is not, since simple technology is used.

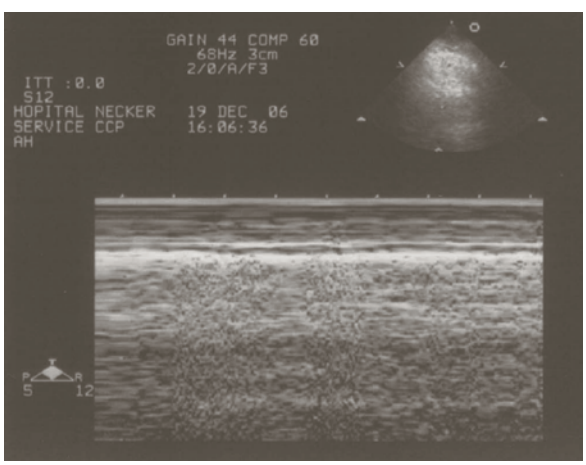

Fig. 2.5 Example of an unsuitable setting for lung ultrasound. The quality of the upper image prevents location of the pleural line (cardiac probe). Since the real-time image is not located at the left of the M-mode image (time-motion), the pleural line cannot be rapidly and safely located. The "seashore" pattern comes maybe from the pleural line, but possibly from a more superficial structure. Please see Fig. 18.1 page 165, which is an even more pernicious setting. Lung sliding in a ventilated neonate

One Critical Word to Summarize Our Seven Requirements

The smart reader has seen that each part of this machine interacts with the others. The cart fits the machine. The quality is evident from the cathode ray tube monitor, which is light thanks to the wheels, which allows the machine to be secure (not stolen) and easily transported. The monitor allows the top to be utilized, i.e., benefiting from a narrow width, one probe finds a natural place upon this top. This perfect probe allows fast ultrasound with easy cleaning, etc. One word for characterizing this type of completion should be: *harmony*.

Additional Details

Coupling System

The gel is advocated to be mandatory, since it creates a coupling between probe and skin. Since the dawn of ultrasound, gel gives a traditional vision of a messy, slippery field: a sticky discipline. It makes a nice culture medium. Squeezed by the stressed hand, it generates gurgling noises reminiscent of undesirable digestive noise, never appropriate in dramatic settings. Visions of dried gel that was not wiped, with on occasional hair stuck on the probe, are common. We are persuaded that this image is not excellent for the propagation of ultrasound, and admit that our attraction for ultrasound was during years shadowed by this gel.

We have made gel unnecessary. We elaborated a new contact medium, based on an equimolecular combination. Totally harmless, odorless, applied with a special compress, which is applied onto the area to be scanned, it provides the same image quality. It vanishes after a few minutes. No residual dust is perceptible on

the skin. All figures in this book have been acquired using it. This product has nothing but advantages.

The main advantage is a major time saving during critical examinations: the time necessary for passing from an area (lungs) to a remote area (lower veins) is reduced to less than 3 s.

Another major advantage is in extreme emergencies (cardiac arrest): the amounts of gel necessary to make the thorax slippery are a hindrance to resuscitation.[1]

The last, but not the least, main advantage is the comfort of making a clean examination, far from this traditional "sticky mess" (see Fig. 30.1).

Our product has appropriate adiabatic properties and can be used warm, which is appreciated by the conscious patient. Since we have begun using it, ultrasound has become a complete pleasure. Our product, recently patented, will soon be distributed. Ecolight, called the "gel-less gel" by Teresa Liu, is one example among others which show that our vision of ultrasound is simple and user-friendly.

Recording the Data

The hardcopy is useful in order to preserve documents. In extreme emergency situations; a videocassette recorder has three advantages: a shorter examination (taking photographs is not necessary), data that can be read subsequently, and data easier to read than static images.

We now live in the digital era, but VHS technology allows us (even today) to make thousands of recordings and hundreds of presentations. We conclude that the problem of digital or analog is not relevant.

The Problem of Incident Light

Critical ultrasound has to be practiced around the clock. Daylight can bleach the screen. Manufacturers do not always think of systems to prevent this inconvenience. We must imagine several temporary set-ups adapted to each unit. The most promising seems to be sliding panels. A matt black cylinder applied to the screen at an oblique angle (towards the operator's eye) is another possible solution.

[1]We thank Sébastien Perrot who, during a Paris-Taiwan flight, although not physician, opened our eyes to this basic point.

How to Practically Afford a Machine in One's ICU

We currently see three approaches.

1. To buy a new one. Very few brand names are present in the recent critical care congresses but the buyer who considers the width instead of the height will discover a large choice.
2. To acquire a second-hand machine. Occasionally, the radiology department gets rid of obsolete units and leaves them to whoever wants them. These "old" machines can save lives; some of them can be excellent. Note that cathode ray tubes give better resolution than digital screens.
3. To steal it. The possibility of stealing a machine is an option which must be considered, now that ultrasmall machines have invaded our hospitals. These lines have been written with serious intent, and we want to make colleagues aware of this unpleasant scenario; it has already occurred in prestigious institutions. Fixing a portable unit solidly on a cart is the solution, which immediately makes the ultraminiature technology of lesser relevance. Consequently, the user will benefit from all the disadvantages of low-height machines, and should carefully search the advantages (see Chap. 30). *We ask the reader to consider this basic point.*

Which Solutions for Teams Already Equipped with Small-Sized Technologies?

That equipment can be used. Indeed, any kind of machine can give useful information. Things are just more difficult, ranging from slightly to extremely. Since the author is accustomed to working with "perfection" since 1992, which he has looked for over several years in the modern laptop market, the index of 100 was given to this system and permanently compared with modern technologies.

Each centimeter in width >33 cm creates additional difficulty (take the cart size into account).

Each decrease in resolution <100 detracts from accurate use.

Each button to be cleaned is a hindrance.

Each second over 7 s for start-up increases psychological barriers.

Each millimeter of surface of the probe head >10 × 20 mm makes access to difficult parts more difficult.

Each centimeter of length of the probe >9 cm makes posterior analysis more difficult.

A wide choice of probes is not necessary, especially if the ideally designed one is missing.

Each additional dollar >16,000 makes purchase more difficult.

Laptop machines which have *simultaneously* a width >33 cm, a resolution image <100, a number of buttons >1, a start-up time >7 s, a probe length >8 cm, not the suitable probe shape and property, and a cost >$16,000 are not used by the author.

Those who currently lack the necessary equipment but want to have an idea of lung and venous ultrasound made in the spirit of the BLUE protocol (see Chap. 20) will find the best compromise in image quality using the abdominal probes, which have poor ergonomy. They will find the best compromise in ergonomy with the cardiac probes, which have poor image quality. They will find the best superficial resolution using linear probes, which have poor ergonomy and limited field. Not taking into account the properties of our 1992 unit, the modern laptop machines have not decreased the difficulty of ultrasound – which is in its current, traditional state a discipline for experts.

Although we think the community lost an opportunity to discover critical ultrasound in the way of simplicity, we are optimistic and hope for a simple solution (dealt with in Chap. 30).

Which Machines for Those Who Work Outside the Hospital or in Confined Space?

The few doctors who work in airplanes (or helicopters, ambulances, *spaceships*...) will be interested in hand-held machines, which are an absolute revolution, in this very setting where each centimeter counts in the *three dimensions*. Laptop machines of around 6 kg are a bit too heavy for our use. In our part-time work as flying doctor, we use a compact 1.9-kg machine constructed according to our wishes, mainly using a flat, incorporated screen and one probe (making a substantial gain in size and weight since the year 2000). It is 15 × 12.5 × 13 cm in size (we have stuck the battery to the back). The image quality is suitable for lung imaging. It holds, with the probe, the contact product, and emergency procedures material, in a 26 × 17 × 19-cm market bag which opens at the top, i.e., a perfect bag providentially found in Boulevard Saint-Michel (Paris 6th, left river side, free ad).

Ultraportable machines were available long ago [2,3]. We have conducted the first world evaluation of a hand-held unit devoted to critical ultrasound using one of these rudimentary machines at the end of 1995 [4]. This 3.5-kg battery-powered machine allowed us to cover the Paris-Dakar rally from our medical helicopter (see page 271).

Seven important points

1. The important dimension (for optimal mobilization) is the lateral width, not the height.
2. The cathode ray tube technology (not heavy thanks to the wheels of the cart) provides the best image quality.
3. A flat keyboard is easy and rapid to disinfect.
4. An immediate start-up time (7 s) is important.
5. An intelligent cart does not annihilate the advantages of miniaturization.
6. One probe can be used for the whole body (a 1–17-cm range microconvex probe).
7. Doppler and other sophisticated modes (harmonics, etc.) are not of major utility in our setting.

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Specific Notions of Critical Ultrasound in the Critically Ill

3

The critically ill patient in the ICU is not any patient. Usually immobilized in the supine position and sedated, this fragile patient cannot indicate pain location, maintain apnea, etc. The intensive care creates some limitations but also many decisive positive points.

Limitations Due to the Patient

An ambulatory patient can be positioned laterally with inspiratory apnea for studying the liver, or sitting for pleural effusions, or again with legs hanging down for venous analysis, etc. The problem of the critically ill patient has rarely been dealt with in the literature. In this ventilated patient, the supine position is the only setting. The ultrasound approach must be adapted to this position. We will see that suitable equipment is the key for facing this limitation.

Intensivists performing echocardiography have long adapted their technique by major use of the subcostal route, often the only available for the heart.

When an organ dysfunction is suspected (best example: gallbladder), the pain is absent in a sedated patient. Willing to make this basic sign appear by temporarily decreasing the sedation does not work. In fact, ultrasound *must speak* for the patient. This step requires the mingling of descriptive and interpretative steps, using simple elements such as the clinical context (read for instance Chap. 8).

Limitations Due to Equipment

The critically ill patient is surrounded by cumbersome life-support equipment: ventilator, hemodialysis device, pleural drainage kits, and others. The operator must make sufficient room to work comfortably, a mandatory condition. This limitation is greatly minimized if we are equipped with *narrow* compact apparatus on a compact cart, like the one we have used since 1992. This point is of critical importance. Laptop equipment that is 7 cm high but 44 cm wide will be larger than our 33-cm machine (which is 27 cm hight it is true – but not a problem – not the important dimension).

The barrier is lowered, thoracic electrodes are withdrawn for heart and lung study (even better, the paramedic team has been trained for applying the electrodes once for all on nonstrategic areas such as the shoulders and sternum), and the elbows are gently spread from the chest in order to study the lateral areas (lung, etc.).

Apnea cannot be obtained: the patient is either mechanically ventilated or, if not, is often dyspneic or encephalopathic. Usually, lung ultrasound in a dyspneic patient is perfectly feasible (see Chap. 20).

Strength of Ultrasound in the Critically Ill Patient

The critically ill patient is – in a way – a privileged patient with respect to ultrasound.

The sedation facilitates all interventional procedures.

Providentially, a supine patient offers wide access to the critical areas: optic nerve, sinuses, anterior and lateral areas of the lungs, most deep veins, heart, abdomen, etc., are anterior. Turning a patient is never easy nor fully harmless. The hidden side of the patient conceals information on very posterior alveolar consolidations, sometimes the abdominal aorta (lumbar approach). The 9-cm long microconvex probe we use all through this book is the key-point for reducing this "hidden side" (explored using Stage 3, defined in Chap. 14).

D. A. Lichtenstein, *Whole Body Ultrasonography in the Critically Ill,*
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Table 3.1 Feasibility of whole-body critical ultrasound (from head to feet, expressed as a percentage of cases where the item was analyzed)

Organ	Explorable organ	Optimal exploration	Exploration with a risk of error
Optic nerve	100	94	6
Maxillary sinuses	100	100	0
Internal jugular veins	98	95	3
Subclavian veins	93	87	6
Anterior lung surface	98	98	2
Lateral lung surface	92	86	6
Peritoneum	98	NA	NA
Abdominal aorta	84	51	–
Liver	96	72	22
Gallbladder	97	82	14
Right kidney	97	87	10
Left kidney	100	63	37
Spleen	98	75	22
Pancreas	70	51	19
Femoral veins	98	NA	NA

NA not available

We have withdrawn from this old table data from the pleural cavity performed using the obsolete abdominal approach

Mechanical ventilation allows exploration of subcostal organs that were previously hidden. When the subcostal approach is limited, one theoretical possibility is to lower the diaphragm by increasing the tidal volume, if there is no risk of barotrauma.

Prolonged parenteral feeding may result in a decrease in digestive gas, which increases ultrasound performance. Developing an efficient system to eradicate bowel gas in any critically ill patient will be a great step forward in abdominal ultrasonography, and at the time of this 2010 edition, we just work on a simple, nontoxic method. The utility of ultrasound has been proven in the critically ill, and we expect each patient to benefit from one or more examinations during a long stay.

A fluid overload is frequent in septic patients with impaired capillary permeability. This is not an obstacle, fluids are good ultrasound conductors.

The feasibility of ultrasound varies with the patient and the area. There is a gradation between perfectly observed organs, with a clear answer to the clinical question, and impossibility to assess them. In our institution, a study showed a 92% feasibility, all areas combined [1]. The belly examination was classified as optimal in 71% of cases. The pancreas and abdominal aorta were the difficult organs, mainly because of gas (Table 3.1). In some instances, conditions reputed to prevent the examination can provide precious information: a gas barrier preventing abdominal analysis can indicate pneumoperitoneum. All in all, one idea should be highlighted: ultrasound examination is always indicated, since only beneficial information can emerge from this policy.

Studies done by radiologists were conducted in the ICU. Although limited to the abdomen and including findings without therapeutic relevance, they indicated, however, that it was possible to take an ultrasound machine to the patient's bed [2–4]. Our hospital is in all probability the first to study assessing the usefulness of whole-body ultrasound, handled by the intensivist himself for immediate patient management, using a set-up belonging to the ICU [5]. The principal study made in this setting found a 22% utility rate (with immediate therapeutic changes) for consecutive patients, including only validated fields of traditional ultrasound [5]. Note that our study did not take into account negative results (with positive outcome on patient management),

cardiac results, interventional procedures, nonclassic indications such as lungs, maxillary sinuses, optic nerve, and repeated examinations for monitoring critically ill patients (lung status, venous thromboses, etc.). If it had, the percentage of patients benefiting from the ultrasound approach would not have been 22% but a number not far from 100%. Interestingly, this 22% rate is near to the 31% rate of unexpected findings made from ICU patients and using large autopsy studies [6].

Driving an Ultrasound Examination

The region of interest will be studied first, especially in our fast protocols (the BLUE protocol in Chap. 20, the SESAME protocol in Chap. 29), but it is satisfactory – time permitting – to make comprehensive examinations, to fully exploit the potential of this noninvasive method. Table 3.2 is a suggestion of an ultrasound report made with this spirit.

In good conditions, the whole-body can be analyzed in less than 10 min (the BLUE protocol takes less than 3 min). Remember that only one probe and our coupling agent allow major time-saving. The examination can be recorded in real-time without losing time taking down figures. When the question is simple and focused (left pneumothorax or not, common venous thrombosis or not, bladder distension or not), only a few seconds are required.

Disinfection of the Kit

Prevention of cross-infections is a major care in the ICU. Asepsis in ultrasound is not only mandatory, but above all *really easy to follow*. Some reflexes quickly become automatic. We take particular pride in driving an ultrasound examination with a spirit not far from that for a central venous catheterization.

A smart ultrasound unit is compact, with a flat keyboard. Other configurations make disinfection attempts more difficult (from slightly to highly). Such a machine has been in existence since 1982 (ADR-4000).

Care must be taken to adopt a one-probe philosophy (this textbook explains how). Using more than one probe makes extremely constraining maneuvers of disinfection.

We start up the machine before any contact with the patient. We define as "open parts" the few parts which will be touched during an examination: the probe, the keyboard, and the contact product if used several times (Fig. 3.1). We define as "closed areas" all other parts of the ultrasound machine and avoid touching them without reason during the examination.

Once the work has finished, the patient covered and the barrier up again, we leave the probe on the bed (provided the patient is not encephalopathic). We come back with clean hands. An on-site disinfectant product (which was in a dedicated place and was not handled during the examination) is poured onto a simple but special compress which allows efficient work. The stock of compresses is located in a "closed area" of the machine. Traditional moist wipes are not as efficient as our system of a well-soaked compress. Then, the work of disinfection is particularly simple: only the "open parts" are cleaned.

1. The flat keyboard is cleaned in a few seconds.
2. The (unique) probe is cleaned in a centrifugal way, from the cable to the probe. The probe is then inserted onto its stand. The stand is a basic closed part. Cleaning a stand is difficult and inefficient. Using our way, the stand does not need to be cleaned.
3. The contact product, if used twice, is cleaned. [Helpful note: the body of this bottle (easy to clean) is an open part, the top (hard to clean) a closed part. Therefore, a clean hand takes the bottle by the top, the other hand can clean the bottle without any fault.]

It is not forbidden to touch "non-contact" parts of the unit without necessity. Nonchalantly putting soiled hands on closed areas of the unit, leaving the contact product bottle lying on the bed, or again handling the disinfectant with soiled hands is allowed, provided the user carefully cleans everything after the examination. When the steps are automatic and executed in a logical order, the cleaning time is estimated at 30 s, and the unit remains clean.

Which disinfectant do we pour on our compress? We do not like to see products devoted for the purpose, as they may contain too much detergent for our subtle equipment. The probe silicone must not be damaged by the product. Manufacturers have always given us obscure answers and we have been obliged to take some risk and build up experience over the years, and with the microconvex probe of our Hitachi EUB-405 unit,

Table 3.2 Usual report of whole-body critical ultrasound

Hôpital Service de
Ambroise-Paré Réanimation Médicale
ULTRASOUND REPORT
Urgent/Scheduled
Name Day **DATE 2010** Hour
D. Lichtenstein Unit: Hitachi EUB-405 – 5-MHz microconvex probe Birth date Setting Day XX
Clinical question:
Conditions, patient's echogenicity: correct OR ELSE
Ventilatory status and position: mechanical/spontaneous ventilation Tidal volume PEEP 02 Eupnea/dyspnea Patient not or sedated not or curarized supine position semi recumbent armchair other
Various items for research design (auscultation data, description of radiography, etc.)
Thorax
Right lung
- stage 1 analysis:
- Upper BLUE point:
- peak lung sliding: present abolished
- artifacts: A-predominance or B-predominance ORxELSE
- Lower BLUE point: same items
- stage 2 analysis:
- lateral: B-lines ORxELSE
- pleural effusion:
- alveolar consolidation:
- phrenic point: Cupola: eutopic ORxELSE. Amplitude xxx mm
- stage 3 analysis:
- PLAPS point: PLAPS (+ details) or not – ORxELSE
- stage 4 analysis:
- apex analysis:
- comprehensive posterior scanning:
- free text

Left lung
- same items

Mediastinum
Thoracic aorta (initial, arch, descending aorta): normal ORxELSE
Right pulmonary artery: visible ORxELSE
Superior caval vein: visible ORxELSE Expiratory mediolateral caliper Inspiratory collapsus or not
Heart (two-dimensional approach). Easy examination ORxELSE
Pericardium: sub-normal ORxELSE
Left ventricle: free text
- diastolic caliper – systolic caliper
- i.e.: global contractility: low normal exaggerated
- dilatation: absent moderate substantial

Right ventricle: free text
- volume: normal or enlarged
- free wall: thin thick ORxELSE
- contractility

Other elements: free text
Deep veins
Two-dimensional, short-axis, controlled compression method
Internal jugular (dominant: right or left): free ORxELSE
Subclavian: free ORxELSE
IVC: correct exploration, empty vessel ORxELSE
Iliac: correct exploration, empty vessel ORxELSE
Femoral: free ORxELSE
Popliteal: free ORxELSE
Calf: at least partially (%) compressible ORxELSE
Head
Right (left) optic nerve: Caliper xxx (hM) Micro-bulging: yes/no Sinuosity checked: yes/no
Maxillary sinus (supine/erect patient) (nasogastric probe: yes/no) **Right (left)**: Sinusogram absent OR present If present: complete OR incomplete

Table 3.2 (continued)

Abdomen
Examination: optimal/suboptimal (reasons: body habitus, gas, dressings, others)Fluid peritoneal effusion: absent ORxELSE
Pneumoperitoneum: absent (gut sliding present and/or splanchnogram) ORxELSE
Stomac: full empty gastric probe visible in situ ORxELSE
Small bowel: peristalsis present or abolished or not accessible Wall: thin ORxELSE Caliper: normal ORxELSE
Contents: anechoic or echoic Unaccessible bowel
Colon Same items Search for air–fluid levels
Aorta: regular ORxELSE
Inferior caval vein: Expiratory size at the left renal vein = xxx mm Patency :
Adrenal: analyzed ORxELSE
Kidneys: nondilated pelvis ORxELSE
Bladder: full empty correctly drained Uterus:
Gallbladder: No elective pain Not enlarged (nn × nn mm) Wall not thickened (mm) Wall regular homogeneous Contents anechoic, or sludge (%) No satellite peritoneal effusion ORxABSENCExOF THESExITEMS
Liver: no visible acute anomaly – no portal gas – on comprehensive or limited examination ORxELSE
Biliary tract: fine ORxELSE
Spleen: normal size ORxELSE Homogeneous pattern ORxELSE
Portal system: no anomaly ORxELSE
Pancreas: normal in size and echostructure ORxELSE
Retroperitoneum: analyzed ORxELSE
Other remarkable elements seen:
Miscellaneous
Musculo-fat ratio. Thickness of the crural muscle (right thigh):
SYNTHESIS
A practical synthesis is written (time permitting) in a style allowing any physician, even without ultrasound culture, to understand the main points of the clinical situation. It focuses on immediate management changes.

The style of this report has been designed for a printing that can be done rapidly in an overburdened shift. It contains data pertinent to the initial examination of an unstable patient as well as routine examinations in stable, ventilated patients. This makes a kind of initial photographic reference that can be useful for later examinations.

This report does not require a comprehensive filling. Some items can sound weird ("patient not or sedated"), but this time-saving system favors immediate filling. The words "OR ELSE" (with an invisible link for quicker deleting) has been created in order to show without any ambiguity to the reader that the item was not analyzed or not filled, for any reason (time lacking, not a region of interest). Positive as well as negative items are specified. Serendipitous findings with immediate or delayed (aneurism) consequences are recalled here.

and a 60% alcohol-based alkylamine bactericide spray with neutral tensioactive amphoteric pH. We have used this system since 1995, and our probe has not shown any damage. Some authors have proposed 70% alcohol as a simple and efficient procedure [7], but a majority of authors find it risky for the probes and not effective enough in terms of decontamination. An aldehyde-based and alcohol-based spray has been advocated [8], but this is a questionable approach if this blend fixes proteins. The gel is a culture medium for bacteria. Many constraining procedures have been designed for carefully withdrawing all marks of gel. Some advocate using an absorbent towel between patients [9]. Particularly in the ICU, this solution seems really questionable. Since we do not use gel, these complicated procedures can be forgotten.

Indications for an Ultrasound Examination

Simple admission to an ICU is an obvious sign of gravity, and justifies a routine ultrasound examination with no place for hesitation, in the same way a physical examination is always made. Even a simple drug poisoning benefits from a lung ultrasound, in order to check (better than with a radiography, which can be postponed) signs of aspiration pneumonia. Too often, even in prestigious places, we have seen complex patients not benefiting from immediate ultrasound. These patients endured a troubled course, eventually receiving an ultrasound examination which indicated, immediately but too late, the cause of the disorder.

Fig. 3.1 Bacteriological partition of our unit. Only the *circled* parts need to be touched, and should therefore be disinfected after use. As seen here, a flat keyboard is immediately cleaned. One single probe can efficiently be cleaned before insertion on its stand. For all the other parts (with *crosses*), there is no need to touch them during the examination (or if so, they should just be cleaned afterwards)

Ultrasound must be used before the irreversible inflammatory cascade has started up.

In practice, we perform a whole-body ultrasound approach for each new patient admitted to our ICU. It is repeated as many times as necessary. Schematically, three steps can be described. The initial step is the one of initial diagnosis. The second step is material management, i.e., time for interventional ultrasound (puncture of suspect areas, insertion of catheters, etc.). The third step is for early recognition of the usual complications (pneumonia, sinusitis, thromboses, etc.). Not going this way is performing blind medicine.

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Part II

Organ by Organ Analysis

Introduction to Abdominal Ultrasound: Normal Patterns

4

"General ultrasound" has become assimilated into abdominal ultrasound over the years. Although this is a modest part of critical ultrasound, we will begin with this classical field and provide the young physician with a better understanding of the abdominal examination. This chapter includes only notions useful for managing critical situations.

As opposed to lung ultrasound (which is a simple field since there is only one organ) the abdomen is a more complicated field, because 20 organs are concentrated here. Scanning through the abdomen requires some experience and a nice recollection of in anatomy. The recognition of one organ allows another organ to be better located, and vice versa. A suggestion of sequential analysis is suggested in Table 3.2 page 22.

The following figures were obtained using a 5-MHz microconvex probe and a sectorial 3.0-MHz probe.

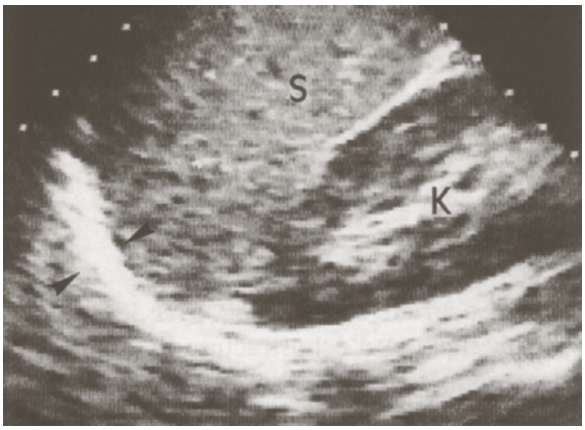

Fig. 4.1 Spleen and left kidney in a longitudinal scan. Note the left hemidiaphragm (*arrows*) just over the spleen (*S*). The kidney (*K*) is located in the splenic concavity. As in Fig. 4.8, the interface between spleen and kidney is fully distinct from the cupola. Note that the structures located above the cupola cannot be interpreted; they can be ghost mirror echoes as well as alveolar consolidation. This route is not adequate for lung or pleural ultrasound

Diaphragm

The diaphragm is a vital muscle that separates the abdomen from the thorax. Its analysis can appear complex due to the shape and the relation between aerated organs (lung/colon). There are two ways to approach its analysis.

1. It was traditionally studied with abdominal probes during abdominal examinations through the liver or the spleen when the probe head was inclined toward the patient head. The hemidiaphragm and the joined pleural layers form a large stripe, hyperechoic, curvilinear, concave downward, covering the dome of the liver or spleen, normally descending on inspiration (Fig. 4.1).
2. Using a microconvex probe, the direct intercostal approach gives another vision of the diaphragm that is of clinical interest. It will be detailed in Chaps. 14–19.

Peritoneum

The peritoneal cavity is normally virtual, but the peritoneal line is precisely located with the dynamic of gut sliding (Fig. 4.2).

D. A. Lichtenstein, *Whole Body Ultrasonography in the Critically Ill,*
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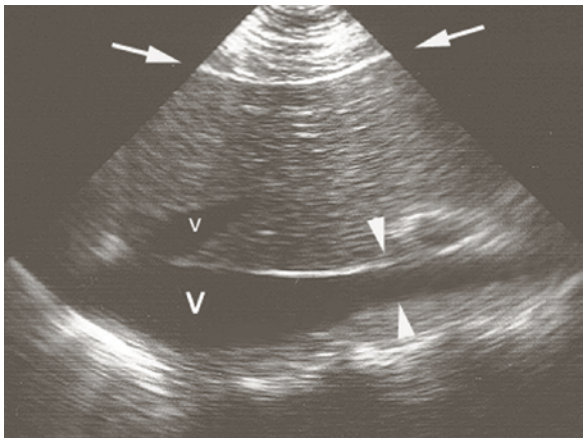

Fig. 4.2 Inferior vena cava (*V*), longitudinal view. Note the bulge (at the *V*), frequently seen. We do not measure the venous caliper of the inferior vena cava at this level but lower down (*arrowhead*). Note also the median hepatic vein (*v*), not to be confused with the inferior vena cava. The *arrows* indicate the peritoneal line

Lumbar Rachis

This is an important landmark, recognized on transversal scan as a large (4-cm) medial curved image stopping the ultrasounds, with the two main large vessels just anterior (Fig. 4.3).

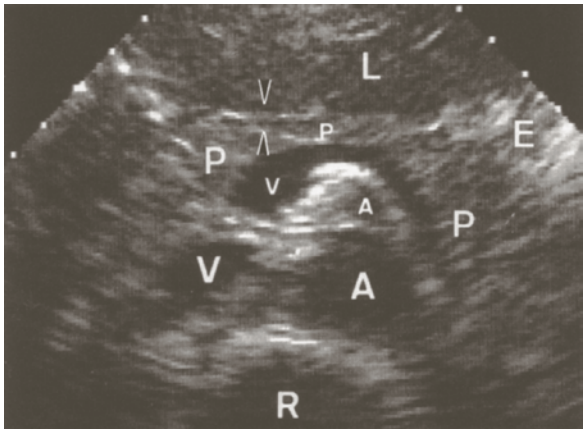

Fig. 4.3 Pancreas, transverse scan. Identifiable from rear to front are: the rachis (*R*), then the aorta (*A*) and inferior vena cava (*V*), then the left renal vein, and then the superior mesenteric artery (*a*). Just anterior to it, the splenic vein (*v*) has a comma shape. The splenic vein constitutes the posterior border of the pancreas, which is now located. Its head (*P*) is in contact with the inferior vena cava. The isthmus and body (*p*) are in continuity with the head. Anterior to the pancreas, the virtual omental sac (*arrows*), the stomach (*E*) and the left lobe of the liver (*L*) are outlined. These structures are rarely all present in a single view

Large Vessels

The abdominal aorta descends anteriorly at the left of the rachis. Its caliper is regular. The celiac axis and the superior mesenteric artery arise from its anterior aspect (Fig. 4.4).

The inferior vena cava rises anterior to the rachis at the right of the aorta, passes posterior to the liver (Fig. 4.2) and ends at the right auricle (Fig. 4.5). It receives the renal veins and the three hepatic veins, just before opening into the right auricle. The walls are rarely parallel, and wide movements are often observed. In thin patients, the vein can be compressed.

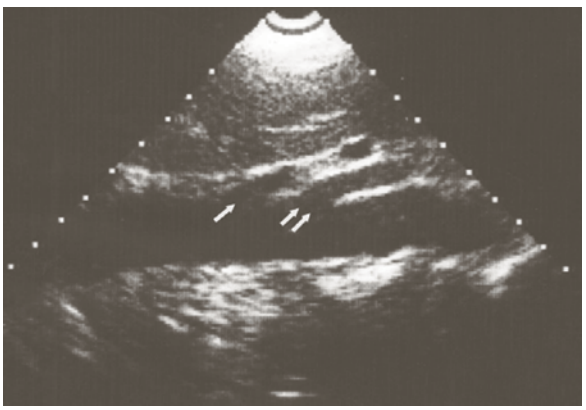

Fig. 4.4 Abdominal aorta. Longitudinal view, with the origin of the celiac axis (*arrow*) and the superior mesenteric artery (*arrows*)

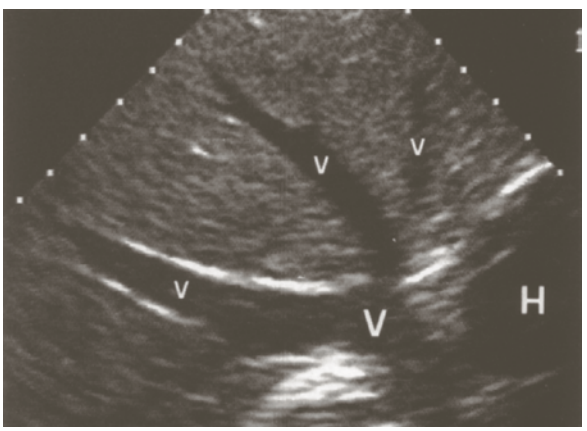

Fig. 4.5 Liver and the three hepatic veins. Oblique scan through the axis of the three hepatic veins (*v*), which meet in the inferior vena cava (*V*), a little before it opens into the right auricle (*H*). Although reputed as having no visible wall, they can, like the right vein here, be separated from the liver by a thin echoic stripe

With all these features, the aorta and inferior vena cava cannot be confused.

Liver

The liver can be studied by longitudinal and transversal scans. Its anatomy is complex to describe, with a right lobe occupying the right hypochondrium, and a smaller left lobe extending to the epigastrium. Radiologists use precise reference scans. Analysis of the hepatic segmentation is of no use to the intensivist. *We advise the beginner in critical ultrasound not to invest too much energy on the liver, biliary tract or portal system, as far as other critical domains (lung, veins, simple heart) are not mastered.*

Several vessels cross the liver. Using more or less transverse scans, and from top to bottom, one recognizes:

- The three hepatic veins, which converge toward the inferior vena cava (Fig. 4.5).
- The branching of the portal vein (Fig. 4.6).
- The portal vein, which has reached the inferior aspect of the liver, in an oblique ascending right route (Fig. 4.7).

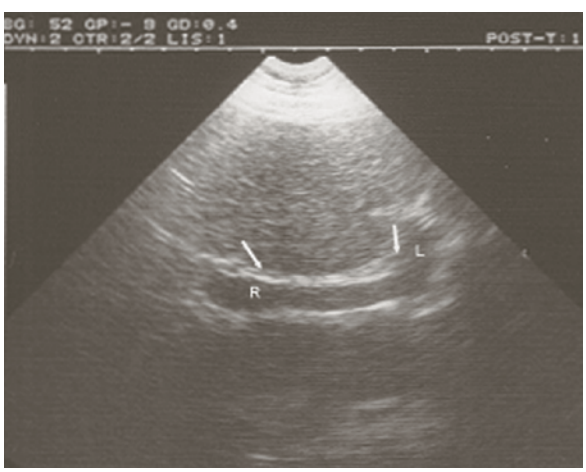

Fig. 4.6 Portal branching. Subtransverse scan (slightly oblique to the top and left). This scan shows the right branch (*R*) pointing to the right, and the left branch (*L*), also slightly pointing to the right. The walls of the veins are thick and hyperechoic, a sign which, among others, distinguishes portal from hepatic veins. Intrahepatic bile ducts are anterior to the portal branching and are normally hardly visible (*arrows*). This is one of the rare figures in this book with moderate clinical relevance in the acute patient

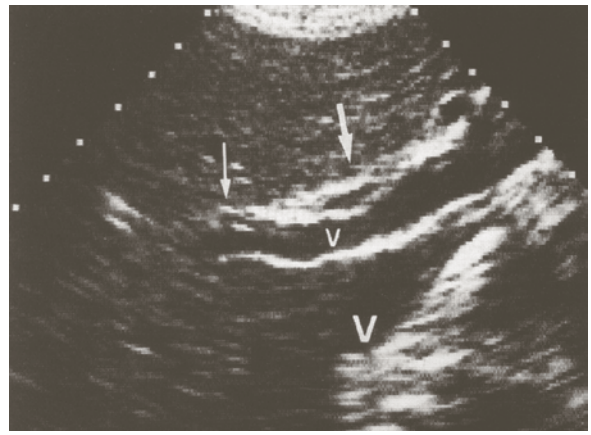

Fig. 4.7 Portal vein, long axis. The common bile duct (*thick arrow*) and the hepatic artery (*thin arrow*) run anterior to the portal vein. The inferior vena cava (*V*) passes posterior to it

- The biliary intrahepatic ducts should be looked for just anterior and parallel to the branching of the portal vein (Fig. 4.6).
- The common bile duct passes anterior to the portal vein. Its normal caliper is less than 4 mm (7 mm for some) (Fig. 4.7).
- The portal vein comes from the union of the splenic vein, horizontal, coming from the spleen (Fig. 4.3), and the superior mesenteric vein, visible anterior to the aorta (see Fig. 6.17 page 50).

In longitudinal scans, the liver is visible, from right to left, anterior to the right kidney (Fig. 4.8), the gallbladder (Fig. 4.9), the inferior vena cava (Fig. 4.2), and the aorta (Fig. 4.4).

Gallbladder

The gallbladder is located at the inferior aspect of the right liver, with a piriform shape (Fig. 4.9). It should be sought first in the right hypochondrium, but can be found in unusual places such as the epigastrium or even the right lower quadrant. It is often visible only via the intercostal approach. In order to avoid gross confusions (with renal cysts, normal duodenum, enlarged inferior vena cava, aortic aneurysm, etc.), one should locate the gallbladder by first locating the right branch of the portal vein, from which arises a hyperechoic line (called the “fossa vesicae felleae”), which leads to the gallbladder.

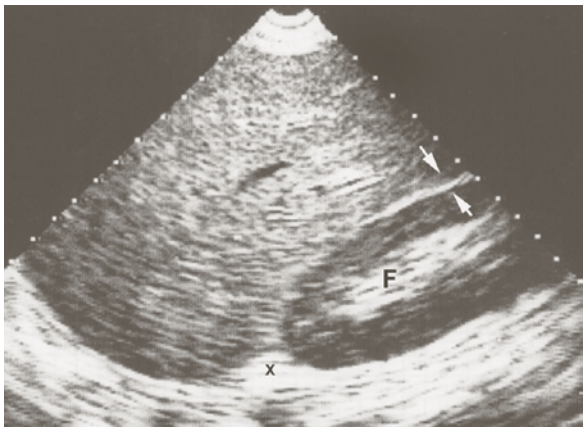

Fig. 4.8 Liver and right kidney. Longitudinal scan. The kidney has a normal size in its long axis, regular boundaries, a mildly echoic peripheral area, an echoic internal area (*F*). The interface (*arrows*) between liver and kidney (Morrison's space) should not be confused with the diaphragm. The technique of lung ultrasound, described in pages 117–127, makes this mistake impossible. Note for the expert level: the adrenal area (*X*)

Kidneys

The right kidney is located behind and below the right liver. From the surface area to the core, a gray, then white, then black pattern can be described. The gray, echoic peripheral pattern corresponds to the parenchyma. The pyramids (or medulla) are slightly less echoic than the cortex, with little clinical relevance to our knowledge. The white, hyperechoic central pattern corresponds to the central zone, an area rich in fat and interfaces. The dark zone, at the core, is inconstant and corresponds to the renal pelvis, which is normally barely or not visible (Fig. 4.8).

Just under the spleen (Fig. 4.1), the left kidney is less easy to access than the right.

Over each kidney, the adrenal is normally not identified within the fat (Fig. 4.8).

Below, the psoas muscle is recognized, with a striated pattern. It descends, vertically, from the rachis to the ala ilii.

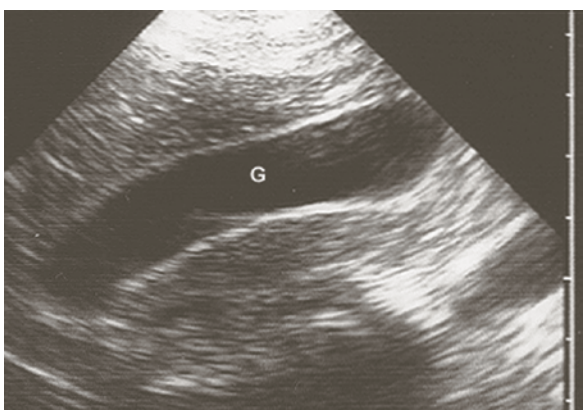

Fig. 4.9 The gallbladder (*G*). It is usually located at the inferior aspect of the liver, and a familiar piriform shape. It is seen here in the long axis, has thin walls, anechoic contents and usual dimensions

Normal dimensions in a normal fasting subject are approximately 50 mm in the long axis and 25–30 mm in the short axis. The content is anechoic. The wall is at best measured by a transverse scan of the gallbladder. The proximal wall should be preferentially measured. Tangency artifacts should be avoided by making a transversal rather than an oblique scan. A normal gallbladder wall is less than 3 mm thick.

Bladder

If empty, it cannot be detected. If half-full, it shows a medial fluid image over the pubic area, with a square section in the transverse scan (Fig. 4.10) and piriform in the longitudinal scan. When full, the bladder

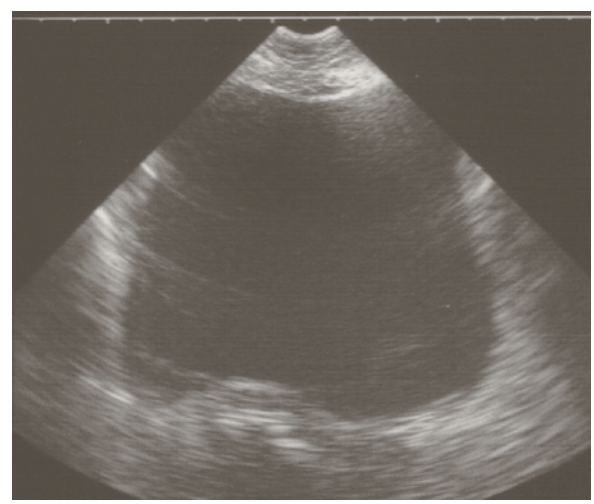

Fig. 4.10 Normal bladder. Transverse scan over the pubis. Its roughly square shape (in fact slightly concave) indicates moderate repletion

becomes enlarged and round. An usual laterolateral caliper of a full bladder in a normal adult is roughly 7–10 cm, with probably large variations.

Pancreas and Celiac Area

We strongly advise the intensivist not to invest too much energy in this field, as long as critical domains (lung, veins, simple heart) are not mastered. The pancreas, with the plexus celiacus area, is one of the most intricate to master. The surrounding vessels make it possible to recognize it, with, from rear to front, in a transverse scan, the following ten structures (Fig. 4.3):

1. The rachis, large (4–5 cm) echoic arc concave backward.
2. The inferior vena cava to the right, the abdominal aorta to the left.
3. The left renal vein, oriented horizontally between the aorta and the superior mesenteric artery.
4. The superior mesenteric artery in cross-section. It is easily located since it is surrounded by hyperechoic fat.
5. The splenic vein, horizontal and comma-shaped with a large end to the right, where it receives the superior mesenteric vein. Both give rise to the portal vein.
6. The pancreatic gland is then recognized anterior to the splenic vein. The head is anterior to the inferior vena cava. The isthmus and the body are parallel to the splenic vein.
7. The main pancreatic duct can be observed within the gland, horizontal.
8. The virtual omental sac anterior to the pancreas.
9. The horizontal portion of the stomach even farther anterior.
10. The left liver.

Maximal dimensions of a normal pancreas are 35 mm at the head, 25 mm at the isthmus and 30 mm at the body [1]. The celiac axis is located in a superior plane, and gives the splenic artery to the left and a hepatic artery to the right, which converges toward the portal vein and is applied anterior to it. All these details are rarely of interest to the critical care physician.

Spleen

In a supine patient, the probe should virtually sink into the bed since the spleen is more posterior than lateral. The technique is the one for the left PLAPS point, described on page 121, just aiming lower.

Located under the left hemidiaphragm, the spleen has a familiar convex/concave shape and is homogeneous (Fig. 4.1).

Normal Ultrasound Anatomy in a Patient in Intensive Care

To the previous descriptions, one must add the gastric tube (see Fig. 6.8 page 46), urinary probe (see Fig. 9.12 page 72), central venous catheters (see Fig. 12.5 page 92) and tracheal tube (see Fig. 24.11 page 251).

Reference

1. Weill FS (1985) Pathologie pancréatique. In: Weill FS (ed) L'ultrasonographie en pathologie digestive. Vigot, Paris, pp 345–375

Peritoneum

5

The search for detection of a peritoneal effusion or a pneumoperitoneum is of critical importance in the critically ill patient. The peritoneum covers the major part of the gastrointestinal (GI) tract, abdominal organs, and the abdominal wall. The abdomen is an area where, traditionally, gas collections have discouraged the operators. The static and dynamic analysis of the air will be used for prompting life-saving diagnoses anyway. The abdomen was dealt with before the lung chapters, which standardize this semiotic of air. Meanwhile, one practical suggested label for designating the abdominal gas structures is the term "G-lines" – *G* for gut.

A 5-MHz microconvex probe is perfect for investigating the peritoneum.

Positive Diagnosis of Peritoneal Effusion

Ultrasound diagnosis of peritoneal effusion is a basic point that, for many, embodies the place of ultrasound as a tool for the emergency physician (the search for free blood). Peritoneal effusion gives characteristic patterns.

1. Dark echogenicity is an accessory sign. In fact, depending on the etiology (blood, digestive fluids, pus), the liquid can be frankly echoic.
2. Location. In ventilated patients in the supine position, the effusion can collect roughly everywhere. Radiologists have described five sites, which were taken again by some surgeons. In our opinion, this corresponds to a typical application of ultrasound for sonographers (i.e., 3-year post-graduates), who are required to make extremely standardized views in order to allow the radiologist to make a report. Ultrasound performed by one and read by another is *not* critical ultrasound. We have heard of these windows but are accustomed to simply make a liberal ultrasound scanning protocol instead of searching those windows. This being said, we will nonetheless describe usual sites (Fig. 5.1).

The diaphragm must be localized in order to avoid any confusion with pleural effusion (Fig. 5.2). See Chap. 14 page 119 for basic details.

The effusion is searched for:

- Surrounding the liver. One can explore the last intercostal spaces, where the pattern is characteristic

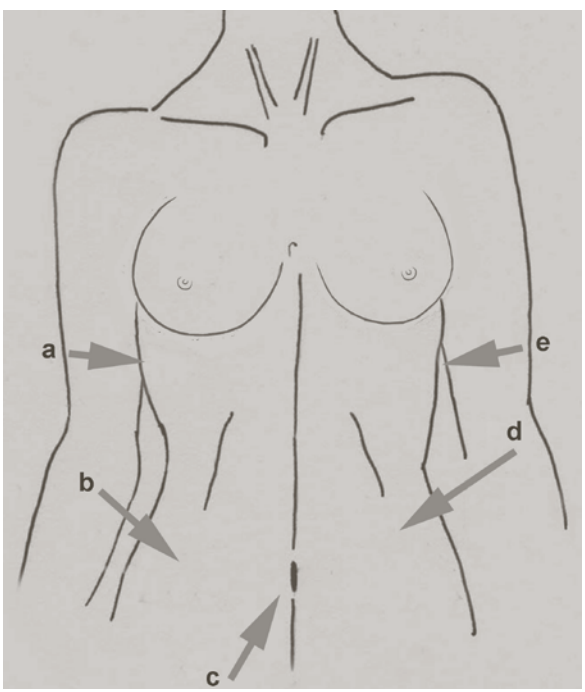

Fig. 5.1 The five classical areas where peritoneal effusion are traditionally searched for: (**a**) right hypochondrium, (**b**) right flank, (**c**) pelvis, (**d**) left flank, (**e**) left hypochondrium. Note that we placed *arrows A* and *E* in the intercostal spaces, not under the ribs

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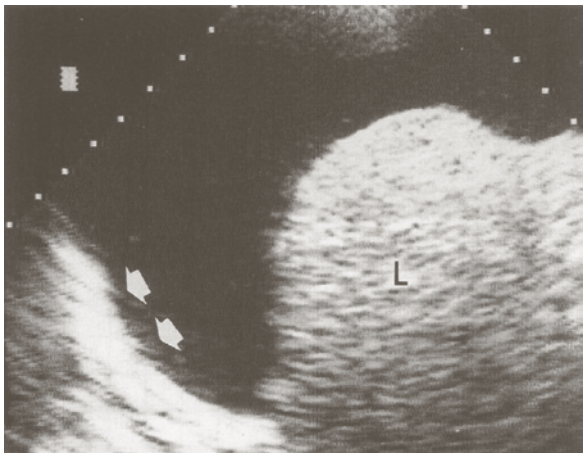

Fig. 5.2 Voluminous suprahepatic effusion, longitudinal scan. The cupola (*arrow*) is separated from the liver (*L*) by the effusion, which means peritoneal location of the effusion. The anechoic pattern is suggestive of a transudate

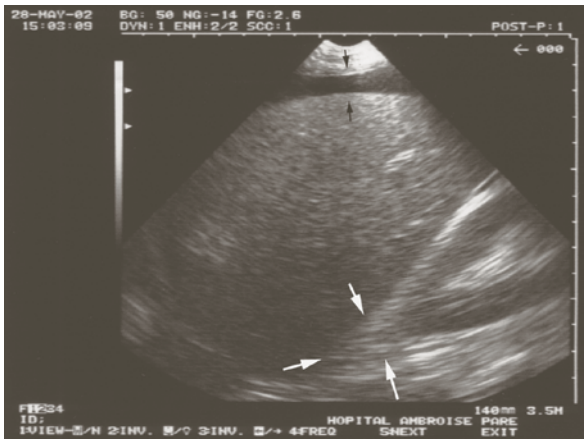

Fig. 5.3 Minute prehepatic peritoneal effusion (*black arrows*), on intercostal scan. Here anechoic effusion, whose thickness varies with the respiratory cycle (yielding a sinusoid). An exploratory puncture at this level is fully feasible. This figure also indicates the adrenal space (*white arrows*) for the Chap. 10

(Fig. 5.3). We immediately emphasize this very upper location, at the intercostal spaces.

- Surrounding the spleen, with the same comment (Fig. 5.4).
- At the flanks.
- In the pelvis (Douglas pouch) (Figs. 5.5 and 9.13 page 73).

Morrison's pouch is a familiar area, easy to standardize, but usually redundant when liberal ultrasound scanning is performed.

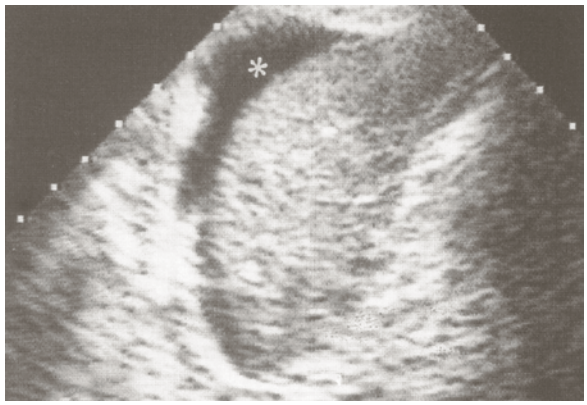

Fig. 5.4 Perisplenic effusion (*asterisk*), clearly identified although minimal. The moon shape, between the spleen and diaphragm, is a minimal equivalent of the bat wing sign. Longitudinal scan

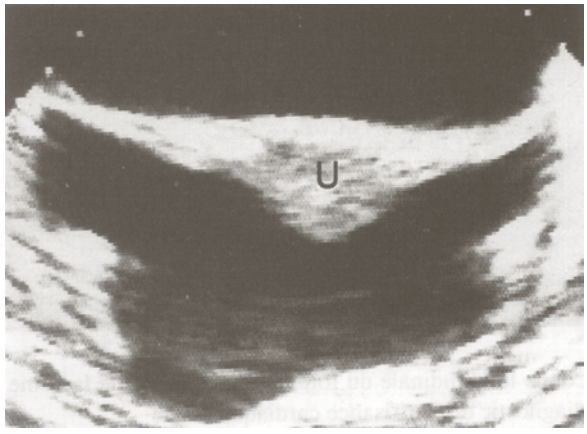

Fig. 5.5 This substantial pelvic effusion isolates the uterus (*U*) and the ligamentum teres. Transversal subpubic scan

3. The shape is characteristic. The collection has an outside convexity and inside concavities, since they surround intraperitoneal organs such as liver, gallbladder, urinary bladder, GI tract, etc. (Fig. 5.6). For this basic sign, we suggest the label of the bat wing sign (Fig. 5.7) – distinct from the bat sign (see Chaps. 14–19). Conversely, encapsulated fluids (gallbladder, urinary bladder, renal cyst, digestive fluid, etc.) have only convex limits. A fluid image with convex limits outside cannot correspond to free peritoneal effusion. A scanning of the area shows that a peritoneal effusion is an open structure, whereas an encapsulated fluid gives a closed shape (this image appears and then disappears during scanning).

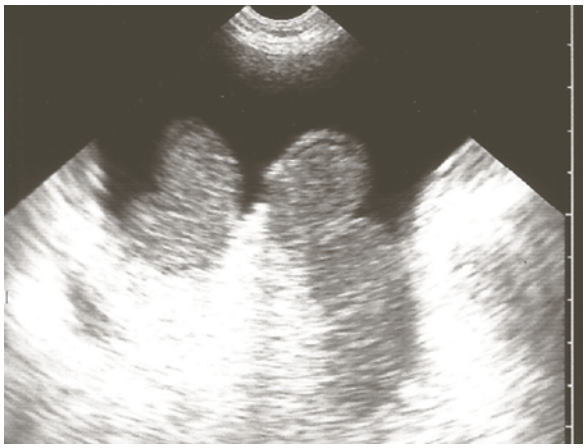

Fig. 5.6 Substantial pelvic effusion. Illustration of the bat wing sign (see Fig. 5.7). The effusion allows a fine analysis of the bowel loops: wall, here fine and regular, without villi (ileal type); content: echoic and homogeneous

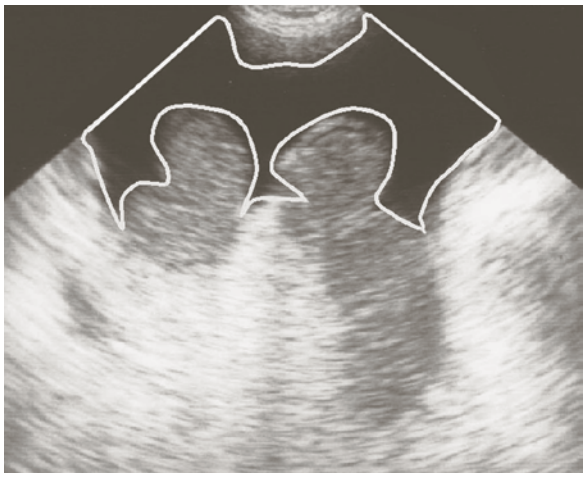

Fig. 5.7 The bat wing sign. It is illustrated, from Fig. 5.6: each border is concave inside. When the effusion is echoic, this sign has major relevance

Special comment: In the pelvis, in a hasty transversal scan, a peritoneal effusion may simulate a half-full urinary bladder, with roughly square section (see Fig. 9.13 page 73). The fluid is collected in the Douglas pouch, which cannot generate any bat wing sign. Two keys are available to easily get out of this slight pitfall: scanning this transversal image using a large Carmen maneuver to check simply whether the top is closing (bladder) or opening (peritoneum); or remaining longitudinal to obtain the same answer (convex or concave angles at the left of the image).

4. Dynamic patterns. We will see in Chap. 15 that a pleural effusion yields a sign called the sinusoid sign, due to the changes of volume of the lung. At the abdominal level, there is no lung, but the probe can exert (if not hurting) a small pressure that will result in decreasing the size of the effusion. A suggestive term for this characteristic pattern is the induced sinusoid sign (Fig. 5.8). Bowel loops swimming within the effusion are an equivalent of this sign.

Ultrasound sensitivity is high for detection of even minimal effusions [1]. A substantial effusion will fill the entire peritoneal cavity and outline the organs. Bowel loops thus become easier to analyze.

Perihepatic effusions can be distinguished from pleural effusions provided the intercostal approach is used, thus first detecting the diaphragm (Figs. 5.2 and 15.4 page 131). When the subcostal route was used, the notion that only a pleural effusion could locate behind the inferior vena cava still works (see Fig. 15.1 page 129).

Last, ultrasound easily rules out what physical examination wrongly interprets as an effusion. Ultrasound regularly allows us to avoid inserting a needle in cases of agglutination of bowel loops with fluid contents, which clinically simulates free fluid (Fig. 5.9).

Diagnosis of the Nature of the Effusion

In the ICU, peritoneal effusions are frequently observed (38% in our initial series). The anechoic tone usually indicates a transudate, but can be observed in exudates and hemoperitoneum. Obstacle to venous return (e.g., mechanical ventilation, right heart failure), capillary leakage, or portal hypertension are possible causes of transudate. Most of these etiologies have characteristic ultrasound patterns (right heart dilatation, cirrhosis, etc.). Multiple fluid locations (pleural, pericardial, peritoneal) usually indicate fluid overload, in principle not needing a diagnostic tap, but we have a rather safe procedure for these patients (see below).

The effusion can contain a multitude of echoes, slowly moving in suspension, as if in weightlessness, in rhythm with respiration: the plankton sign is a self-identifying label (see Fig. 15.10 page 135). This

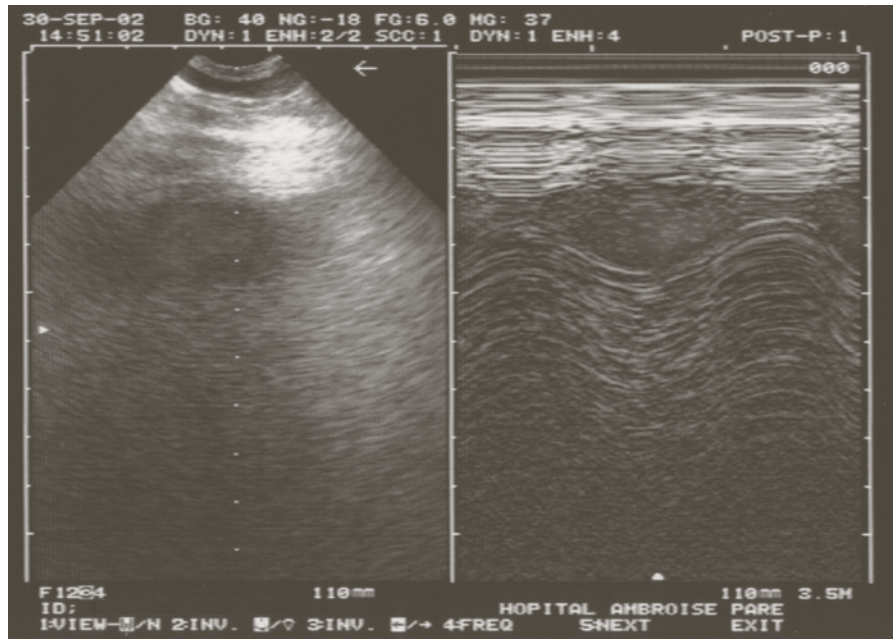

Fig. 5.8 Induced sinusoid sign. *Left:* suspicion of peritoneal effusion, in spite of the rather echoic pattern. *Right:* M mode. Slight pressures by the probe create this sinusoidal pattern, indicating that the image is not solid

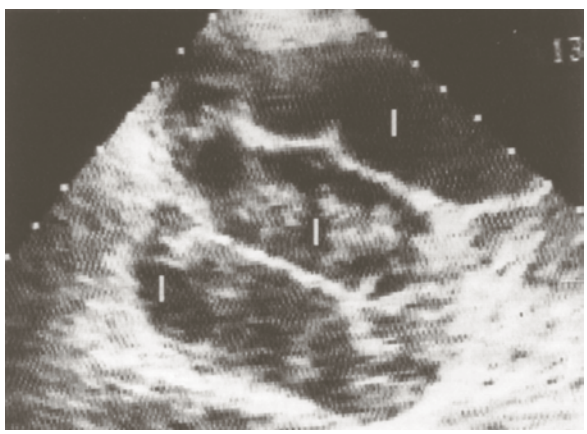

Fig. 5.9 A slight clinical pitfall. This patient had hydric dullness in the left iliac fossa. An ultrasound examination precluded a puncture, which would have been unproductive or even ... bloody. It shows absence of peritoneal effusion and several agglomerated bowel loops (*I*) with fluid inside

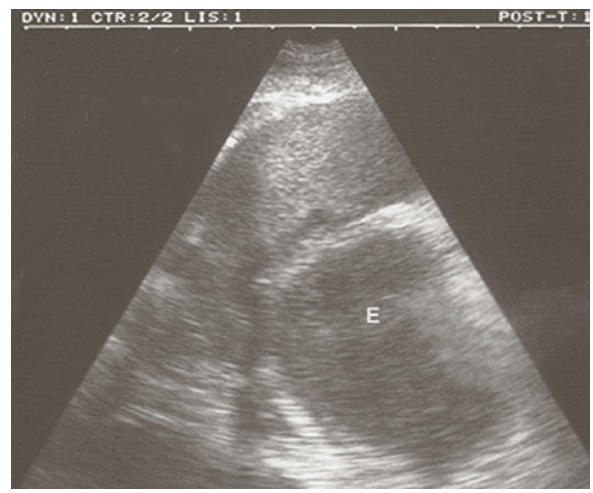

Fig. 5.10 Traumatic hemoperitoneum. In a longitudinal scan of the left hypochondrium, this mass surrounding the stomach (*E)* looks like a typical, normal spleen. This quietly invalidates the current practice where a sonographer makes the examination and a radiologist reads it. Any involved user will immediately notice a plankton sign within this mass. The real spleen will be recognized a little backward

cannot be a transudate. We heard that color Doppler can create the same pattern. Hemoperitoneum, peritonitis and, also hemorrhagic ascites yield this plankton sign (Fig. 5.10). The effusion can contain multiple septations, indicating inflammatory effusion – generally, peritonitis (Fig. 5.11). Note that these septations are not visualized with CT.

Our large policy of puncture in a critically ill patient, especially for anechoic effusions without a perfectly clear explanation, is allowed thanks to the excellent benefit/risk ratio authorized by using ultrasound (see Chap. 26).

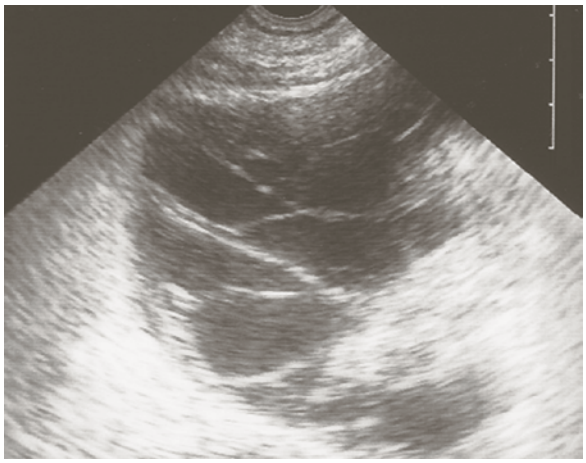

Fig. 5.11 Peritonitis. This effusion contains multiple septations (usually never seen on CT). Peritonitis due to pneumococcus

Hemoperitoneum

This simple application allows fast life-saving diagnosis of bleeding in traumatized, pregnant, or other patients. Our fast system makes the unit ready after 7 s (the probe and the contact are meanwhile prepared), and we use some additional seconds to find the bleeding using liberal scanning (we do not use the traditional radiological sites). Free fluid is an extreme emergency, generating a new hierarchy of roles, as we pointed out in 1992 [2]. We see three kinds of echogenicity: anechoic collection, or a plankton sign (Fig. 5.10), or an echoic mass. The plankton sign is immediately suggestive of free blood. The echoic, heterogeneous mass, due to fast clotting may appear as a challenge if traditional approaches, which require an anechoic collection, are used. The clotted effusion can be mingled with the numerous structures of the abdomen content (bowel loops, omentum, and various types of fat) (see Fig. 9.19 page 75). Figure 29.3 page 283 proves that the blood can become echoic in a few seconds. The bat wing sign is the most efficient way to solve this outward issue. In some subtle cases, clotting appears by successive layers, and can give the illusion of bowel loops. This pitfall is usually easily bypassed, however, using intercostal scans, since in many cases of clotted hemoperitoneum, a nondependent fluid phase is detected. A fast puncture, usually done at the intercostal space, confirms the diagnosis.

A providential examination can demonstrate the site of bleeding, showing images of parenchymal rupture at the splenic or hepatic area, or even a swirl dynamic around an aortic aneurism, but this should not generate any delay. This is the time for fast laparotomy.

In the trauma context, ultrasound has long replaced the traditional diagnostic peritoneal lavage [3]. It has been proven that the use of ultrasound allows faster laparotomy of patients with suspected torso trauma [4].

We devote a simple paragraph to this life-saving application, i.e., not longer than in our 1992 edition, to save space for the multiple other life-saving applications to be dealt with in this textbook. Conversely, we are glad to see that our lines written in 1992 have inspired teams who have showed that some fields traditionally covered by sonography technicians could also be performed by managing doctors [5].

Peritonitis

Perforating peritonitis can complicate any critically ill patient. In acute abdominal disorders, physical examination is insufficient in sedated, aging patients. Additionally, plain abdominal radiographs are always hard to obtain and usually generate useless irradiation.

In patients with any acute diagnostic problems, detection of peritoneal effusion is decisive. Minimal effusions are more suspect that substantial ones (the fact of cirrhosis or overfluid therapies). A peritoneal effusion in a patient whose hydric balance is negative is suspect. Detection of pneumoperitoneum makes the diagnosis obvious (see next section).

Echoic effusions or multiple septations suggest peritonitis (Fig. 5.11). Pseudomembranes surrounding the intestinal loops yield echoic layers with apparently thickened walls. Presence of gas within the collection [6] seems a rare observation. Our policy of easy puncture regularly clarifies situations that are complex in complex patients, and surgical decisions are taken before the clinical signs become obvious, giving one precious step in advance to the patient.

Bowel analysis is rich in information (see Chap. 6). Thickened walls and abolished peristalsis are some of the basic anomalies.

Pneumoperitoneum

Ultrasound's potential to detect pneumoperitoneum is rarely exploited. The literature describes an air barrier with acoustic shadow in the extradigestive situation, visible under the left liver, surrounding the gallbladder, in the Morrison pouch [7]. However, the multiple abdominal gas structures can discourage the operator. More standardized signs should be described.

We took point by point the semiotics of the pneumothorax (see Chap. 18), since the logics are exactly the same [8]. We therefore apply our probe in a sky-earth direction, in a supine patient. The free gas will collect at this nondependent area which is particularly accessible.

Preliminary Normal Signs to Be Described

1. Gut sliding. Gut sliding is a gliding sign, a term we suggest for this dynamic of the visceral layer of the peritoneum that moves during respiration, whereas the parietal layer is motionless (Fig. 5.12).
2. Splanchnogram. This is a suggested term for these anatomical structures such as the liver or bowel loops (see Figs. 5.2–5.10). It can refer to the liver or even to the mesenteric fat, and can be called hepatogram or steatogram, for instance. This pattern clearly indicates that no free air interposition is present between the abdominal wall and the visualized organ. Note: we will not confuse *spleen* (the subphrenic hematopoietic organ) and *splanchnos* (any abdominal viscera).
3. Aerogram. This term will refer to all airy structures which yield artifacts. *G-lines* (*G* for gut) are a label suggested to all these artifacts arising from the abdomen. They can be described in the same way as the thoracic artifacts. With a perfect analogy, we can describe horizontal repetitions of the peritoneal line like the lung A-lines, like the B-lines, vertical well-defined laser-like long comet-tails, and again like Z-lines, vertical comet-tail artifacts that are ill-defined, gray, and short. A, B, and Z-lines are labels devoted to the lung (see Fig. 19.3 page 186). In order to avoid any confusion, the abdominal artifacts will be labeled GA, GB, and GZ-lines. The simple difference is that the peritoneal line replaces the pleural line. There is no rib at the abdomen, so there is no bat sign.

In practice, visualization of conserved peak gut sliding or splanchnogram allow pneumoperitoneum to be discounted, at the bedside.

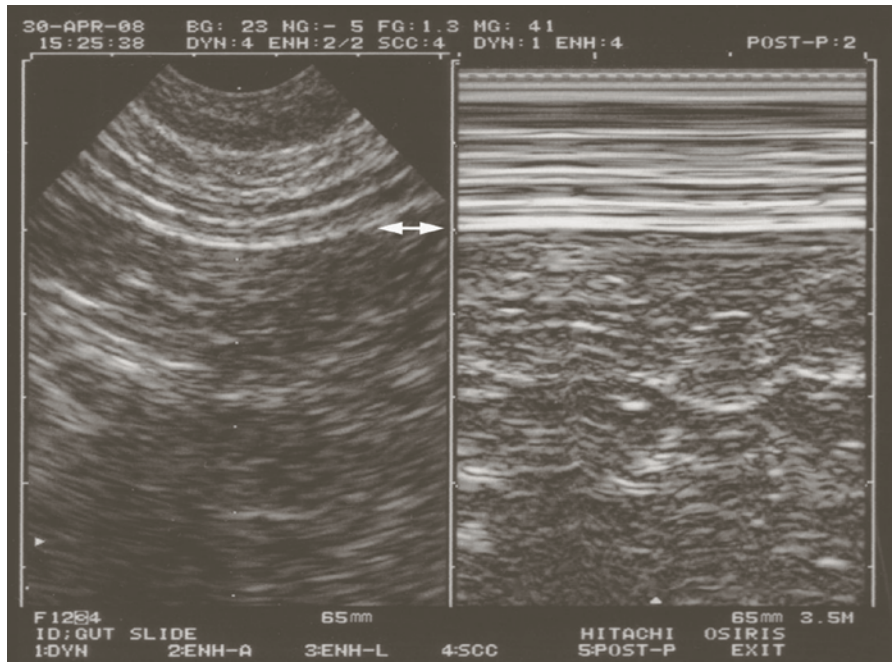

Fig. 5.12 Gut sliding. Sandy pattern below the peritoneal line, regular horizontal pattern above. This pattern reminds the seashore sign of lung terminology. *Arrow*: level of the peritoneal line

Signs of Pneumoperitoneum (Fig. 5.13)

Like for pneumothorax, they can be organized into a decision tree.

1. **Abolition of Gut Sliding** (Fig. 5.14) This sign is observed in most cases of free pneumoperitoneum. Patients with abdominal history (surgical adherences) or with (quasi) absence of diaphragmatic motion can display absent gut sliding. Abolished gut sliding is therefore observed in 8% of patients with absence of pneumoperitoneum proven on CT.

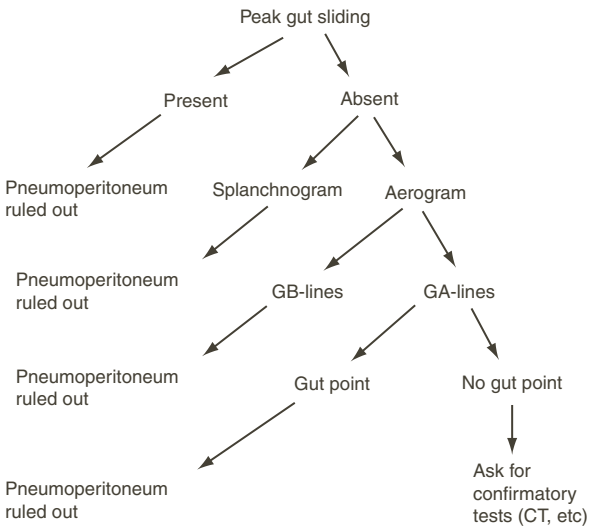

Fig. 5.13 Decision tree for the diagnosis of pneumoperitoneum

2. **Aerogram – i.e., Absence of Splanchnogram** Instead of anatomic patterns, only artifacts are visible from the peritoneal line. This sign is always present at the location of the pneumoperitoneum. It is also an usual finding in a meteorized patient – requiring more subtle signs. A splanchnogram is of precious help to rule out pneumoperitoneum in the cases where gut sliding is abolished.

3. **Absence of GB-Lines** In none of our observations of pneumoperitoneum were GB-lines visible. GA-lines (or GZ-lines, which have the same meaning) are exclusively observed, making a sensitive sign of pneumoperitoneum. The principle of the A-line sign is detailed in Chap. 18.

4. **The Gut Point** This sign is an exact equivalent of the lung point, dealt with in Chap. 18. It has a 50% sensitivity and is a specific sign.

5. **Other Signs** Countless additional signs could be described. Postural change-induced signs may be used, but we do not like to turn these fragile, shocked patients. In addition, the fewer the number of signs, the simpler the use of ultrasound.

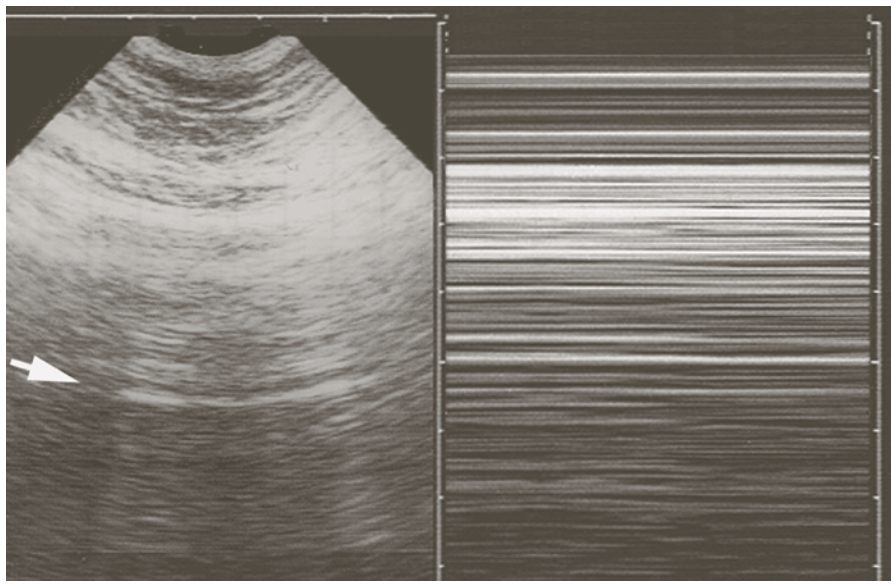

Fig. 5.14 Pneumoperitoneum. *Left* (real-time): massive air barrier with *horizontal* repetition artifact ("A-like line," *arrow*). *Right* (time-motion): this mode objectifies the complete absence of gut sliding

Previsible Pitfalls

Gut sliding can be more or less ample. A patient with peritonitis may have diminished gut sliding, partly explained by antalgic hypopnea.

A distended stomach will come against the anterior wall, making gut sliding hard to detect and able to generate GA lines. Consequently, analysis of gut sliding will contribute more if the stomach was previously localized in one way or another.

Very incipiens pneumoperitoneum with only some bubbles visible on CT should theoretically provide difficulties using ultrasound, but we wait for our first case to conclude.

Advantage of Ultrasound

In acute abdominal disorders, ultrasound was able to replace during decades the traditional radiograph showing cupolas or the positional radiographs, which was delicate to perform in tired, shocked, or ventilated patients. Many patients died from delay in diagnosis. Now, ultrasound must face CT. It will simply be able to avoid the drawbacks of CT (see Chap. 19).

Interventional Ultrasound

When dealing with peritoneal effusion, we practice ultrasound-assisted puncture at the slightest doubt. Free of complications when done properly, it has an excellent risk to benefit ratio. This is especially true in the critically ill patient with complex clinical presentation. We find this attitude paradoxically safer than the risky attitude of inferring the type of effusion from its echostructure. In our routine, basic diagnoses are regularly made, in spite of misleading clinical presentations.

We almost always use a 21-gauge green needle. Ultrasound has the major advantage to allow the puncture far from the traditional landmarks. A tap in the right iliac fossa, classically forbidden, is for us very commonplace: ultrasound shows that a fluid collection is interposed before the caecum. Ultrasound even makes it possible to puncture near to the forbidden area of the epigastric vessels, since they can be clearly identified (Fig. 5.15). Puncturing peritoneal effusions using intercostal route is routine in our current practice.

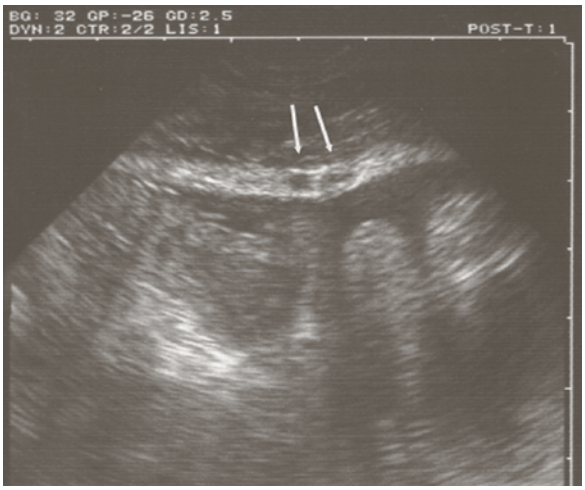

Fig. 5.15 The epigastric vessels. Transverse paraumbilical scan with Carmen maneuver easily showing these two tubular parietal structures (*arrows*). Note the peritoneal effusion deeper

The procedure is simple: one almost always performs the tap just after ultrasound location (see Chap. 26).

We have exceptionally noticed difficult attempts for very localized effusions in the right iliac fossa, or pelvis of elderly patients. One hypothesis is a loose parietal layer which is driven back by the slow needle, without piercing it. In this case, persisting in inserting the needle to the end could result in piercing remote structures (bowel loops, iliac vessels, etc.). Ultrasound guidance is required but, even here, some procedures remain delicate.

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Gastrointestinal Tract

6

The GI tract is a vital organ. Its ultrasound analysis has been rarely listed in abdominal ultrasound reports, since the bowel is often considered a hindrance to the analysis of deeper structures (Fig. 6.1). Yet the GI tract is the location of life-threatening conditions at nearly each segment. Using careful analysis, at least one small part of the 7 m of the abdominal bowel can be analyzed.

Our 5-MHz microconvex probe is perfect for this investigation.

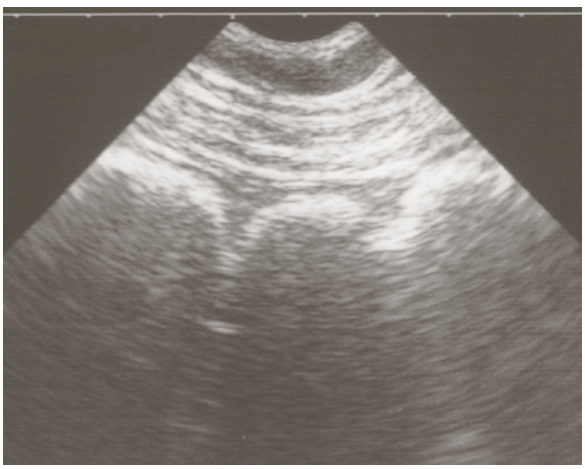

Fig. 6.1 U-lines. The probe is applied on an abdomen full of gas. No deep structure can be identified, since digestive gas stops the progression of the ultrasound beam. Note, however, that the artifacts can be described as inverted U shape – consequently labeled U lines – suggesting colic loops

Normal Ultrasound Patterns

The features of pneumoperitoneum in Chap. 5 have shown that free gas and intradigestive gas have distinctive patterns. We will consider, as usual in critical ultrasound, the static signs (gas artifacts, wall features), then the dynamic sign, of major relevance.

Normal GI Tract: Static Signs

In the absence of a gas barrier, the bowel can be analyzed. Its wall thickness, practically unchanged from the stomach to the colon, ranges from 2 to 4 mm [1].

In the presence of a gas barrier, the GI tract can still be analyzed. The generated artifacts are in fact providers of information. We tried to give a standardized language for describing them in the section about pneumoperitoneum in Chap. 5 page 38. The U-lines are an example of air artifacts (Fig. 6.1). Vertical narrow well-defined comet-tail artifacts reminiscent of the lung B-lines (see Fig. 17.2 page 153) are may be a feature due to jejunal villi.

Normal GI Tract: A Basic Dynamic Sign, Peristalsis

The GI tract peristalsis is a major sign, and will be described in detail. The GI tract is a vital organ. Any vital organ has permanent dynamics (lungs, heart, vessels). Ultrasound has the critical advantage of real-time imaging, enabling assessment of this dynamic (Fig. 6.2).

Peristalsis gives permanent crawling dynamics, with regular contractions [2]. The presence of peristalsis can be objectified in a few seconds. This is the usual pattern in the normal subject. Prolonged observation (at least 1 min) seems necessary to affirm abolition of peristalsis.

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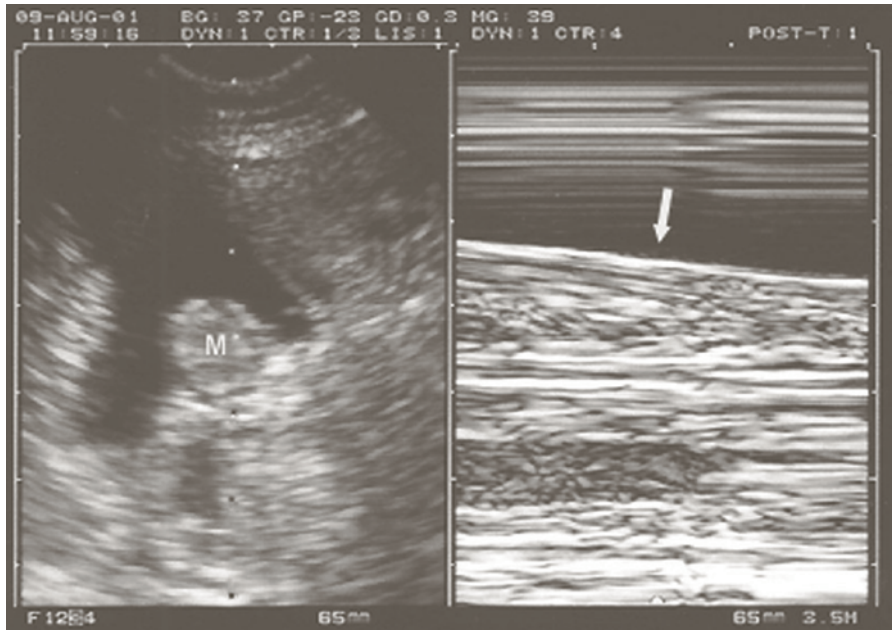

Fig. 6.2 GI tract peristalsis. *Left*: Real-time observation of a bowel loop (*M*) within peritoneal effusion. *Right*: M-mode. These oblique lines (*arrow*) demonstrate a normal peristalsis. This simple image also invalidates the dogma that peritoneal fluid in itself creates abolition of peristalsis

The peristalsis can be seen from the stomach (antrum at least) to the ileon, and does not seem, in our experience, visible at the colic area.

Observations clearly showed that a number of situations are *not* able to abolish bowel peristalsis:

- Mechanical ventilation with high-dose morphinomimetic sedation and even curare administration.
- Peritoneal fluid like massive ascites: this is clearly established by our observations.
- A recent laparotomy, even with a procedure touching the bowel, such as colectomy. We have observed peristalsis of the small bowel clearly present 24 h after colectomy.

Even when the bowel is full of gas, the peristalsis can again be seen, through characteristic dynamics of the gas contents (the "crawling gas sign").

Esophagus

The cervical esophagus descends behind the trachea, but is slightly visible to the left (see Fig. 24.11 page 251).

The upper thoracic esophagus is rarely visible using an external approach. Below the carina, if there is a sufficient heart acoustic window, the esophagus is recognized as a tubular flattened structure that passes in the angle between the heart and descending aorta (Fig. 6.3).

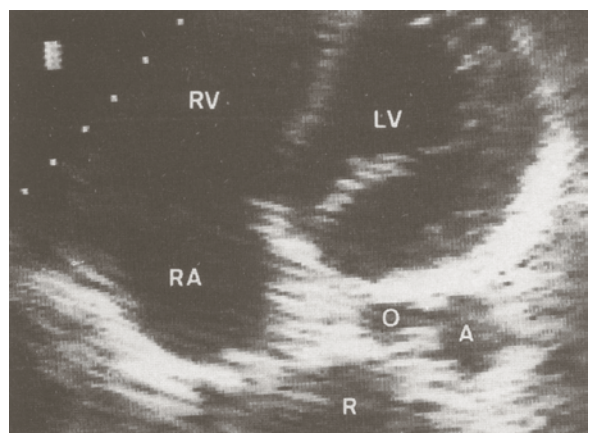

Fig. 6.3 Thoracic esophagus. Transverse, pseudo-apical scan of the heart. The esophagus (*O*) is surrounded by the rachis (*R*), the right auricle (*RA*), the left ventricle (*LV*) and the descending aorta (*A*)

In the critically ill patient, the gastric tube and above all its frank acoustic shadow make a landmark that facilitates the location of the esophagus. The esophageal balloon of a Blakemore tube can be visualized posterior to the left auricle (Fig. 6.4).

The esophagus penetrates the abdominal cavity just anterior to the aorta. The frank acoustic shadow of a gastric tube is a practical landmark (Fig. 6.5).

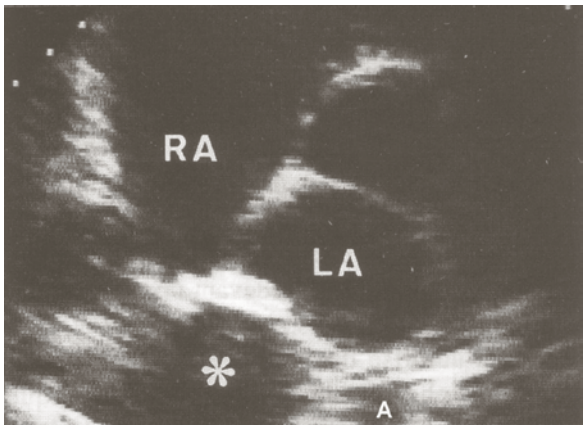

Fig. 6.4 Blakemore probe. The inflated esophageal balloon (*asterisk*) drives away the posterior wall of the left auricle (*LA*)

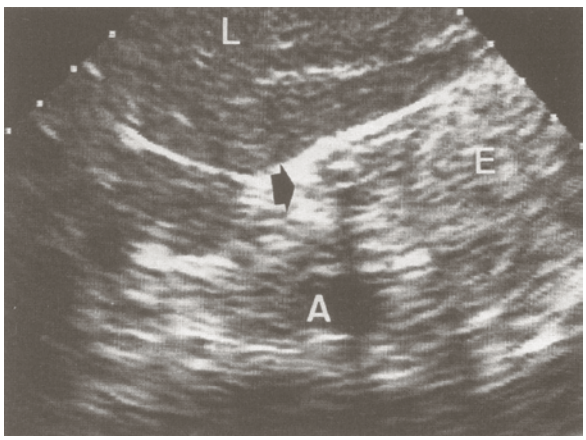

Fig. 6.5 Abdominal esophagus. It is seen (*arrow*) anterior to the aorta (*A*), behind the left hepatic lobe (*L*) and continuing up to the stomach (*E*). The frank posterior shadow arising from the gastric tube (*arrow*) is an efficient landmark. Transversal epigastric scan

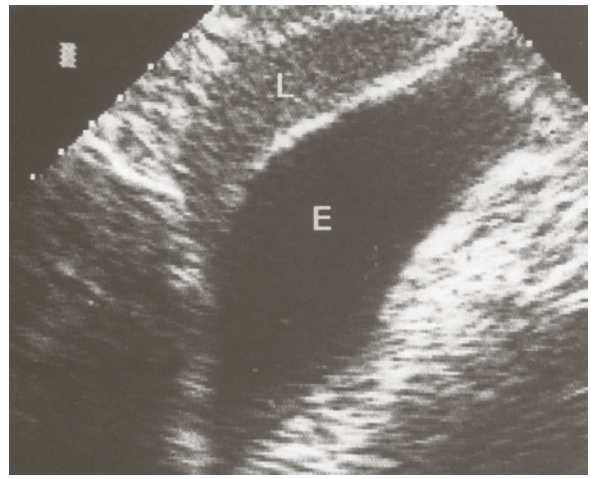

Fig. 6.6 Vertical portion of the stomach (*E*), outlined by an anechoic fluid content. Longitudinal scan. *L* hypertrophied left hepatic lobe

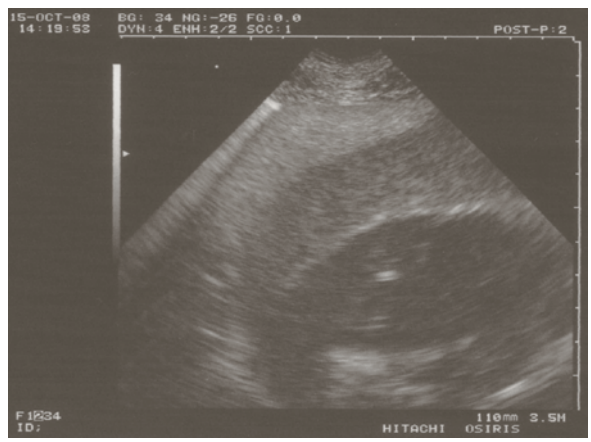

Fig. 6.7 How we search for the vertical portion of the stomach through the spleen. Note in this image from left to right a part of the lung (with a lung artifact), an hypertrophic steatosic liver (clear echostructure), the spleen, and the stomach (here in distension). Longitudinal scan of the left phrenic point

Stomach

The vertical portion, or fundus, passes between the liver and spleen (Fig. 6.6). It is better visualized by a lateral, transsplenic approach, visible in the concavity of the spleen, than by an anterior approach (Fig. 6.7).

The horizontal portion, or antrum, should be investigated by the epigastric approach. The antrum (analyzed by a longitudinal scan) is round or ovoid, its size is a function of its content that can be empty or filled (Fig. 6.8).

Duodenum

The duodenum is probably not a segment for the beginner. The duodenal bulb follows the pyloric stricture. The second duodenum descends vertically and surrounds the pancreas head. Duodenal fluid sequestrations should not be confused with pathological images (the gallbladder, which is at the contact of D2, the vena cava, aorta, etc.). The third duodenum is visible between the aorta and the superior mesenteric artery.

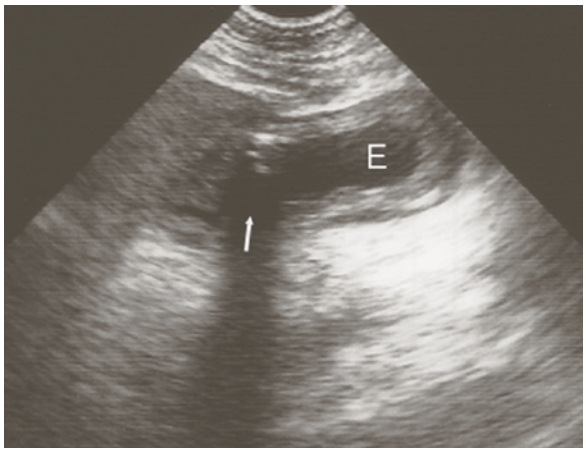

Fig. 6.8 Nasogastric tube. It is immediately detected using the frank acoustic shadow (*arrow)* more than the tube itself. Horizontal portion of the stomach (*E*), just under the liver. Note how precisely the wall thickness can be measured and an anechoic fluid content described. Epigastric longitudinal scan

Small Bowel

It is almost always possible to visualize at least some loops of the small bowel. The jejunum is recognized by the endoluminal villi (Fig. 6.9). The ileum has a tubular, regular pattern (see Fig. 5.6 page 35). Observation shows that acute life-threatening disorders of the bowel affect the whole of the bowel. Consequently, ultrasound analysis of an even small portion can be rich in information. Many relevant items can be extracted:

1. Peristalsis (see upper).
2. Cross-sectional area. The normal caliper of the small bowel is approximately 12–13 mm.
3. Contents can have either a homogeneous echoic (see Fig. 5.6 page 35) or hypoechoic pattern (Fig. 6.9). The clinical relevance of this distinction is being investigated.
4. Wall thickness ranges from 2 to 4 mm [1]. Fine analysis of the wall is greatly facilitated when there is liquid contrast from both sides, i.e., peritoneal effusion associated with fluid content, two conditions often present in acute disorders (Fig. 6.9).

Colon

The colon is a tubular structure with visible haustra (Figs. 6.10 and 6.11), without identifiable peristalsis. Roughly, the ascending and descending colon are vertical structures located in the flanks, the transverse colon is horizontal at the epigastric level and distinct from the stomach.

Rectum

We still have not found indications for critical ultrasound at this area.

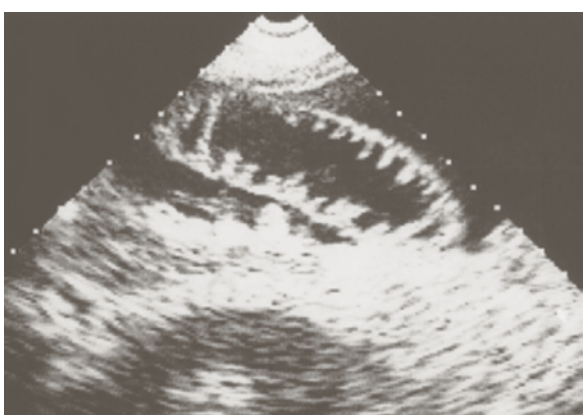

Fig. 6.9 Dilated jejunal loop. The wall, perfectly outlined between peritoneal effusion and fluid content, is thin. The fluid is here hypoechoic. The caliper of this loop is 30 mm. Jejunal villi can be recognized (the fishbone sign). Small intestine occlusion. Transverse scan of the pelvic area

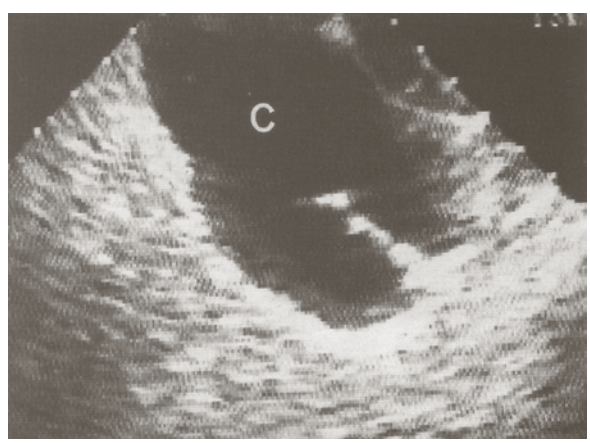

Fig. 6.10 The cecum (*C*) in a longitudinal scan. Fluid sequestration makes it easy to identify. If such huge amounts of fluid are seen in the whole bowel of a shocked patient, the diagnosis of hypovolemia as the cause or a major participation in the shock can be reasonably envisaged

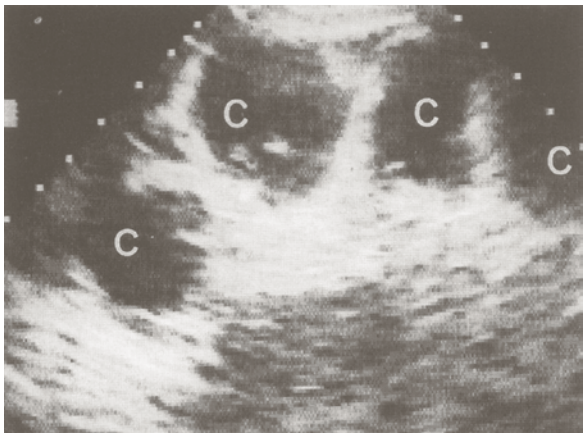

Fig. 6.11 Descending colon and its haustra. Round, anechoic images, piled up along the left flank in a longitudinal scan (*C*). Slight Carmen maneuvers of the probe show that all these images communicate. This patient had hypovolemic status

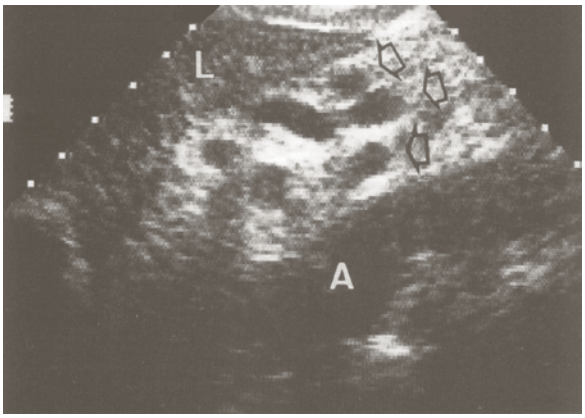

Fig. 6.12 Esophageal varices. In this longitudinal scan, several tubular anechoic images are visible below the liver. The Carmen maneuver shows that they communicate with each other along the lesser omentum (*arrows*). These are stomachic coronary varices (*L* liver, *A* aorta)

Pathologic Findings

Esophagus

Before dealing with the rare esophageal emergencies, one application is useful in extreme emergencies: recognition of esophageal intubation when the clinical diagnosis is difficult (see Fig. 24.11 page 251).

Esophageal rupture is an emergency whose low frequency usually makes the conditions for a late diagnosis, typically yielding a poor prognosis. Ultrasound can alter this usual vicious circle. A routine ultrasound examination performed facing any thoracic or abdominal drama will promptly show one of these elements: pneumothorax, cervical subcutaneous emphysema (see Fig. 18.14 page 176), pleural effusion, which appears as complex (due to a mingling of gas and alimentary particles), and frank pus withdrawn from liberal ultrasound-guided thoracentesis.

As regards hemorrhage, ultrasound does not replace fibroscopy. However, esophageal varices are accessible to ultrasound: they give sinuous tubular anechoic structures along the lesser omentum, a hyperechoic area located inside the smaller curvature of the stomach (Fig. 6.12). With GI tract hemorrhage, detection of esophageal varices makes an argument for portal hypertension as the cause of bleeding – demanding suitable therapy. Ultrasound can provide other signs of portal hypertension (see Chap. 7).

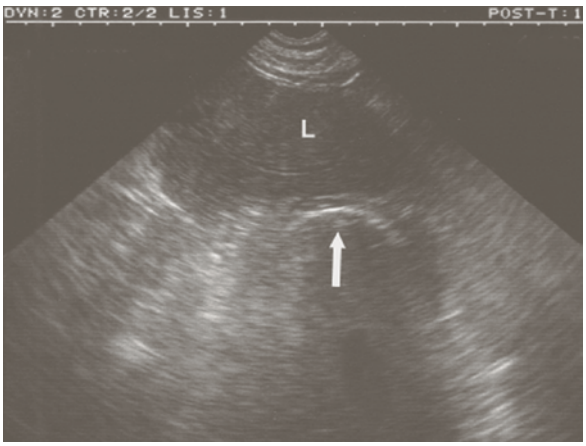

Fig. 6.13 Blakemore probe, gastric balloon. This arciform structure that may mimic an "U line" stops the echoes (*arrow*). On echoscopy, one can see it stumble upward when traction is exerted on the tube, since it outlines the gross tuberosity, the very aim of the procedure. Epigastric transversal scan. *L* liver

A Blakemore–Linton tube can be inserted using ultrasound guidance. The intragastric position of the tube, before filling, can be detected by visualizing the acoustic shadow, which is frank, tubular, and unique. The gastric balloon can then be inflated. It makes a large, round image, convex outside, highly echoic, with a frank acoustic shadow. The tube is then pulled to the head until resistance is encountered. The gastric balloon becomes visible at the top of the fundus (Fig. 6.13). The esophageal balloon can then be inflated. It creates a mark behind the left auricle

(Fig. 6.4). Monitoring thus with ultrasound is quick and reliable if the operator is trained and the patient has favorable echogenicity.

Stomach and Duodenum

Ultrasound analysis of the stomach can provide a great deal of information. Preoperative checking for vacuity or repletion requires only a few seconds in good conditions, allowing to avoid the traditional 6-h fasting. One can also search for a residue during enteral feeding. Acute gastric dilatation can be seen in patients with acute abdominal disorder, and is also a rare (but easy to detect) cause of acute dyspnea, which gastric aspiration can relieve.

Gastric liquid retention gives a massive collection with multiple echoic particles, like in weightlessness, and sometimes an air–fluid level (Fig. 6.14). This pattern can be unsettling for young operators, and should not lead to diagnoses such as splenic abscess. Similarly, if the stomach is ectopic, i.e., intra-thoracic, such an image should be recognized as *not pleural* (see page 135). Gastric stasis can be associated with bulbar ulcer [3].

The correct positioning of a feeding tube within the gastric lumen can be assessed, alternatively with the mandatory radiograph. Its tubular structure and above all its frank acoustic shadow allow easy recognition (Fig. 6.8). This application is contributive when the end of the tube is at the antrum level, far less when it remains in the fundus area.

Ultrasound can document gastric or duodenal ulcer. Without replacing fibroscopy, it is a reasonable initial approach. The ulcer is rarely detected, showing a thickened, irregular wall. A duodenal ulcer can be associated with gastric stasis [3]. In the case of fluid collection outside the duodenum with gas bubbles, or pneumoperitoneum (see Chap. 5), the diagnosis of complicated ulcer (with leakage) is probable [4].

The stomach can be used as an acoustic window for exploring deeper structures such as the pancreas. The stomach should be filled with water, using the gastric tube that is usually present. A slight right decubitus will trap the air bubbles in the vertical portion of the stomach [5]. Last, a full stomach can be precisely located in the still hypothetical aim of performing bedside gastrostomy under sonographic guidance.

In caustic intoxications, ultrasound can detect diffuse edema along the GI tract, with a thickened and hypoechoic wall. Search for a left pleural effusion (a sign of esophageal rupture) or peritoneal effusion is part of the initial examination and the follow-up of the patient.

Ultrasound's contribution in the diagnosis of GI tract hemorrhage is detailed in Chap. 29.

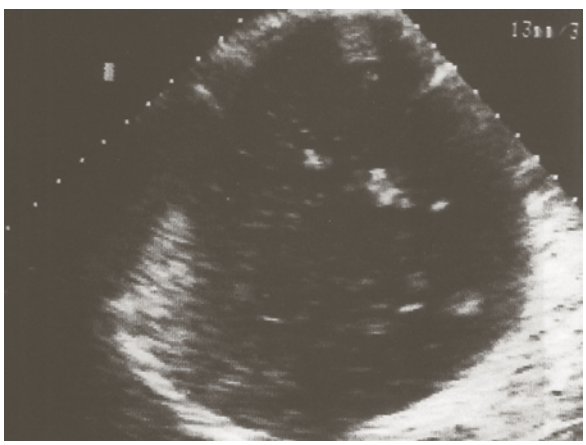

Fig. 6.14 Acute gastric dilatation. Major fluid stasis. The content is heterogeneous with hyperechoic alimentary particles. Epigastric transversal scan. Patient in acute dyspnea – relieved by the gastric draining - a rare cause of acute dyspnea

Small and Large Bowel: Introduction

Ultrasound plays a priority role, even compared with plain radiographs, colonoscopy, or even CT. In the critically ill, two major changes are accessible:

1. Abolished peristalsis

See description above. Observations have shown a high correlation between abolished peristalsis and the existence of an abdominal drama such as mesenteric infarction or GI tract perforation. The presence of peristalsis is as a rule a reassuring finding. In a series of 20 patients considered for emergency surgery, seven of them actually surgical cases, the sensitivity of an abolished peristalsis for the diagnosis of an abdominal disorder requiring prompt surgery was 100%, the specificity 77% [6]. Consequently, in a suspicion of acute abdomen, the detection of the presence of peristalsis is a strong argument for ruling out a GI tract disorder requiring surgery.

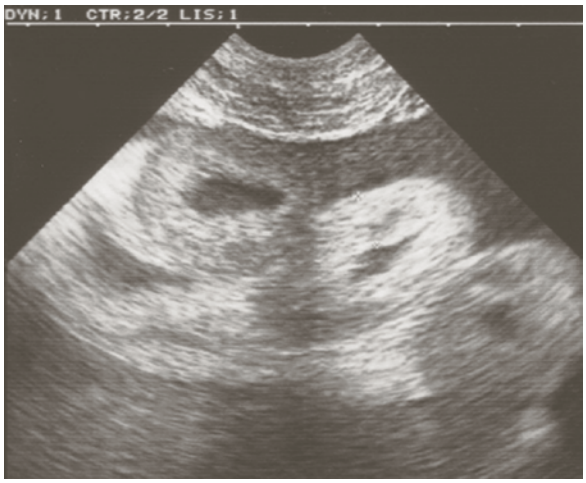

Fig. 6.15 Thickened bowel. Three loops are visible in cross-section. Note the substantial wall thickening, accurately measured between a peritoneal effusion and anechoic fluid digestive content

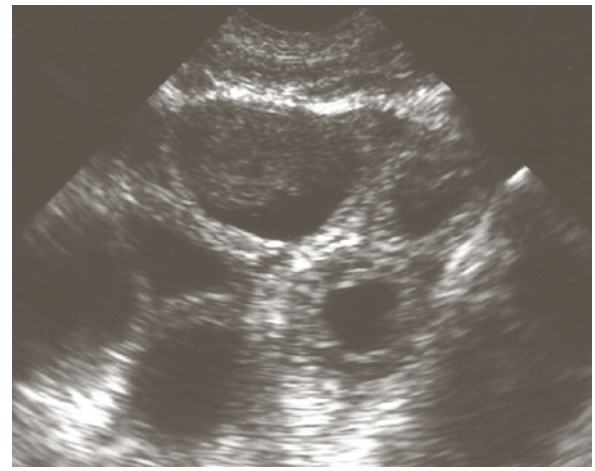

Fig. 6.16 Mesenteric infarction. Thickening of the wall (observable through the entire small bowel), and above all complete absence of peristalsis. Akinesia of this vital organ is striking in real-time. Note the fluid content of the bowel loops. Pelvic scan

Let us recall that a recent laparotomy or sedation with morphine or curare is not an explanation for bowel standstill.

2. Wall thickening (Fig. 6.15)

Parietal thickening occurs in many severe situations. The observation seems to indicate that even in the case of focal disorder, a large portion of the GI tract is involved, helping in making a rapid diagnosis even if scanning limited areas.

Small Bowel: Acute Ischemic Disorders

We have grouped different disorders, such as mesenteric ischemia, mesenteric infarction, and mesenteric necrosis, into this single section. Classically, it is due to arterial occlusion, venous occlusion, or, may be more often in the ICU, low outflow. The difficult diagnosis, which usually results in delayed treatment and a poor prognosis, is widely acknowledged [7]. Plain radiography can show pathologic gas (portal gas, pneumatosis intestinalis). Tonometry has been tried. Duplex sonography may be interesting in occlusive causes, although not replacing arteriography. Additionally, laparoscopy has been proposed, but cannot show basic patterns such as mucosal thickening, not apparent from outside. Colonoscopy is useful for colonic locations. CT, apart from classical drawbacks (cost, transportation, etc., see page 182 of Chap 19), can yield troublesome false-negative results.

In this context, ultrasound deserves a top-ranking place. Our observations usually show a complete and diffuse abolition of peristalsis. Sensitivity of this single sign is 87%, specificity 75% considering nonselected controls, and 88% considering controls with clinical suspicion [6]. A small percentage of ICU patients (12%) without GI tract impairment show abolition of peristalsis, for reasons not mastered at this moment for lack of gold standard. A thickening of the wall (which is moderate, 5–7 mm) is found in only half of our cases (Fig. 6.16). Peritoneal effusion is present in half of the cases. Portal gas is rare but quasispecific (see Figs. 7.2 and 7.3 page 54).

The literature describes dilated loops, abolition of peristalsis, very thin wall (1 or 2 mm) in the arterial causes, and thickened and hypoechoic wall in the venous causes [8, 9]. In late cases, parietal microbubbles and flattening of the jejunal villi, peritoneal effusion, portal gas or even hepatic abscesses and portal or mesenteric venous thrombosis have been described [10, 11].

The superior mesenteric vein is accessible in the absence of gas (Fig. 6.17). Since it passes anterior to the rachis, a compression can be made in order to assess its patency, and without the help of the Doppler technique (see Chap. 12).

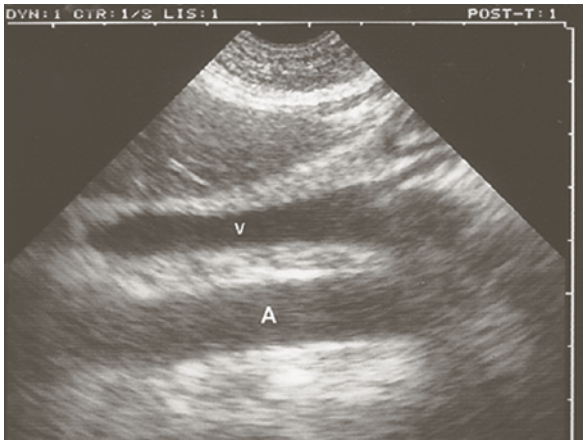

Fig. 6.17 The superior mesenteric vein. It is usually visible (*V*). Young users often confound it with the inferior vena cava, but it passes anterior (not lateral) to the abdominal aorta (*A*). The good quality of the image makes it possible to study the venous content, here anechoic. A compression maneuver completely collapses the lumen. Longitudinal view

Doppler could find a place if finding signs of impaired perfusion [12,13]. We wait to collect enough cases in order to see whether Doppler is redundant with our other findings.

Large Bowel: Acute Ischemic Disorders

In the case of colic ischemia and necrosis, our observations often show thickened colic wall (Fig. 6.18). Small bowel peristalsis appears nearly always abolished, a beneficial finding for an early diagnosis.

Pseudomembraneous Colitis

Studying the ultrasound features of this complication of antibiotics may theoretically select the requirements for colonoscopy. The ultrasound pattern, insufficiently described in the literature [14], shows marked thickening of the colic wall, collapse of the lumen and frequent hemorrhagic ascites. Our rare observations also showed irregular debris floating within abundant intraluminal fluid, a pattern evoking parietal dissection.

Mucitis

Few observations in oncologic patients show thickened intestinal wall and abolished peristalsis.

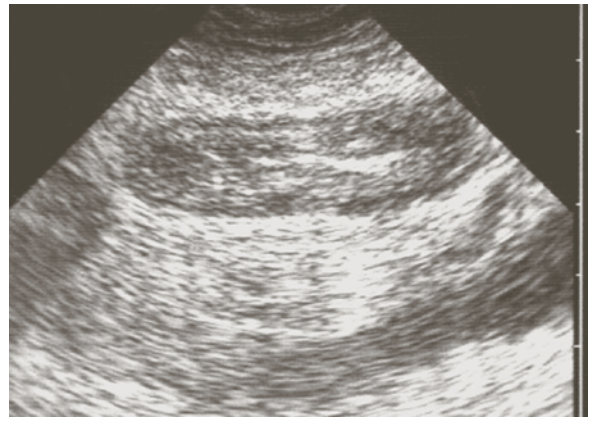

Fig. 6.18 Colic ischemia. Cross-section of the descending colon. The lumen is virtual, but the wall can be accurately measured, here to 7 mm

Bowel Dilatation

The diagnosis of intestinal obstacle was classically made using plain radiographs, which raises problems in the supine patient. For some more X-rays, CT has replaced plain radiographs. Yet ultrasound is a rapid alternative, showing these two signs:

1. Dilatation of the bowel [15]

A dilated jejunum has a characteristic pattern (Fig. 6.9). More subtlety is required to distinguish between dilated ileum and normal colon. The best clue: the colon is a frame surrounding the small bowel. Disseminated loops of the same caliper are an excellent sign of small bowel.

2. An air–fluid level

Two maneuvers are possible.

1. Using the swirl sign. In a supine patient, when the probe is applied vertically on the abdomen, a gas pattern is first observed. A slight pressure (not to harm) is then applied on the abdomen with the probe and free hand (see Fig. 11.9 page 86). When this pressure is shifting the gas collection, a fluid pattern immediately appears on the screen. At this moment, small movements made at the side of the bed will create swirls. These swirls generate a characteristic ultrasound pattern: sudden (fleeting) succession of gas phases with fluid phases (Fig. 6.19). This suggestive pattern does not require long explanation.
2. This maneuver (unnamed): the probe is held transversally on the anterior wall of abdomen (therefore

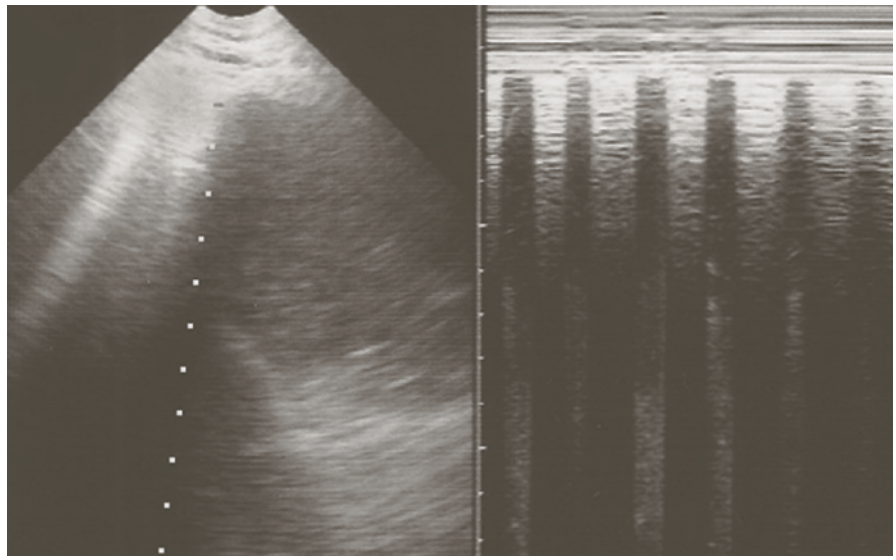

Fig. 6.19 Occlusion with air–fluid level. Demonstration of the swirl sign using the M-mode. *Left:* Real-time: air barrier at the left, fluid mass at the *right* of the screen. *Right:* Time-motion: the air–fluid level has been gently shaken and the swirl created is the source of these sudden changes due to air or fluid transmissions

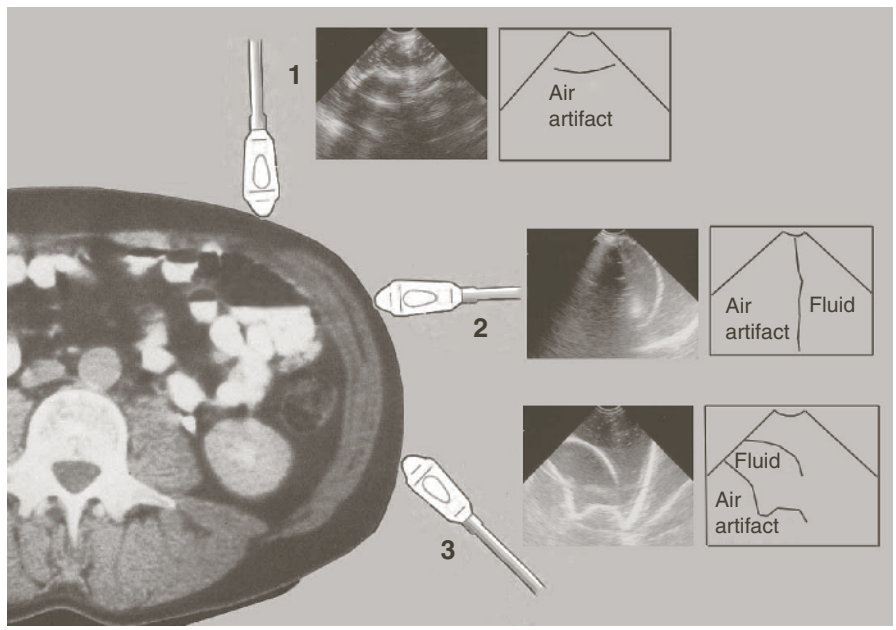

Fig. 6.20 Occlusion with air–fluid level. The probe *1* is vertical. The gas stops ultrasound displaying a horizontal line. The probe *2* is inserted at the horizontal level of the gas–fluid level. *To the right* of the image, fluid is observed; *to the left*, the image is hard to analyze, since air artifacts are tangential. The probe *3* reaches the gas–fluid level from behind. Probe *3* displays fluid, then an air artifact (the right beams reach this line earlier, hence the oblique line displayed). The air–fluid interface has a permanent dynamic characteristic of an air–fluid level, making a variant of the swirl sign

pointing to the ground), then shifted to the left side of the abdomen, in such a way that the probe is now parallel to the ground. The top of the screen is oriented to the anterior part of the abdomen, the bottom of the screen to its posterior part. Therefore, the gas is at the left of the image (with acoustic barrier), the fluid at the right, and the gas–fluid level is at the middle. Now, if the probe gets slightly a little posterior, the beam will reach first the fluid content, then be stopped by the gas content. Therefore, the gas–fluid line will be depicted on the screen, with a shimmering dynamic of this line (Fig. 6.20).

Once the diagnosis is done, real-time ultrasound can specify details that radiography and often CT do not: especially bowel dynamics. Complete absence of wall motion is seen in the paralytic ileus. To-and-fro movements of fluids due to ineffective contractions of the bowel can be seen in cases where there is an obstruction.

Peritoneal effusion is possible – and its analysis (tap) can be instructive.

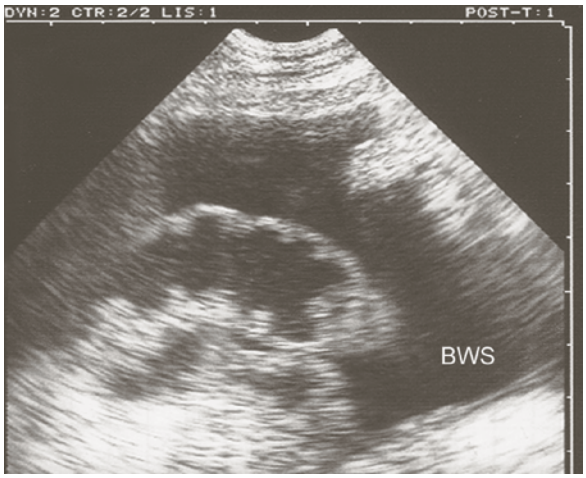

Fig. 6.21 Melena. This portion of the small bowel, outlined by ascites (*BWS* – for bat wing sign), is hypoechoic, indicating fluid. As was the case in this patient, this pattern can be the first sign of a GI tract hemorrhage, preceding any other sign

Fluid Digestive Sequestration

In a patient with shock, ultrasound detection of fluid sequestration within the intestines (Figs. 6.6, 6.10, and 6.14) immediately assumes a hypovolemic mechanism caused by digestive disorders (this sign will be associated with other ultrasound signs of hypovolemia). Scanning the abdomen makes it possible to roughly evaluate the sequestrated volume of fluid, which can reach several liters.

In a patient with clinically occult hemorrhagic shock, ultrasound can identify not yet exteriorized melena, which will appear as a fluid in the bowel (Fig. 6.21). This pattern is not specific, but ultrasound can be considered the first test able to detect GI tract hemorrhage, before the appearance of any clinical or biological anomaly.

Miscellaneous

Appendicitis and many semi emergencies are not in the scope of this book. Complicated appendicitis with shock usually yields moderate peritoneal effusion, which can be punctured. Intussusception yields suggestive signs on occasion [16]. Among some signs of midgut volvulus, the superior mesenteric artery can be seen right to the vein (the "whirlpool sign").

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Liver

7

Although it is the most voluminous plain organ, the liver is rarely a target for emergency therapeutic decisions in the critically ill.

When the liver is located high, intercostal scans should be taken. Liver analysis is not exhaustive in such conditions, but this limitation has little consequence in the critically ill patient.

Our 5-MHz microconvex probe is perfect for scanning the liver, especially for intercostal scans. We do not use abdominal probes. Their only use seems to be for accurate measurement of hepatic size, which is a tool of interest for the radiologist but not yet a tool for the intensivist. Unexpected uses may emerge from knowing the size of the liver, but this can be achieved using our probe.

Portal Gas

This diagnosis may be the main reason for scanning the liver in a shocked patient, since it immediately evokes the mesenteric infarction and allows immediate therapy with, in our experience, a possibility of healing. Portal gas usually requires immediate surgery [1, 2]. Portal gas is traditionally considered a pejorative sign [3], but this feeling is based on a radiographic culture. More sensitive than radiography [1], ultrasound allows the patient to from an early diagnosis. Portal gas has been described, in the adult, in volvulus, strangulation, ulcerous colitis, and intra-abdominal abscesses, which are always surgical emergencies [3].

We consider two signs of portal gas.

1. *Static portal gas*. This term refers to punctiform hyperechoic images (without acoustic shadow), which are disseminated within the liver parenchyma and usually are peripheral. Static portal gas looks like an alveolar consolidation with air bronchograms (Fig. 7.1).
2. *Dynamic portal gas*. This term refers to the detection of mobile hyperechoic particles within the portal vein (Fig. 7.2). Showing such a flow coming from the superior mesenteric vein and not from the splenic vein clearly indicates that the gas bubbles come from the GI tract. Particles that are echoic but not hyperechoic (like gas) have a differential diagnosis (possibly cell and platelet aggregations).

Confusion may result from aerobilia, which yields numerous air opacities. Aerobilia is a subtle diagnosis for radiologists, since the air collections are visible along the biliary vessels, which converge to the hilum, which is a more central location than in portal gas. Aerobilia can be physiologic\after biliary surgery, but rarely pathologic (ileus by impacted gallstone).

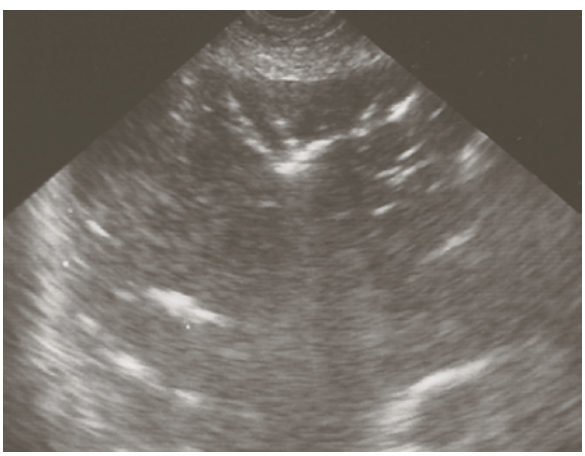

Fig. 7.1 Mesenteric infarction and static portal gas. Numerous hyperechoic punctiform opacities, without acoustic shadow, within the liver. This patient survived (perhaps because of an early diagnosis)

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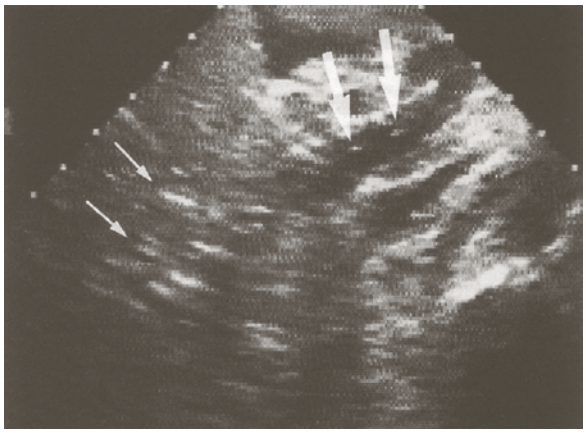

Fig. 7.2 Mesenteric infarction with dynamic portal gas. A visible flow with hyperechoic particles (*large arrows*) is observable in the portal vein. Static portal gas can be seen (*small arrows*). Oblique scan of the right hypochondrium, in the axis of the portal vein (*large arrows*). Patient was a 70-year-old woman with septic shock

Grotowski's law elegantly solves this problem. A septic shock *often* requires laparotomy. Aerobilia is *rare*. Aerobilia without previous biliary history (simply detected by the surgical scar) is even more *infrequent*. In these conditions, gas in the liver is nearly always aeroportia. From the small number of patients for whom an erroneous diagnosis of aeroportia (patients who had simple aerobilia) ordered surgery, we must withdraw the patients for whom the surgery was *useful*, finding the real cause of sepsis. The level of morbidity following useless laparotomy is probably not zero, but certainly is *low*. All these factors are mutiplied by one another, resulting in a nearly negligible number of complicated laparotomies, compared with an optimal rate of well-indicated laparotomies.

Hepatic Abscess

Although a rare diagnosis, ultrasound is a quick and user-friendly method of diagnosis, since it spares the highly unpleasant pain caused by liver shaking. Yet pain can be absent in encephalopathic, shocked patients, hence the interest in a systematic fast ultrasound examination for any critically ill patient on admission.

An abscess yields a roughly round image within the regular hepatic echostructure (Fig. 7.3). It has a heterogeneous, usually hypoechoic echostructure. A characteristic sign is sometimes observed within the mass:

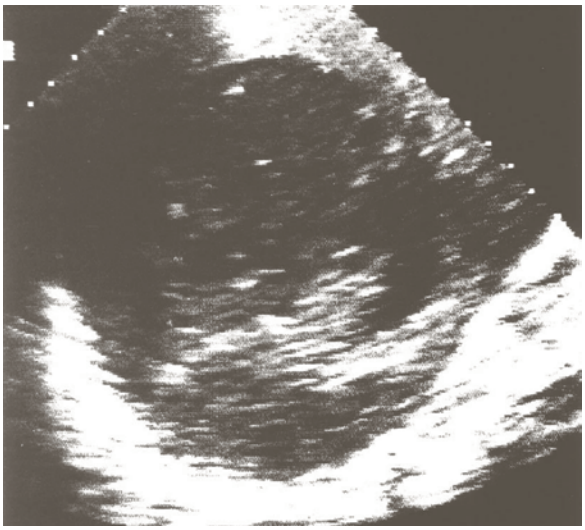

Fig. 7.3 Hepatic abscess. Huge round hypoechoic mass, which in real-time has a slow internal motion, characteristic from a fluid nature. Percutaneous ultrasound-guided drainage (see Fig. 26.3 page 263) has withdrawn 1,150 cc of frank pus (*Streptococcus milleri*)

a slow internal movement, in rhythm with respiration. This is the inertia of the pus caused by the movement, the equivalent of the plankton sign discussed in Chap. 5. In our observations, it proves the fluid nature of the collection (regardless of the presence or absence of posterior enhancement), and it indicates pathological fluid (pus, blood). Highly echoic images, if present, indicate microbial gas. Amoebic abscess yields a hypoechoic, well-limited collection.

Hydatidosis should be classically evoked before any puncture of fluid hepatic mass. This does not cause a problem when the cyst is well defined and anechoic, since there is no emergency, but it may in the suppurative forms, when the cyst becomes echoic and heterogeneous (Fig. 7.4).

Isolated Hepatomegaly

Some operators may evaluate the weight of each lobe. Others find that a subjective view is sufficient [4]. Measuring the liver makes ultrasound an expert discipline. The cause of an enlargement usually appears on the screen: acute right heart failure yields a homogeneous pattern with dilated hepatic veins, inferior vena cava, and right heart chambers (Fig. 7.5). Abscesses

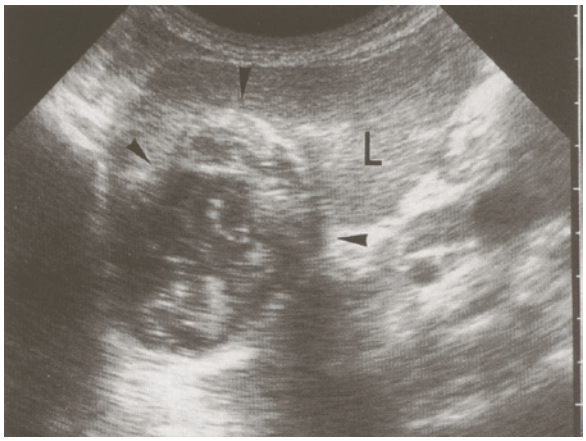

Fig. 7.4 Hydatid cyst of the liver. The heterogeneous pattern (*arrowheads*) indicates a complication, here suppuration, which was confirmed at the laparotomy of this 45-year-old man in septic shock. Longitudinal scan of the liver. *L*, liver

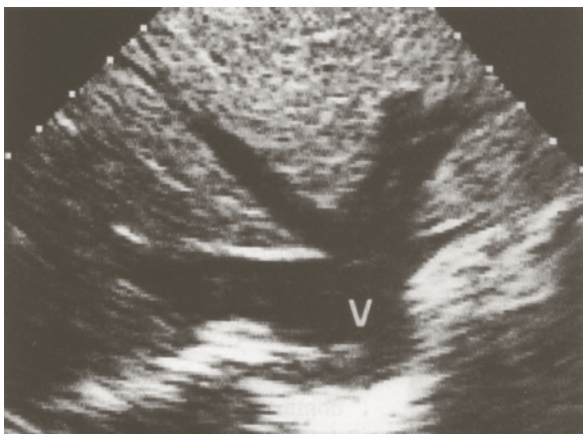

Fig. 7.5 Cardiac liver in right heart failure. Dilatation of the three hepatic veins, which open into an inferior vena cava (*V*), also dilated. Note that this scan is far from the ideal site where the IVC caliper should be measured (see Figs. 4.2 and 23.4). Epigastric subtransverse scan

and tumors will be usually detected without problem. We will describe the steatosic liver here, but interested readers can find a portion of fatty liver in Fig. 6.7 page 45.

The cirrhotic liver yields a coarse or nodular pattern, atrophy or hypertrophy of one lobe with resulting global dysmorphia, absence of suppleness of the parenchyma, signs of portal hypertension with dilatation of the portal vein, ascites, reopening of the umbilical vein, splenomegaly (see Fig. 10.6 page 78) and others. Please call a radiologist who knows these signs and can sharply measure a liver. See Fig. 6.12 page 47 for an illustration of esophageal varices.

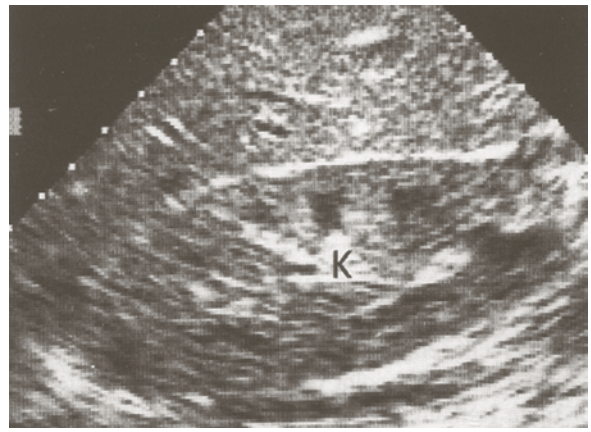

Fig. 7.6 Diffuse tuberculous miliary. In this longitudinal scan of the liver and the kidney (*K*), it is hard to detect frank anomalies. Real-time showed that the liver parenchyma pattern was homogeneously granular, but one can consider it as a subtle sign–requiring experience

Diffuse Infectious Disorders

Tuberculous hepatic miliary can be missed by ultrasound (Fig. 7.6). When there is strong clinical suspicion, a prompt liver biopsy should provide bacteriological confirmation.

Cholestasis

Cholestasis often occurs in ventilated patients. Ultrasound is a quick way to check for the bile ducts. Yet in our observations, the cause of cholestasis is always medical: for example, sepsis, impairment of venous return, drug interactions. We are still awaiting a surgical cause of cholestasis in a patient initially admitted in the ICU for a medical reason. We therefore advise the non-radiologist to invest energy in priority targets (lung, etc.) and call the radiologist in this setting in order not to lose time.

The intrahepatic duct is anterior to the portal bifurcation (Fig. 7.7) and the main duct anterior to the portal vein (Fig. 7.8). The maximal normal caliper of the main bile duct is said to be 7 mm for some (up to 12 mm in

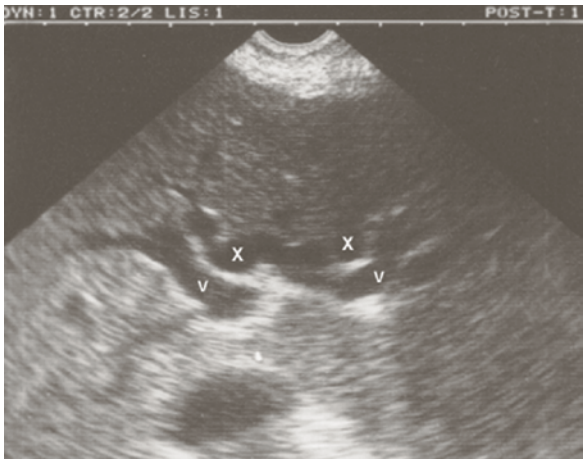

Fig. 7.7 Dilatation of intrahepatic bile ducts. Biliary vessels (*X*) are visible anterior to portal bifurcation (*V*), producing a double-channel pattern

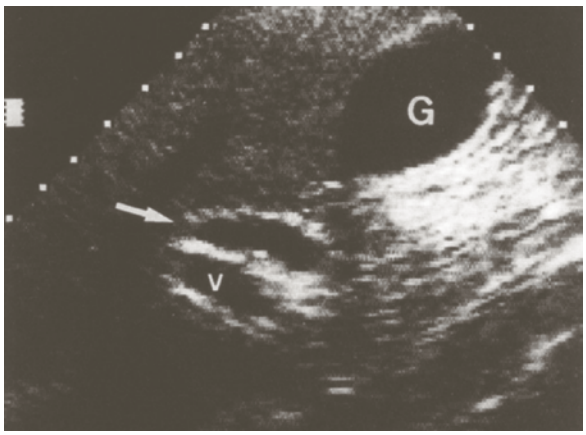

Fig. 7.8 Dilatation of the common bile duct. Anterior to the portal vein (*V*), the common bile duct (*arrow*) is dilated (9-mm caliper). Oblique scan of epigastric area. *G*, gallbladder

the case of an old cholecystectomy), but 4 mm for others authors [5]. A dilated common bile duct acquires a tortuous route and cannot be visualized in a single view. The sensitivity of ultrasound is limited for detection of common bile duct calculi, which rarely produce posterior shadows, even if massive [6].

Hepatic Veins

Ultrasound is a noninvasive method for examining hepatic veins [7]. They are easy to analyze when anechoic and surrounded by echoic hepatic tissue (Fig. 7.5). They can often be compressed using probe pressure (look out for painful sensitivity in those patients being seen for abdominal pain). In critically ill patients, frequent right heart failure or liberal fluid therapy makes hepatic veins appear more easily. In hepatic vein thrombosis (Budd-Chiari syndrome), the veins are filled with echoic material. They can therefore appear filiform or even isoechoic to the liver. The inclusion of other signs would deviate too far from our aim (critical ultrasound, a simple discipline).

The Budd-Chiari syndrome is a *rare* cause of acute abdominal pain, at least in our institutions. The frequent causes will be usually detected using simple ultrasound. The detection of *non*anechoic veins in a patient who is *really suspect* for hepatic vein thrombosis makes ultrasound extremely contributive. The decision of providing a unit with Doppler for this sole indication would condemn the user to very rarely exploit this potential. If the suspicion is high, then and only then may DIAFORA logistics (referral to an outside Doppler examination) be envisaged.

In critically ill patients, mobile gas is sometimes observed in the median and left hepatic veins, which are the nondependent veins (Fig. 7.9). Maybe air accidentally coming from perfusions (in the arms, for instance) is trapped in these veins. A tricuspid regurgitation, frequent in the mechanically ventilated patient, may be the cause.

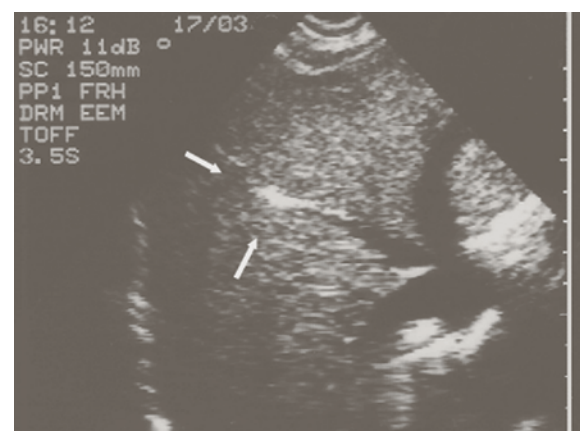

Fig. 7.9 Hyperechoic structure, highly dynamic in real-time, is visible at the median hepatic vein (*arrows*). Trapped air in the hepatic venous system. Subtransverse epigastric scan acquired with an Ausonics 2000 unit (a 39-cm width, 14-kg machine – although of limited resolution)

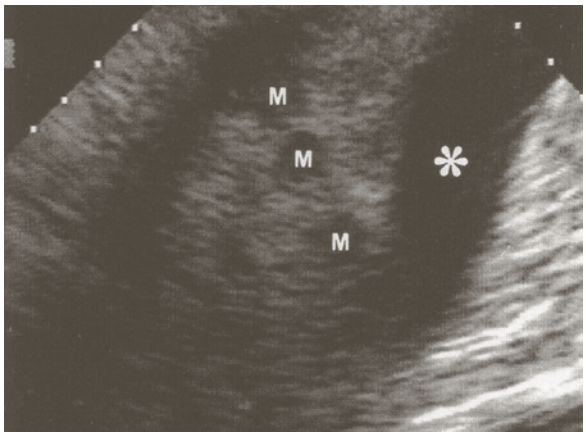

Fig. 7.10 Hepatic metastases. Hypoechoic masses, disseminated in the liver, surrounded by peritoneal effusion (*asterisk*)

Hepatic Tumors

Metastases are sometimes a fortuitous discovery. This recognition may be useful in some cases. Multiple disseminated images with random distribution, isoechoic, hyperechoic with a fine hypoechoic stripe, or again hypoechoic images are possible (Fig. 7.10). Other tumors do not need particular management during the stay in the ICU. A round, regular, anechoic image is generally a biliary cyst, sometimes an uncomplicated hydatid cyst. An echoic heterogeneous mass within a cirrhotic parenchyma will be suggestive of hepatocarcinoma. These tumors and others (adenoma, focal nodular hyperplasia, angioma, primitive malignant tumors, heterogeneous steatosis, etc.) are extensively described in excellent textbooks [4, 8, 9]. We should here refer the patient to imaging specialists.

Trauma

Direct signs of liver contusion can be detected in favorable cases (see Fig. 28.4 page 275).

Interventional Ultrasound

We successfully aspirate from time to time hepatic abscesses with the material described in Chap. 26. Too deep locations or locations near the dome may cause technical problems.

Percutaneous or Transjugular Liver Biopsy

Liver biopsies are not performed in the ICU. Using our simple equipment, it is possible to monitor this procedure at the bedside. Some indications can be imagined in the ICU: documenting fulminans hepatitis or suspected diffuse tuberculosis, having a definitive proof of malignancy if this can alter management. Usually, hemostasis disorders require a transjugular approach, which means transportation of a critically ill patient to a specialized center. Yet transjugular hepatic biopsy could be performed at the bedside under sonographic guidance, with a triple impact: immediate catheterization of the internal jugular vein (see Chap. 12); ultrasound guidance toward the target; and accurate guidance to an hepatic vein. Ultrasound works in the three dimensions and thereby is better than radioscopy, which gives a nice overview but works in only two dimensions, with occasional hemorrhagic accidents.

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Gallbladder

8

The gallbladder has been assessed using ultrasound since 1951 (see Fig. page viii). Acute acalculous cholecystitis is a traditional complication and a classic target for general ultrasound in the intensive care unit. Time has not modified the opinion we expressed in our previous editions, using histological examination as the "gold standard". First, this disorder seems to remain exceptional in the medical ICU and affects mostly surgical patients. Second, if ultrasound can accurately describe data, the very interpretation of these data remains subtle. In fact, the gallbladder can show a wide variety of patterns, from the normal to the pathological, in passing even picturesque (Figs. 8.1 and 8.2). A strictly normal gallbladder in the ICU is an infrequent finding (see Fig. 4.9 page 30). The variations in volume, wall thickness, content, shape and surroundings create infinite combinations. Some are variants of the normal, some are pathological but do not require emergency procedures, and others need prompt surgery.

It is timely to describe our mix of experience. Comparing systematic observations from our medical ICU and a surgical ICU with major vascular surgery, we found one case of acute acalculous cholecystitis every 500 days of physician presence for medical patients and 23 days for surgical patients. This means a frequency 20-times lower for medical patients.

A 5-MHz microconvex probe is perfect for this investigation.

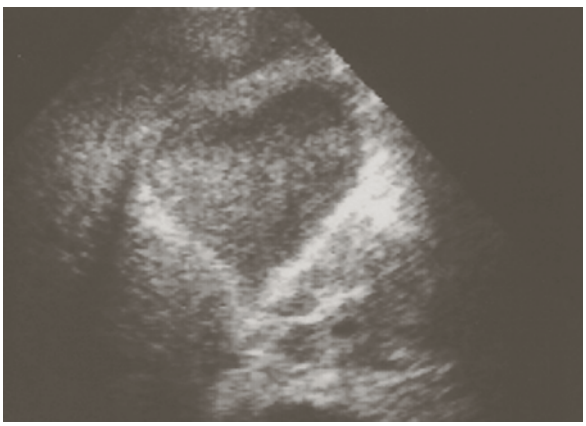

Fig. 8.1 A picturesque gallbladder. Elegance is not forbidden in an organ as critical as the gallbladder. A simple folding at the hepatic aspect is enough to confer this discrete charm

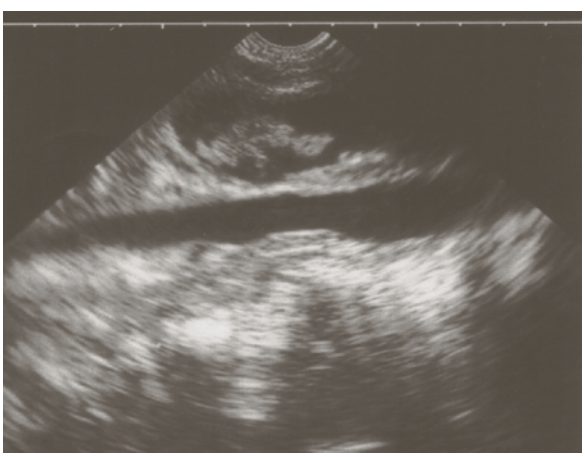

Fig. 8.2 In another gallbladder, a very irregular sludge seems to represent a crouched coyote (asymptomatic patient)

Classical Signs of Acute Acalculous Cholecystitis

Acute acalculous cholecystitis is found in 5–15% of acute cholecystitis and 47% of postoperative cholecystitis [1]. The diagnosis is suggested by infectious syndrome and local signs in an exposed patient [2]. Histology alone provides definite diagnosis, a mandatory sign being

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wall infiltration by neutrophils. Classically associated ultrasound patterns:

- Size: enlarged gallbladder, with a long axis caliper over 90 mm and a short axis over 50 mm.
- Wall: thickening greater than 3 mm.
- Content: sludge (echoic, compact, dependent sediment).
- Surroundings: perivesicular fluid collection.
- Murphy's sign: pain due to the pressure of the gallbladder. Ultrasound precisely locates the gallbladder, making Murphy's sign more accurate.

Sensitivity of ultrasound is weak (67%) for some [3], high (90–95%) for others [4,5]. When distension, thickening and sludge are combined, sensitivity falls and specificity climbs [2].

Our Observations of Acute Acalculous Cholecystitis

Acute acalculous cholecystitis seems to be specific to the surgical ICU. It may complicate major trauma or major vascular surgery such as aorta surgery. Although ultrasound can localize the gallbladder and accurately delineate the phenomena described above, we suspect that these signs, taken one after another or even together, should be interpreted. Our observations of histologically proven acute acalculous cholecystitis have led to the following observations (Fig. 8.3).

Size: On average, the gallbladder measured 103 mm on the long axis (range, 65–150 mm) and 40 mm on the short axis (range, 29–55 mm).

Wall: The wall was always moderately thickened, measuring on average 4.6 mm (minimum observed, 3.0 mm; maximum, 6.2 mm).

Content: Sludge was present in 90% of cases.

Surrounding: We observed selective effusion in 12% of cases.

Murphy's sign: We observed a genuine Murphy sign in 8% of cases.

The problem begins when we also consider a disorder encountered in our histology reports: chronic subacute cholecystitis. This frequent disorder will raise serious diagnostic problems.

Chronic Subacute Cholecystitis

This is a histological definition. In fact, neither ultrasound nor even perioperative findings can distinguish it from acute acalculous cholecystitis (Fig. 8.4). Nearly half of our patients operated on for suspicion of acute acalculous cholecystitis had chronic subacute cholecystitis. This disorder does not seem to require surgery.

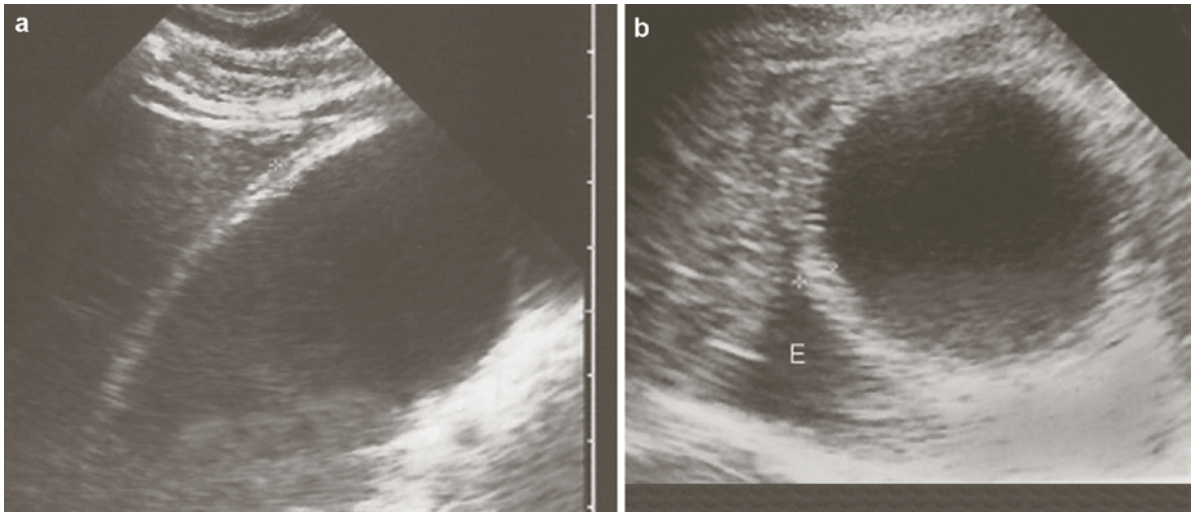

Fig. 8.3 Acute acalculous cholecystitis, with histological proof. A homogeneous thickening of the wall (4 mm), a caliper of 30 mm, and dependent sludge are depicted. There was no pain in this sedated patient, but this gallbladder is suspect because the patient developed fever after major aortic surgery. (**a**) Axial scan. (**b**) Short-axis scan, in which a moderate peritoneal effusion is visible (*E*)

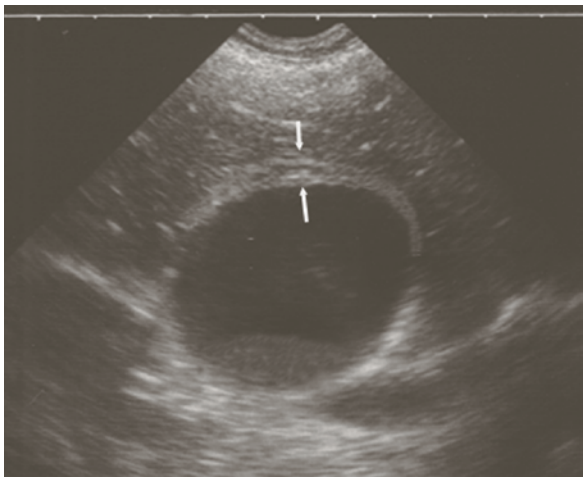

Fig. 8.4 Cholecystitis. This gallbladder has a homogeneous 5.5-mm thickened wall, a pattern not really different from Fig. 8.3. Sludge is also discretely present. Pathological examination confirmed the diagnosis of chronic subacute cholecystitis

Table 8.1 Acute acalculous versus chronic subacute cholecystitis

	Acute acalculous cholecystitis	Chronic subacute cholecystitis
Wall thickening	4.6 mm (3.0–6.2)	4.5 mm (3.0–7)
Long axis	103 mm (65–150)	105 mm (84–160)
Short axis	40 mm (29–55)	37 mm (23–56)
Sludge	90%	66%
Localized perivesicular effusion	12%	0
Murphy's ultrasound sign	8%	10%

Extreme values are *in parentheses*

In our observations, the average long axis was 105 mm (range, 84–160 mm), average caliper 37 mm (range, 23–56 mm), average wall thickness 4.5 mm (range, 3.0–7.0 mm), sludge was present in 66% of cases, Murphy's sign in 10%, and localized effusion was never present.

These data are quite similar to those seen in acute acalculous cholecystitis (Table 8.1). One consequence is that this disorder is diagnosed, with subsequent surgery, with the same frequency as acute acalculous cholecystitis. This means useless surgery, which is increased operative risk, but above all, an initial problem that remains undiagnosed. A perioperative pattern is sometimes misleading, and many gallbladders deemed acute or even gangrenous become simple chronic subacute cholecystitis once under the microscope.

Common Gallbladder Patterns Seen in the Intensive Care Unit

In our critically ill patients with no superimposed clinical problem, the majority of their gallbladders are enlarged and contain sludge. Wall thickening is frequent; the major form of this thickening will be dealt with in a later section. Peritoneal effusion is routine in critically ill patients. All these changes are routine and of little relevance, even when integrated in a suggestive context. Let us examine them in detail.

Volume

Volume can vary between complete vacuity to distension. Detecting an empty gallbladder requires experience. One should first identify a portal structure, then the right portal branch, which leads to the fossa vesicae felleae, which always leads to the gallbladder space (Fig. 8.5). An empty gallbladder is, in principle, functional, since it is able to contract. It may also be perforated. A distended gallbladder (long axis >90 mm, short axis >50 or 40 mm) is the rule in patients under parenteral feeding and morphines (Fig. 8.6). The lumen can be virtual and the wall thickened (Fig. 8.7). Among other patterns, one can see septate contents, variations

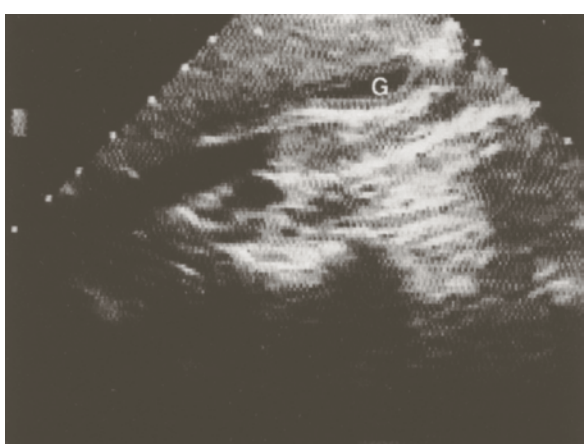

Fig. 8.5 Empty gallbladder. This discrete image should be recognized to avoid erroneous diagnoses

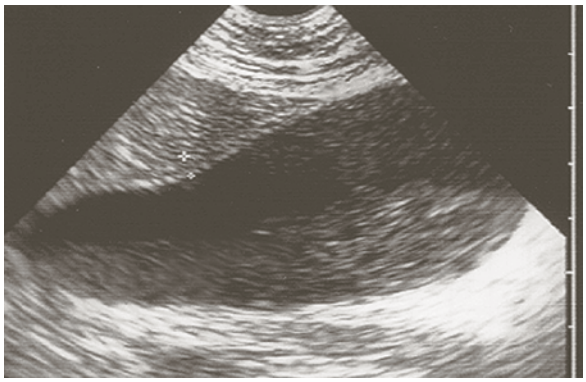

Fig. 8.6 Enlarged gallbladder. The volume is 100 × 40 mm, the wall 3.6 mm (slightly thickened), the content 40% sludge. This is frequent in the ICU. However, this gallbladder did not provoke symptoms. This female patient admitted for ARDS (aspiration pneumonia) fully recovered

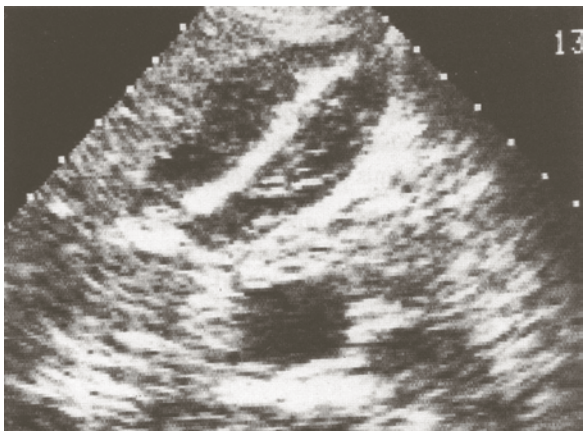

Fig. 8.7 The lumen of this gallbladder is virtual, reduced to an echoic stripe, and an extremely thickened wall, to 12 mm. Laparotomy and pathology revealed simple gallbladder edema in this patient in septic shock with major lung injury

in length, complete calcifications of the wall, or tumors. Images of these anomalies are accessible in abdominal ultrasound textbooks [6, 7].

Wall Thickening

The normal wall measures between 1.5 and 3 mm. With modern units (i.e., since 1992), the resolution precision allows us to consider 3 mm as a cutoff. The measurement is easy when the wall is outlined between a peritoneal effusion and the bile (Fig. 8.8), but difficult when the wall continues with an isoechoic hepatic

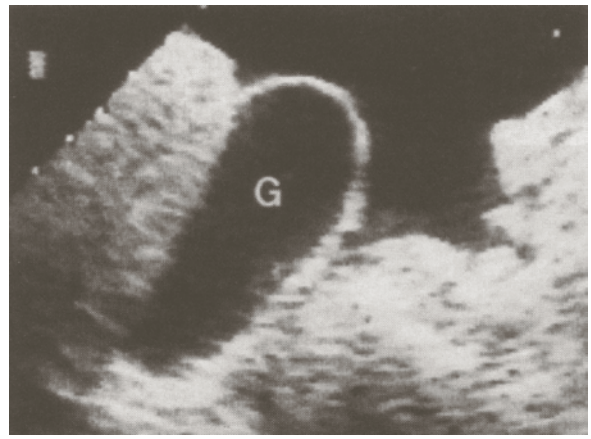

Fig. 8.8 The wall of this gallbladder is perfectly outlined between bile (*G*) and ascites. This wall is perfectly fine. This figure easily invalidates the traditional idea that ascites causes gallbladder wall thickening

parenchyma, with superimposed edema, which makes any precise measurement illusory.

We routinely find a thickened wall (Fig. 8.6). It can be split, with two echoic layers surrounding an hypoechoic layer. A striated pattern is described as a sign of acute acalculous cholecystitis [8], but the follow-up of our patients does not support this impression.

Traditionally, a thickened wall is nearly equivalent to acute acalculous cholecystitis. Experience shows that this sign has very low specificity. The classic list of causes includes ascites, hepatitis, hypoalbuminemia, and cardiac failure, a rather vague term [9]. Observation shows that, in the case of ascites and in spite of the traditional widespread belief to the contrary, the wall can be perfectly thin (see Fig. 8.8). We regularly observe thin walls in gallbladders surrounded by massive volumes of ascites, proving that peritoneal effusion is not in itself a cause explaining wall thickening. Cardiac failure is an overly vague notion. In contrast, acute right heart failure should certainly be considered a prominent cause. We even speak of "cardiac gallbladder" (see next section).

Sludge

Sludge is nearly always present in the critically ill patient, since the gallbladder does not work in a physiological way. The pattern can vary greatly, although

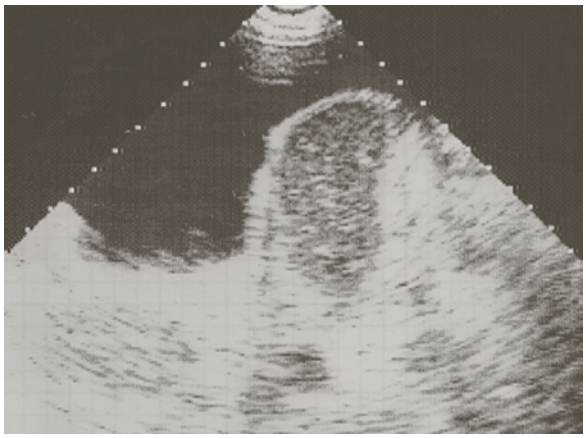

Fig. 8.9 Complete sludge. This gallbladder, floating within massive peritoneal effusion, contains a totally echoic lumen. The patient was asymptomatic

we could not attribute a particular value to each. Sludge can be homogeneous (Fig. 8.6) or heterogeneous, containing hyperechoic dots (microlithiases possibly may be included in the mass). The interface between the sludge and the anechoic nondependent bile can be regular (Fig. 8.6) or ragged (Fig. 8.2). Sludge can be discrete or massive: in some cases, 100% sludge yields a pattern isoechoic to the liver – a hepatization of the gallbladder, so to speak (Fig. 8.9). Solid knowledge of anatomy is then required to recognize the gallbladder. The sludge may be tumor-shaped. Sludge usually appears during a prolonged stay, but may be present at admission. Eventually, it may completely vanish.

Peripheral Peritoneal Effusion

Peritoneal effusion is frequent in the critically ill patient. Localized effusion in acute cholecystitis is a rare finding.

Murphy's Sign in Ultrasound

Murphy's sign is rarely contributive since critically ill patients are sedated or, if not, they are in shock or encephalopathic. Pain is either absent or diffuse over the entire body.

A Distinctive Feature: Major Wall Thickening of the Cardiac Gallbladder

We regularly observe gallbladders with the remarkable feature of major wall thickening, more than 7 mm, up to 18 mm (Fig. 8.10). This pattern always occurs in patients with right heart failure, such as acute asthma, pneumonia, adult respiratory distress syndrome, pulmonary embolism, acute tricuspid regurgitation, and exacerbation of chronic obstructive pulmonary disease, in the most severe forms. This population is more often seen in medical ICUs, hence possibly a higher rate of cases observed here. There is no local sign in these sedated patients. The gallbladder cavity itself is often small, possibly because the walls enlarge to the detriment of the cavity. Time allowing, one can observe the complete regression of this major thickening (Fig. 8.11). A dozen observations among a large number benefited from histologic examination, using laparotomy, for instance. All of these observations were the result of wall edema, sometimes chronic subacute cholecystitis, but never up to now acute acalculous cholecystitis.

We suggest labeling this frequent observation of overly thickened wall the "cardiac gallbladder," with analogy to cardiac liver or cor pulmonale. It can be assumed that the cardiac gallbladder:

- Is above all the manifestation of congestive phenomena that is observable at the gallbladder wall, which is an accessible area, as retinal vessels are a

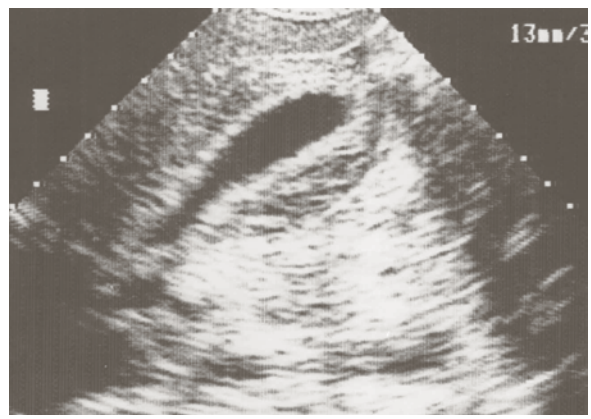

Fig. 8.10 Cardiac gallbladder. The wall of this gallbladder is extremely enlarged, up to 20 mm. The lumen is narrow (max. 12 mm), probably because of the space taken by the walls. This patient has acute right heart failure. Pathology confirmed simple wall edema

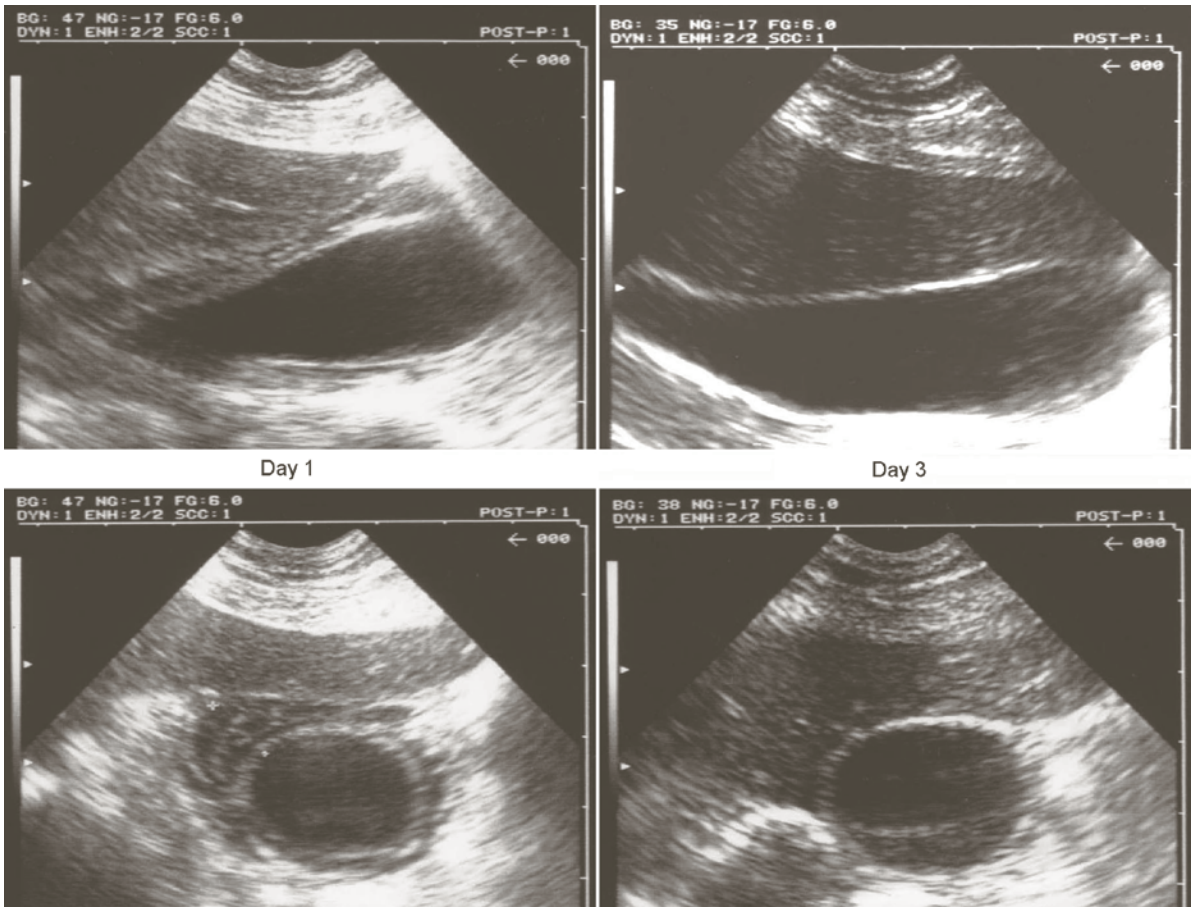

Fig. 8.11 Evolution of a "cardiac gallbladder" in a patient with acute respiratory failure. *Left:* Sections of the gallbladder on admission. *Right:* Same sections 3 days after. Maybe an intermediate analysis would prove an even shorter delay for "recovery"

privileged site to assess general circulatory function.
- Is frequent.
- Can be occult, because this is a transitory feature.

Conversely, an ultrasound examination performed at the climax of the wall thickening can lead to an erroneous diagnosis of acute acalculous cholecystitis, and result in a number of unnecessary laparotomies.

There is a clinical relevance to the recognition of a cardiac gallbladder. Data suggest that the detection of thickening over 7 mm in a patient admitted in a medical ICU with symptoms that may evoke acute acalculous cholecystitis should incite the physician to search for *another cause* to explain the present symptoms (fever, pain). A laparotomy is at risk of being useless if the real cause is not recognized. Frequently, the gallbladder is removed, and the patient comes from the operating theater with no more fever: this is may simply be the postoperative hypothermia. When the fever recurs again, 1 day later, it is usually interpreted as a new problem (and, usually, the pneumonia that was not visible previously has a radiologic appearance, making the diagnosis of pneumonia easier, among examples).

How to Improve the Diagnosis of Acute Acalculous Cholecystitis

We believe that ultrasound is an excellent method for localizing and measuring the gallbladder, but not for distinguishing the surgical emergency from insignificant variants of the normal.

Patient Background and Current Situation

It seems wise to evoke acute acalculous cholecystitis only in well-defined patients. Major vascular (aorta) surgery occurred in half of our cases, a major trauma in a quarter of cases. As for chronic subacute cholecystitis, major vascular surgery occurred in only 16% of cases, trauma in 33%. Most patients with cardiac gallbladder have an acute right heart failure in the setting of ARDS or multiple organ failure, which is less often severe asthma.

Considering Certain Ultrasound Signs

We recall that a wall thickening greater than 7 mm in a medical ICU patient suspected of having acute acalculous cholecystitis should prompt a search for another cause explaining the symptoms.

A subtle study showing parietal ulcerations would be valuable, but our investigations are at a standstill. We sometimes see shreds detached from the mucosa (Fig. 8.12), but with pathology ruling out the diagnosis of acute acalculous cholecystitis. Detachment of the mucosa with shreds floating in the lumen is described in the literature as a sign of gangrenous cholecystitis [10].

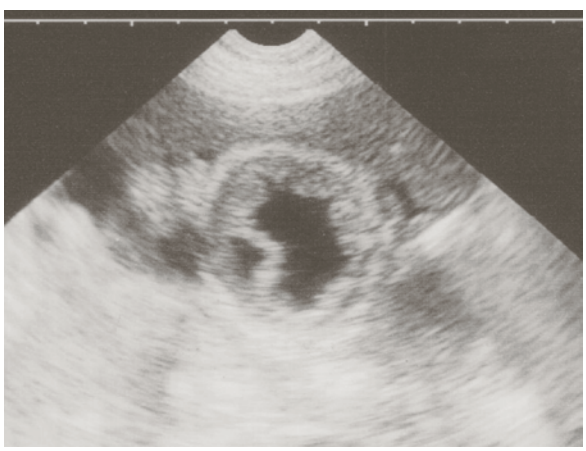

Fig. 8.12 The gallbladder of this patient admitted for exacerbation of chronic respiratory disease had an unsettling pattern: a scalloped wall with possible debris detached from the left aspect. Pathology authenticated a simple chronic subacute cholecystitis

Intramural gas should be observed in emphysematous cholecystitis. We did not have the privilege of observing this sign, which is probably rare. Mural gas should give hyperechoic punctiform images, which should not be confused with cholesterol calculi contained in the Rokitansky-Aschoff sinuses, which are part of the picturesque setting of gallbladder adenomyomatosis, although this is of little interest to us here.

Perforation of the wall. A thin wall is described in the preperforative cases, but we are still awaiting our first case. Facing this potential rarity, we use to make comprehensive scan of the wall. If the wall thickening is homogeneous, a preperforative state is unlikely.

Technical note: a small gallbladder may be normal, or (in theory) the consequence of a perforation.

Doppler

If the Doppler could accurately distinguish between ischemic and edematous wall, it would then be potentially of interest. We await the proof and, above all, the benefit of Doppler. In the supposition of an interest, the degree of emergency disease could give time to use the DIAFORA (Doppler intermittently asked from outside: rare applications) logistics.

CT

CT does not contribute a great deal, since a careful ultrasound is almost always able to analyze the gallbladder. This is the opportunity to see that ultrasound focal resolution appears superior to that of CT (see Fig. 8.13). The measurement of wall thickening is more accurate using ultrasound [11]. This potential is found at many areas (see Figs 19.1 and 19.2 page 184).

Dynamic Cerulein Test and Scintigraphy

Dynamic cerulein tests and scintigraphy are of little value [10]. We fear that cerulein, or any other way able to make the gallbladder contract (like simple fatty food), may be harmful in a critically ill patient.

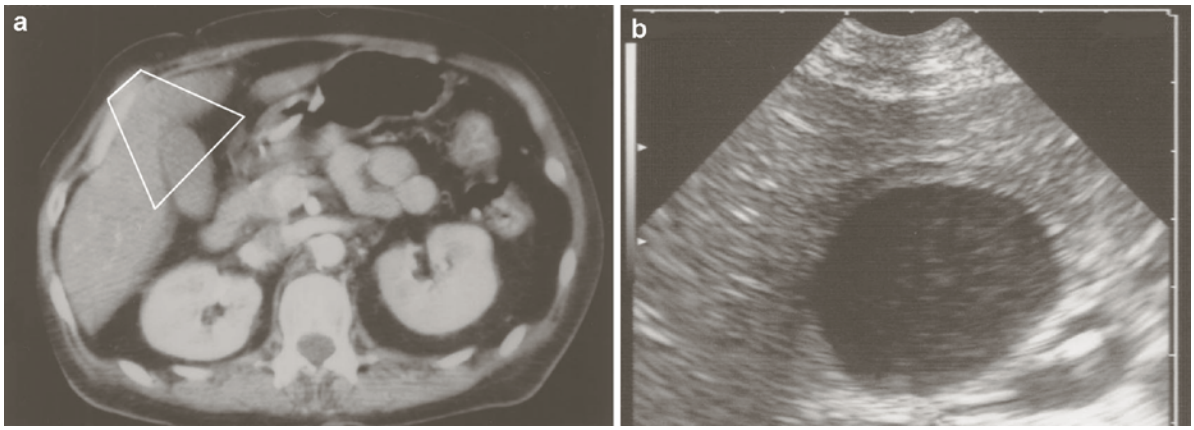

Fig. 8.13 It is easy to objectify ultrasound's superiority (**b**) over CT (**a**) for focal spatial resolution. The area scanned by ultrasound is roughly the one *circled in white* in the *left image*. The gallbladder wall, difficult to measure on CT, is sharply measurable on ultrasound

Ultrasound-Guided Aspiration of Gallbladder Bile

In our experience, this procedure is simple. A 21-gauge needle is sufficient. The gallbladder should be punctured throughout a nonvascularized area of the liver (the hole will be recovered by the liver). Bile leakage cases described in the literature result from transperitoneal approaches. The dependent bile is aspirated, since the nondependent area may yield false negatives. Since pathological bile is viscous, aspiration must be done patiently. The amount of aspired bile should be sufficient to diminish the possible hyperpressure and thus limit the (low) risk of leakage. Conversely, if percutaneous drainage is envisaged, the volume of the gallbladder should not be decreased too much. When the needle is withdrawn, manual compression is applied at the point of puncture. If strong compression is not applied, for fear of bile leakage, hemoperitoneum or subcapsular hematoma of the liver can result in patients with impaired hemostasis. Control at 1 and 12 h will search for perivesicular effusion. The vesicular bile of a critically ill patient is usually dark brown or green brown and mildly sticky. The aspired sludge appears black, like tar.

The risk of vesicular tap is possible though rare. It should be compared with the risk of allowing angiocholitis or cholecystitis to develop, which can be clinically difficult to detect. Of 25 procedures performed as described, we have encountered no complications.

This technique is simple and seems safe. Is it relevant? For some, it is [12], when it provides proof of infection at the bedside, which should be present in 66% of the cases [13]. Other studies [14] question the sensitivity of this procedure, which is almost always performed on patients under antibiotic therapy. For some, leukocytes found in the gallbladder bile should indicate cholecystitis [14]. The most important limit is that acute acalculous cholecystitis appears more as an ischemic than an infectious process [15]. For paucity of cases at the current time, we lack experience to say whether this procedure is contributive or not.

In our practice, when there is a clear infectious history and clinical suspicion of cholecystitis, in patients

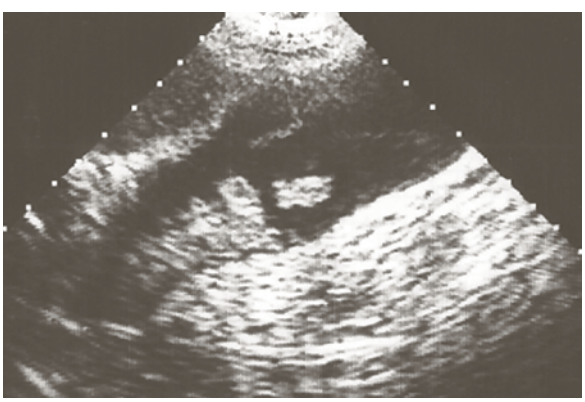

Fig. 8.14 Acute purulent cholecystitis. Dependent areas (*lower part of the image*) are not typical of sludge, since they are rather echoic, nor do they evoke calculi, since there is no posterior shadow. Images of membranes seeming to detach from the wall are visible at the upper part of the image. An ultrasound-guided tap immediately confirmed the diagnosis (frank pus) and the patient was promptly sent to the operating room

admitted for shock, especially when there are unusual echoes within the gallbladder (Fig. 8.14), the puncture is envisaged, sometimes withdrawing pure pus, prompting the patient to the operating room.

Other Pathological Patterns of the Gallbladder

Cholecystectomy Space

Infection of the cholecystectomy space is frequently suspected (Fig. 8.15). Ultrasound-guided aspiration appears to be an accessible procedure and can distinguish pus collection from old sterile blood.

Calculous Acute Cholecystitis

This disorder is rarely of interest to the intensivist. The stone gives a dependent hyperechoic, round image with frank posterior shadow (see Fig. 1.6 page 7). Gallstones are frequently observed. Obviously, the smaller the stones, the more they are able to move and cause trouble. The association of gallstones, thickened wall and Murphy's sign on ultrasound has a positive predictive value of 95%, and the absence of these three signs has a negative predictive value of 98% [16]. Acute calculous cholecystitis rarely raises diagnostic problems.

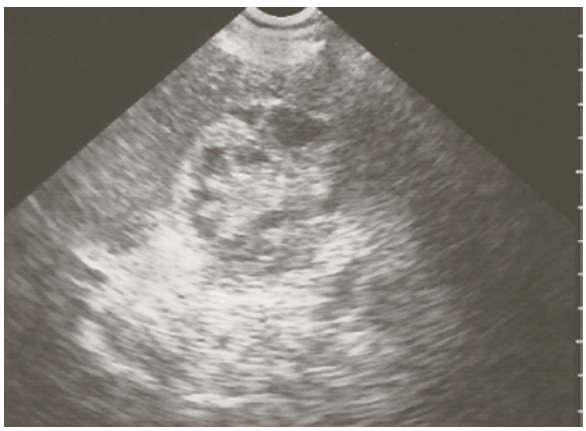

Fig. 8.15 Gallbladder space hematoma. Heterogeneous echoic pattern, often found in the gallbladder space after surgical removal

Acute "Acalculous" Cholecystitis in Calculous Gallbladder

Since gallstones are frequent in the general population, how should we label an acute cholecystitis of critically ill patients occurring in a calculous gallbladder?

Interventional Ultrasound

Diagnostic aspiration has been discussed in "Ultrasound-Guided Aspiration of Gallbladder Bile."

Percutaneous cholecystostomy is a bedside alternative to surgery [17,18]. Some authors find this procedure easy and rather safe [14,17]. Rates of null mortality and 2–5% morbidity are related [19]. Technical requirements are the same as those described for aspiration [20]. Kits are available, with laterally perforated pigtail catheters, preventing parietal perforation and dislocation of material. The procedure provides a decrease in pressure upstream of an obstacle located in the biliary tract. It was even shown to be effective in sepsis without obvious causes [14]. Other teams mistrust this technique, arguing that a fragile wall can easily be perforated [15]. We add two arguments against this procedure. Since histological proof is unavailable, no conclusion can be drawn from why the situation evolves. Above all, acute acalculous cholecystitis is more an ischemic than an infectious disorder. The gallbladder wall should therefore be removed, more than its content.

From a methodological point of view, in a population with clinical and ultrasound patterns suggestive of acute acalculous cholecystitis, it would be valuable to compare the progression of operated versus non-operated patients. Such a study includes the risk of allowing a genuine acute cholecystitis to evolve [21] and the benefit of avoiding useless laparotomy, i.e., which are ethical issues. Note simply that this methodological detail is absent in published studies [14].

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Urinary Tract

9

The study of the urinary tract mingles mechanical, hemodynamic, and infectious disorders. Normal kidney and bladder are described in Chap. 4.

Our 5-MHz microconvex probe is fully suitable for this investigation.

Renal Parenchyma

The diagnosis of acute renal failure is biological. A main purpose of ultrasound is to rule out an obstacle [1]. The ultrasound patterns usually give redundant information, as we will briefly discuss. Acute renal failure is suggested when there is normal or increased size (Fig. 9.1). Chronic renal failure may cause small kidneys with thin parenchyma and irregular borders (Fig. 9.2). Kidneys can show global dedifferentiation. The parenchyma can resemble the sinus (parenchymocentral dedifferentiation); within the parenchyma, medullary pyramids, and cortex, it can have the same echogenicity (corticomedullary dedifferentiation). In the case of severe rhabdomyolysis with acute renal failure, we can observe enlarged kidneys with complete dedifferentiation. Hemolytic uremic syndrome should yield small hyperechoic kidneys. The use of Doppler for calculating renal resistance index may be of interest, but does not seem to be of major relevance for acute decision-making from various sources.

Acute pyelonephritis is usually barely or not accessible to two-dimensional ultrasound, but severe forms, such as hemorrhagic pyonephritis, are sometimes diagnosed. Figure 9.3 shows the routine ultrasound of a 52-year-old female who was admitted for severe sepsis, with massive bilateral enlargement of the kidneys and no differentiation.

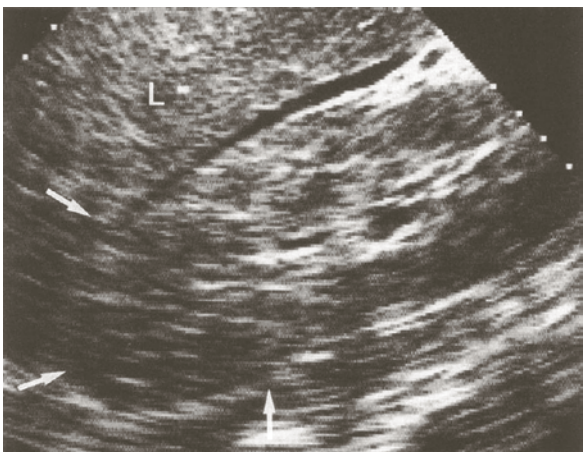

Fig. 9.1 Acute renal failure. The kidney has a homogeneous echoic pattern, i.e., complete dedifferentiation. Kidney and liver (*L*) have the same echogenicity, and the kidney is barely outlined (*arrows*). This scan, as nearly all that follow, is longitudinal

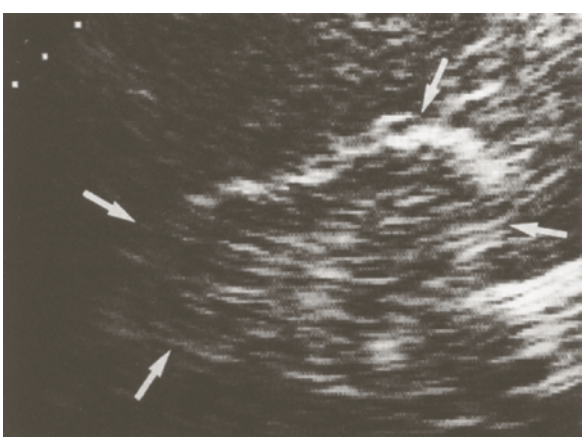

Fig. 9.2 Chronic renal failure. Small size (*arrows*), thinned parenchyma and irregular borders

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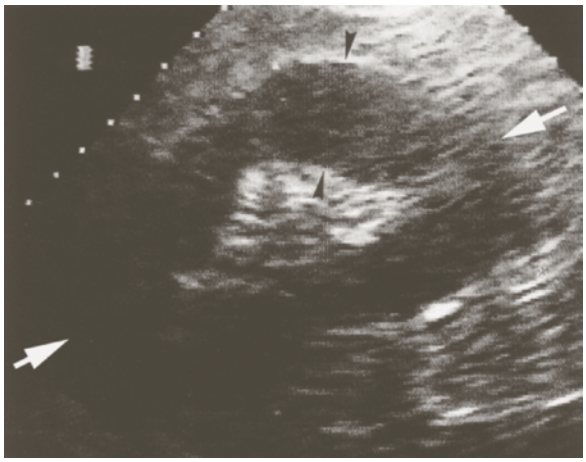

Fig. 9.3 Pyonephritis. This kidney is frankly enlarged (long axis, 14 cm, *white arrows* – the *upper arrow*, left of the screen, extrapolates the upper pole of the kidney) and the peripheral area is extremely thickened (*arrowheads*), without differentiation. This shocked patient had an acute hemorrhagic pyonephritis. Each kidney weighed 500 g and contained multiple areas with pus, necrosis and hemorrhage

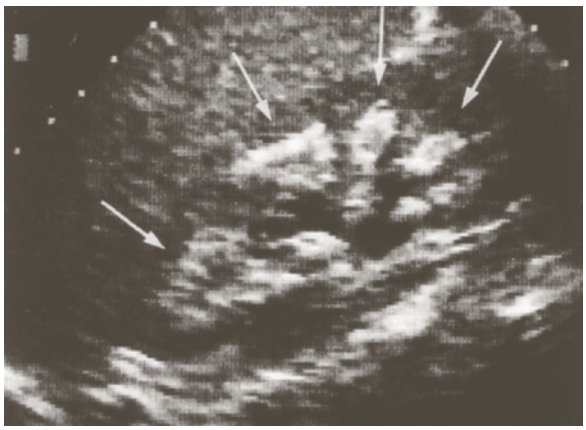

Fig. 9.4 Urinary candidosis. Hyperechoic pattern of the pyramids (*arrows*)

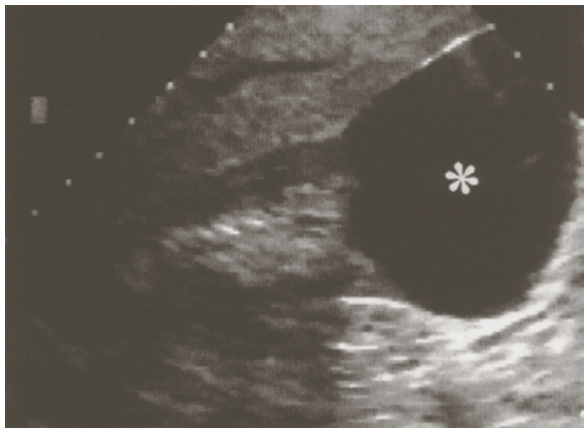

Fig. 9.5 Renal cyst (*asterisk*). The lower pole of the kidney seems to be interrupted, with a ragged edge. This cyst is regular, anechoic. This pattern (featuring here because of its frequency) should not disconcert

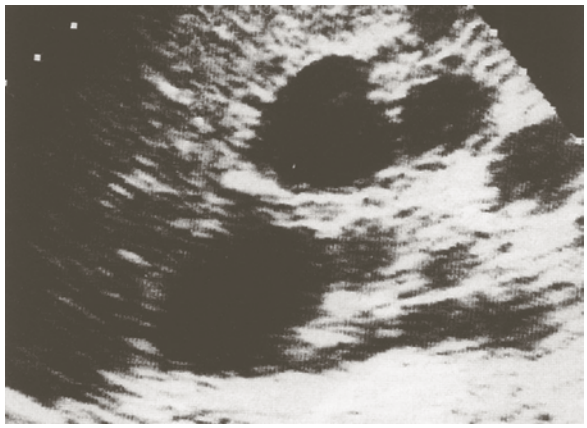

Fig. 9.6 Renal polycystic disease. Cysts have peripheral topography and do not communicate with each other, two features that distinguish them from dilatation of the urinary cavities

Parenchymatous candidiasis can sometimes be diagnosed (Fig. 9.4). Emphysematous pyelonephritis, a rare finding, shows gas bubbles within the parenchyma. Renal trauma is presented in Chap. 25.

In the case of grafted kidney, ultrasound plays a significant role in detecting surgical postoperative complications that can be caused by abscess, hematoma, lymphocele or urinoma. They can be explored with an ultrasound-guided tap. Dilatation of the calices suggests obstruction caused by edema or anastomotic stenosis of the ureter. Stenosis of the renal artery is an indication of Doppler. This rare complication, which can require the DIAFORA logistics, is not in the field of this textbook. Medical complications are traditionally not from the field of ultrasound, in spite of numerous signs of acute or chronic rejection, cyclosporine toxicity or tubulointerstitial nephritis. They are generally diagnosed by renal biopsy [2], yet some recent ultrasonic approaches may be interesting [3].

Renal cysts are frequent findings. In view of its frequency, we insert a characteristic example (Fig. 9.5), and a case of renal polycystic disease (Fig. 9.6). These cysts do not communicate with each other, and will therefore not be confused with renal pelvis dilatation. The renal cyst is one of the very infrequent diseases

induced by ultrasound: the first discovered cysts were nearly systematically surgically removed.

Dilatation of the Renal Pelvis

Facing daily troubles (drop in diuresis, etc.), the possibility of a urinary obstacle can be ruled out in a few seconds. Dilated calices and renal pelvis yield familiar patterns. The three calices and the pelvis, normally barely visible, are clearly depicted, anechoic, communicating with each other (Fig. 9.7). In acute obstacle, the dilatation is rather moderate, with the end of the calyces keeping their concavity. Large dilatation with bulge-ended calices comes rather from chronic obstructions (Fig. 9.8). The ureter (Fig. 9.9) is often hidden by the abdominal structures.

Dilatation of the renal pelvis is rarely but regularly encountered in our experience. Of 400 consecutive critically ill patients in the ICU, 2% had pelvis dilatation, a rate that would increase markedly if only sepsis or acute renal failure were considered. The pain is rarely present in these septic, encephalopathic patients; hence a routine ultrasound examination should be given to any critically ill patient. Causes encountered were pelvic hematoma, bladder distension that is sometimes due to urinary probe obstruction (Fig. 9.10), calculi, blood clot, or hydronephrosis (Fig. 9.8) with superimposed pyonephrosis (Fig. 9.11).

A dilatation without obstacle is seen exceptionally. It could be due to previous chronic infections or the ampullary pelvis, a variant of the norm for some that occurs in 8% of the population [4], the sign of occult obstruction for others [5]. We used to consider a unilateral and moderate dilatation in a septic patient as clinically relevant. A pattern looking like a dilatation, in a hasty examination, is the parapyelic cyst.

Detection of dependent echoic patterns within dilated cavities of hydronephrosis is characteristic of pyonephrosis [6].

Absence of dilatation in spite of an obstacle is rare (we have not yet seen this situation), explainable by decrease in compliance (retroperitoneal fibrosis, etc.), and usually deserving iodine explorations [7–9]. Major hypovolemia should be an associated factor.

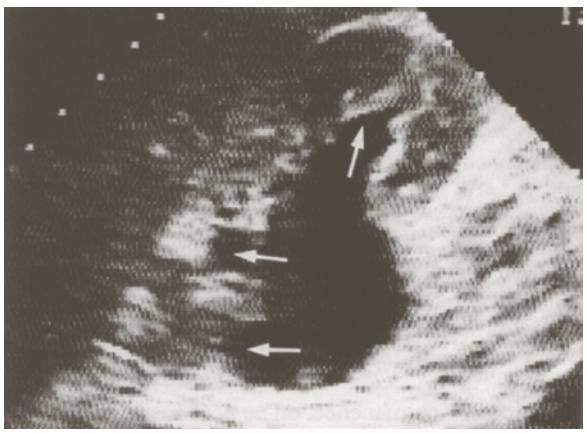

Fig. 9.7 Mild dilatation of the cavities. The pelvis is slightly more dilated. The end of the calyces is concave (*arrows*), usually a sign of acute obstruction. Longitudinal scan, making it possible to visualize the three calyx groups

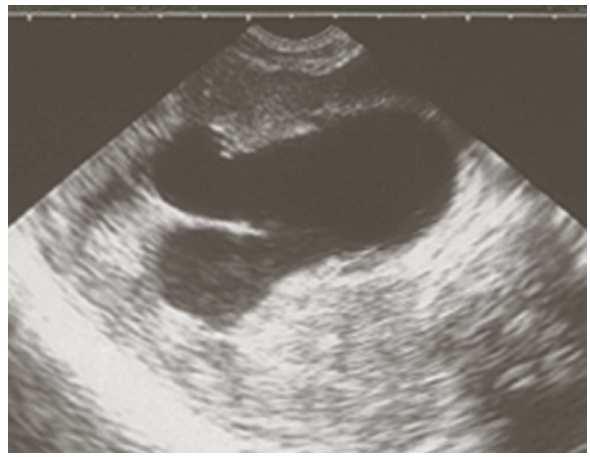

Fig. 9.8 Hydronephrosis. Major dilatation of the renal pelvis. Note the rounded end, which indicates chronic obstruction. This single scan does not show patent signs of acute infection (see Fig. 9.11). Septic shock, transverse scan of the right kidney

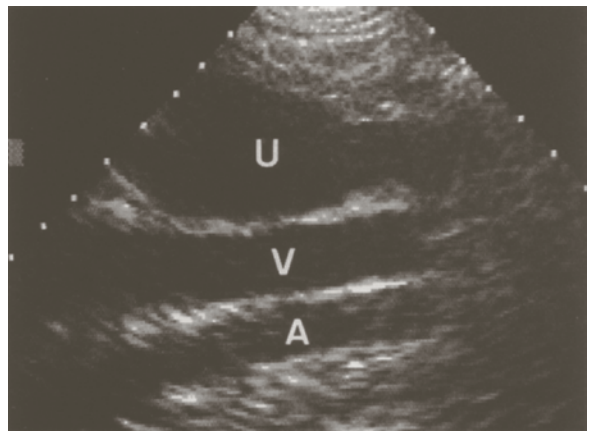

Fig. 9.9 Ureter. In this longitudinal scan of the right flank, one can observe a dilated ureter (*U*), inferior vena cava (*V*) and abdominal aorta (*A*). This is a privilegiated view. The ureter is usually masked by bowel gas

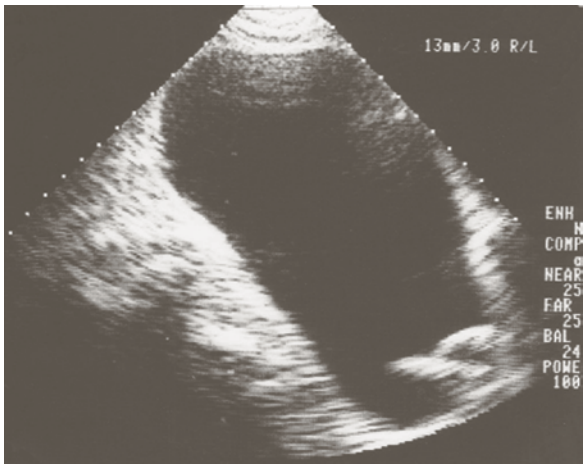

Fig. 9.10 Major bladder distension. Note that it occurred in spite of a urinary probe. The balloon and the end of the probe are visible at the bottom. The probe was obstructed. Longitudinal suprapubic scan

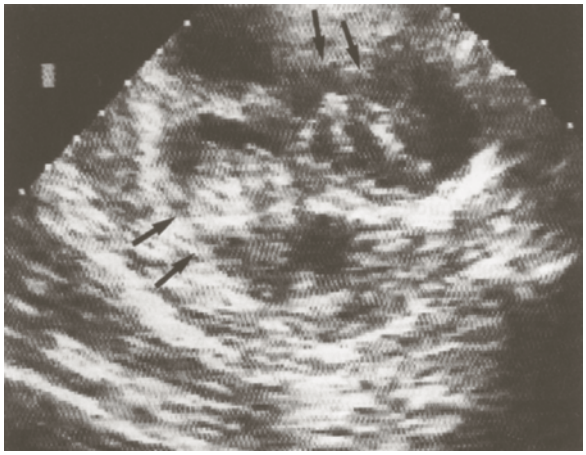

Fig. 9.11 Pyonephrosis. The ultrasound scan of this kidney with hydronephrosis shows heterogeneous echoic masses within the dilated cavities (*arrows*). These images had a undulating motion in real-time. The diagnosis of superimposed infection can now be assumed

Renal Vessels

We advise the reader to get accustomed to checking for the renal veins, especially the left, which is a substantial anatomic part of the abdomen. It crosses from the left (kidney) to the right (inferior vena cava), which cannot be missed in the absence of clouds (gas). We use it for having a reproducible area for measuring the inferior vena cava far from the heart. Other relevant uses are under study.

Bladder

The technique requires a "diving" approach, just above the pubis, made easier using a microconvex probe (Fig. 9.12). As a rule, a catheterized bladder is empty. The balloon of the probe can be detected, round structure lost in the pelvis, always medial (Fig. 9.12).

Distended bladder may be one of the most obvious diagnoses for the beginner in ultrasound (Fig. 9.10). The probe detects a fluid mass which is medial, round, near

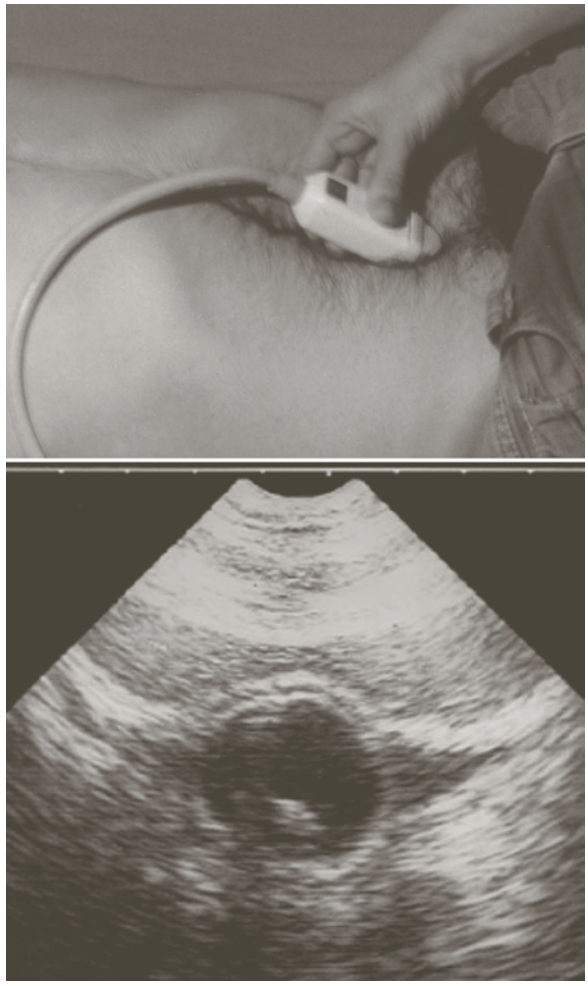

Fig. 9.12 Probed bladder. *Top:* For searching a bladder in the pelvis, we apply the probe nearly parallel to the abdominal wall, pointing to the posterior and inferior direction. Abdominal probes are too cumbersome for this subtle maneuver. This figure is used again for the subcostal heart analysis: just imagine the probe inclined in the same way. *Bottom:* In this suprapubic transversal scan, one can see a regular round and medial structure, the inflated balloon of the urinary probe. The bladder is here correctly drained, thus virtual

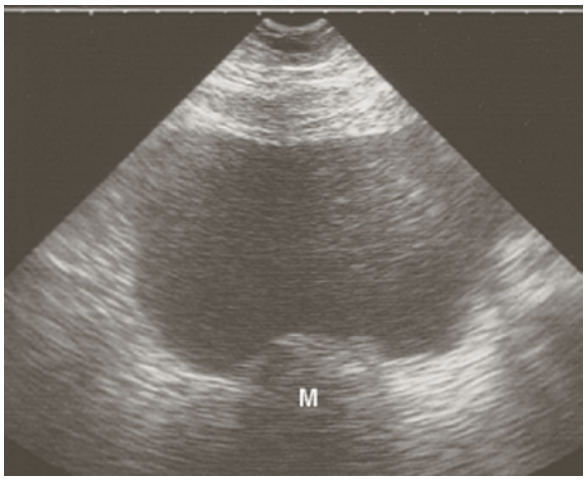

Fig. 9.13 In a suprapubic transversal scan, this medial fluid image with square section may mimic a moderately distended bladder, with a tissular image (*M*) mimicking a prostate. It is in fact a peritoneal effusion in the Douglas pouch. The image at *M* is probably a bowel loop. A dynamic scan upward and downward (large Carmen maneuver) will prevent the error: the bladder will be identified below, and this fluid image will have an opened shape above (with the bat wing sign)

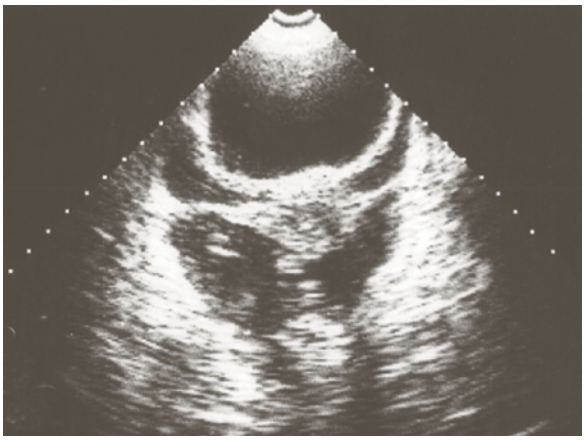

Fig. 9.14 Thai dragon sign. This complex transverse suprapubic scan may intrigue the operator. One can imagine the head of a Thai dragon. This full bladder is associated with peritoneal effusion in a young woman. The bladder is the round shape at the top of the screen. The eyes and the grinning mouth of the dragon reflect the peritoneal effusion. The nose is formed by the uterus and the large ligaments. The teeth are generated by structures floating in the effusion – a hemoperitoneum here

the anterior wall, roughly 10 cm or more in a transverse section. Ultrasound is useful, in particular, in obese patients, where the physical examination is difficult. The pitfalls are easily avoidable. The most frequent is the peritoneal effusion that mimics a distended bladder (Fig. 9.13). See comment on page 35 in Chap. 5.

In the female, the association of peritoneal effusion with a full bladder yields a complex but characteristic pattern, with the suggested name of the Thai dragon-head sign (Fig. 9.14).

A probed bladder that is not empty indicates an abnormal finding (Fig. 9.10). It should be repeatedly examined in order to check an increase of trapped volume. The situation can evolve into a urinary obstacle. Often, in the blind times of intensive care, the sedated patient develops such a complication, which is labeled "anuria," prompting hemodynamic explorations before the distension is clinically detectable. Facing any acute patient under hemodynamic therapy, our fast protocol devotes a few seconds to checking for the absence of bladder distension.

In an anuric patient, a daily ultrasound will detect recovery of diuresis. This rapid procedure prevents a prolonged and useless urinary probe.

The bladder content is informative. Pyuria and blood are responsible for echoic dependent patterns (Fig. 9.15). A calculus gives a dependent image with a frank posterior shadow. An enlarged prostate can be detected (Fig. 9.16).

Some want to know the volume of the urine. By assimilating the bladder to a sphere, taking only one of its dimensions (the easiest, i.e., the transversal distance in a transversal scan) and using the simple mathematic formula for a sphere volume would give a rough and satisfactory estimation. Roughly, by taking only this transversal distance, a 5-cm distance corresponds approximately to 100 mL, a 6-cm distance corresponds to 175 mL, a 7-cm distance corresponds to 250 mL, and an 8-cm distance corresponds to 425 mL.

Uterus, Adnexa, Fertility Organs

We like to take a routine look at the uterus (Figs. 9.17 and 5.5 page 34). An acute disorder in a pregnant woman raises problems [10]. Most current investigations require irradiating tests. If a pregnancy is detected (Fig. 9.18), the reader can refer to Chap. 29, where details about practical management are provided. For this emergency application, we do not need to await full repletion of the bladder. In some cases where the suprapubic approach is impossible (dressings), it is fully

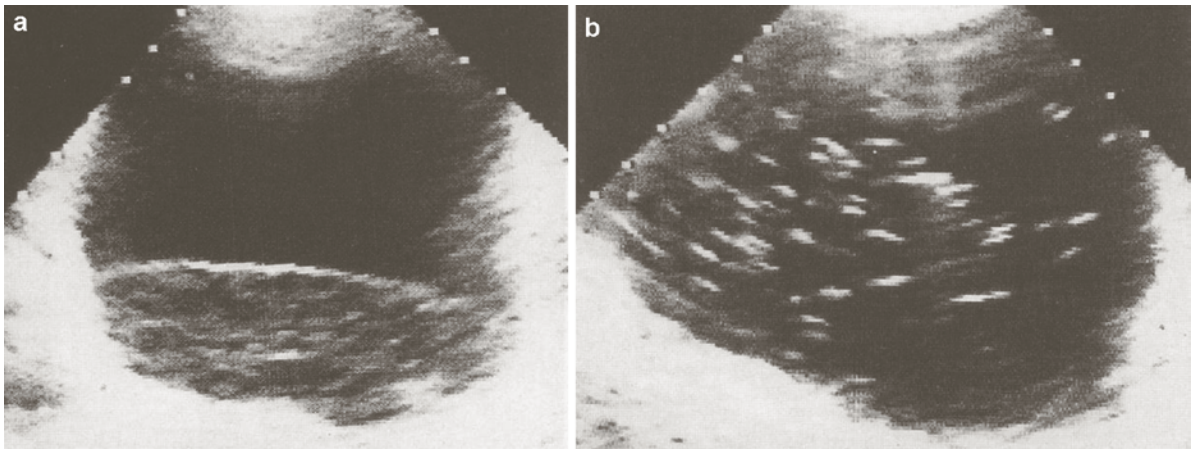

Fig. 9.15 Pyuria. (**a**) Two elements can be distinguished in this bladder, separated by an artifactual line: a dependent echoic sediment and a nondependent anechoic area. Pyuria. Transverse scan of the bladder. (**b**) Another pattern of pyuria. Multiple hyperechoic elements as in weightlessness, indicating microbial gas

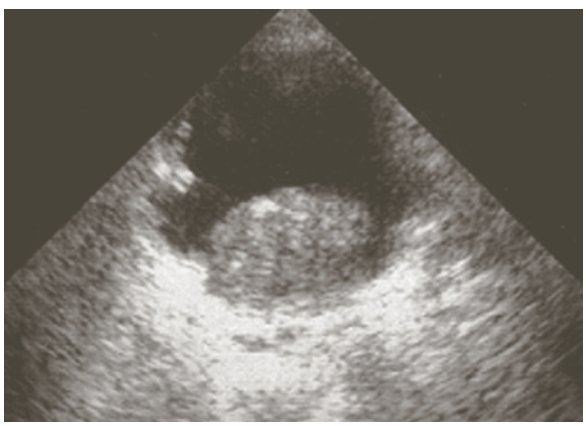

Fig. 9.16 Prostatic adenoma. Typical medial regular tissular mass protruding in the bladder lumen. This finding can be a cause of acute obstructive renal failure. Note the low image resolution, issuing from a cardiac probe

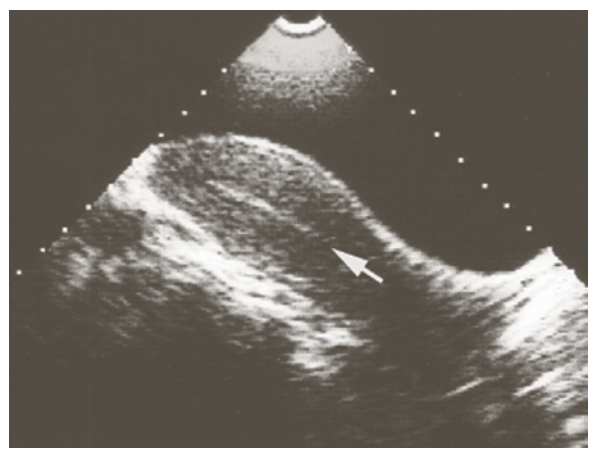

Fig. 9.17 Empty uterus. Long-axis scan, behind the bladder. The vacuity line (*arrow*: endometrial stripe) frankly outlined within the uterine muscle indicates absence of pregnancy

possible to use either a perineal approach, or, more invasive, an endovaginal approach using our microconvex probe covered by a simple glove. This is a typical example of nonacademic but relevant use of critical ultrasound for diagnosing pelvic fluid, for instance.

Ectopic pregnancy shows subtle direct images for the specialist, and a rough indirect image for the nonspecialist, the hemoperitoneum. The reader is not required to locate an interstitial or cervical pregnancy, but rather to make a fast examination of the peritoneum in order to early detect free blood. Any free fluid in this setting should prompt referral to surgery (if possible by obstetricians, in order to save the adnexa), not waiting the evolution of the bleeding. If the surgeon is reluctant or initiates speculative talks about the nature of the fluid (as regularly happened to us, when the potential of critical ultrasound was not yet routine in our surgeons' minds), a fast needle tap will confirm the bleeding and save a life. The pelvic blood can be echoic at the first examination (Fig. 9.19).

Emergency physicians will often face pregnant women with various acute concerns (molar pregnancy, uterine apoplexy, or others). These cases will not be detailed here, but are available elsewhere in the literature. Basically, a woman with positive pregnancy test has usually, at the early stage, a gestational sac instead of the endometrial stripe, containing eventually a fetal

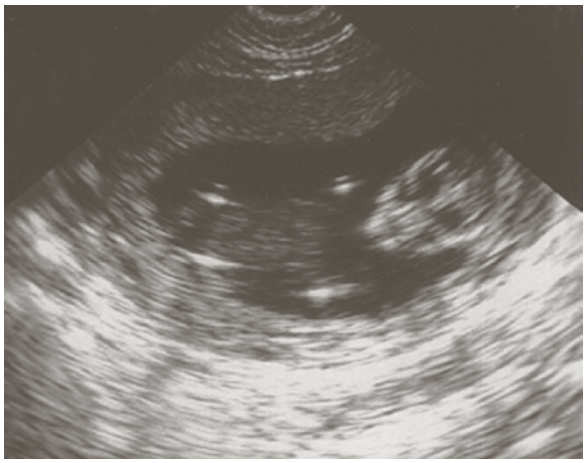

Fig. 9.18 Like a cat turned on its back, head at the right of the image, seemingly observing the viewer, an embryo is visible in the uterus. Here the physician is invited not to overindulge in ionizing radiation procedures, what ultrasound makes possible at the whole body

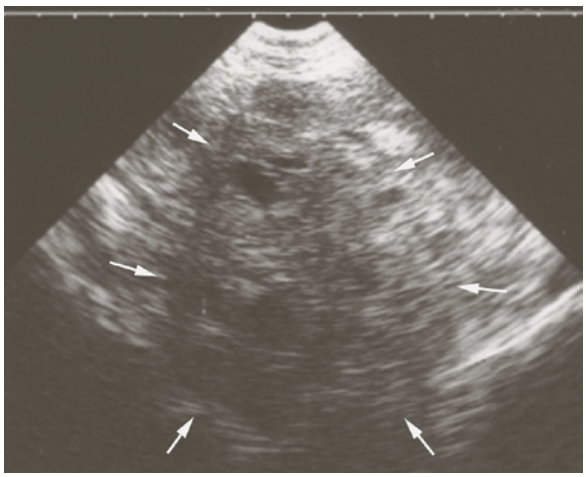

Fig. 9.19 Ectopic pregnancy. This transverse view of the Douglas pouch in a young shocked female immediately confirms the diagnosis, showing a motionless echoic mass (*arrows*) indicating a massive blood clot. Compare with an anechoic effusion in the same incidence, in Fig. 9.13. The Carmen maneuver was more demonstrative that this static image, taken in extreme emergency. The intensivist should not be asked the precise site of the pregnancy, since the recognition alone of a peritoneal effusion, even clotted, indicates immediate life-saving surgery

pole with heart beats, and a yolk sac (round, empty structure). Endometritis produces diffuse edema of the parenchyma [11]. Pyometritis gives a fluid endouterine image. Hyperechoic punctiform images (gas) are a strong argument if there is severe pelvic sepsis [11].

In the young male, the emergencies are not life-threatening, but fertility-threatening. This is discussed in Chap. 28.

Interventional Ultrasound

Percutaneous Nephrostomy

It is possible to treat a urinary obstruction and to drain infected urine at the bedside if ultrasound-guided. The kidney is punctured by the posterior or posterolateral approach (avoiding the colon and the pleura). A needle is inserted in the dilated cavities. Urine is collected for analysis. A guide is then introduced through the needle. A drainage catheter is inserted, sometimes after some dilatations. It is possible, as we did, to use this technique for immediately relieving highly unstable patients with severe septic shock and difficulties of transfer to an operating room. The traditional management can be done later (removing the calculus in the interventional radiology department) in a stabilized patient.

Percutaneous nephrostomy has a mortality rate (0.2%) that is reportedly lower than that of surgery [4]. Complications include hemorrhage or infection and should be balanced with the advantages.

Suprapubic Catheterization

Ultrasound guidance provides visual monitoring. A penetration site more cranial than classically done should theoretically limit the risk of sepsis of the prevesical space. Digestive interpositions can then be checked using ultrasound. Using ultrasound, the operator does not need to wait for massive repletion of the bladder.

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Various Targets in the Abdomen (Spleen, Adrenals, Pancreas, Lymph Nodes)

10

Some disparate abdominal organs are collected in this chapter.

Our 5-MHz microconvex probe is sufficient for this investigation in the critically ill.

Spleen

Spleen analysis is rarely of interest in the critically ill. Splenic rupture yields hemoperitoneum, which is much more relevant to detect than splenic laceration. Splenic abscess can be clinically occult. It typically shows a hypoechoic mass within the parenchyma (Fig.10.1). In rare cases, the abscess can be isoechoic to the spleen, and only a thin edema border, usually hypoechoic, allows the diagnosis (Fig. 10.2). In other cases, the spleen appears enlarged without a distinctive feature (Fig. 10.3). Hemorrhagic splenic suppuration accompanying stercoral peritonitis can yield a hypoechoic enlarged spleen with fluid-like areas and hyperechoic points caused by microbial gas (Fig. 10.4). The spleen can be discretely heterogeneous, not to say normal, in genuine fulminant tuberculous miliaries (Fig. 10.5).

Some (rare) academicians still think that the diagnosis of splenomegaly is clinical. This is a fair thought, but we should give a chance to challenging patients (obese, etc.). A normal spleen can be partly hidden by air (lung and bowel), but an enlarged spleen is easily diagnosed. The homogeneous or heterogeneous pattern of the parenchyma can be appraised (Fig. 10.6). Splenomegaly creates an acoustic window making the analysis of many organs accessible: diaphragm, adrenals, kidney, stomach, and aorta.

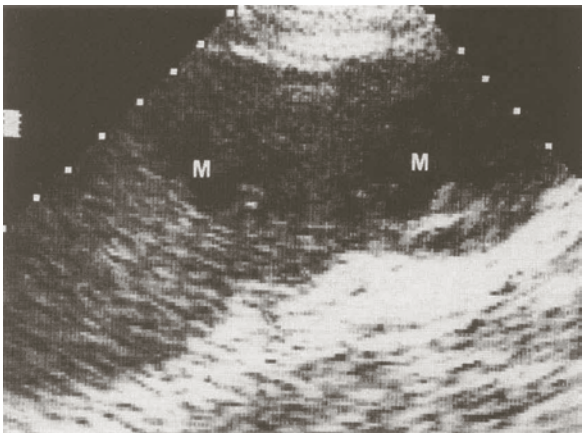

Fig. 10.1 Splenic abscess. Hypoechoic images (*M*) within an enlarged spleen. The ultrasound-guided tap revealed pus with *Staphylococcus* in this 48-year-old male with endocarditis

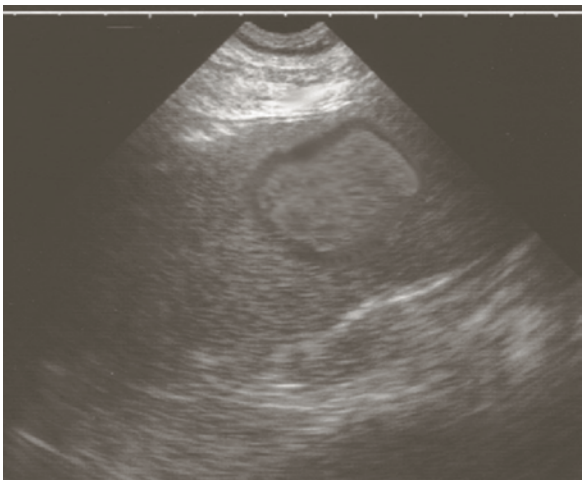

Fig. 10.2 Splenic abscess. This one is isoechoic to the spleen, with just a fine peripheral stripe. Septic shock in a 68-year-old female who had had cold abdominal surgery 1 month before, and without focal clinical signs at the time of the examination

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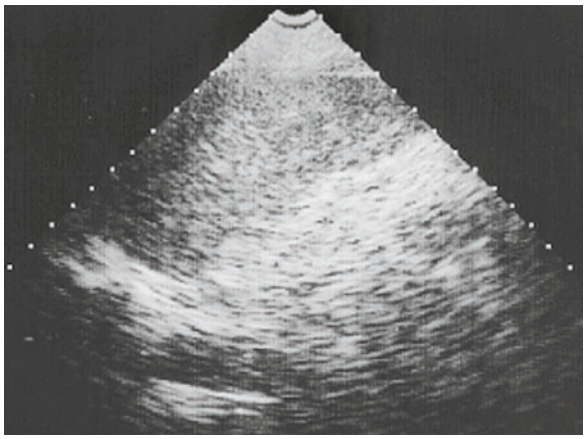

Fig. 10.3 Splenic abscess. This spleen was considered homogeneous using ultrasound, whereas CT revealed an abscess. In these cases, especially in plethoric, poorly echoic patients, the low echogenicity of the image should be recognized and considered as a limitation, in order to request other imaging modalities

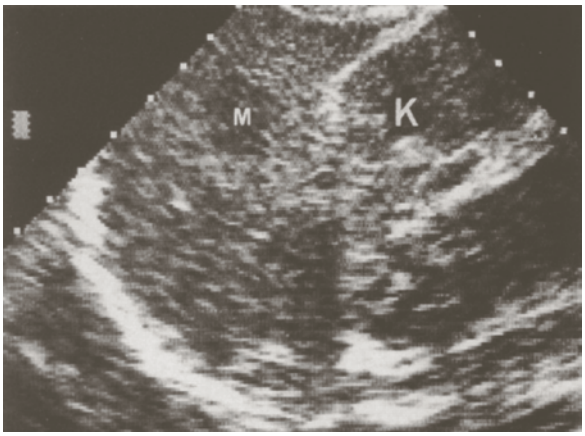

Fig. 10.5 Miliary. This spleen has normal dimensions and quasi-normal echostructure, except for some mildly hypoechoic areas (*M*). An experienced eye – or here a retrospective lecture – was able to see a mildly granulose pattern of the parenchyma. Autopsy of this young man with septic shock revealed diffuse tuberculous miliary, including the spleen. Longitudinal scan. *K* left kidney

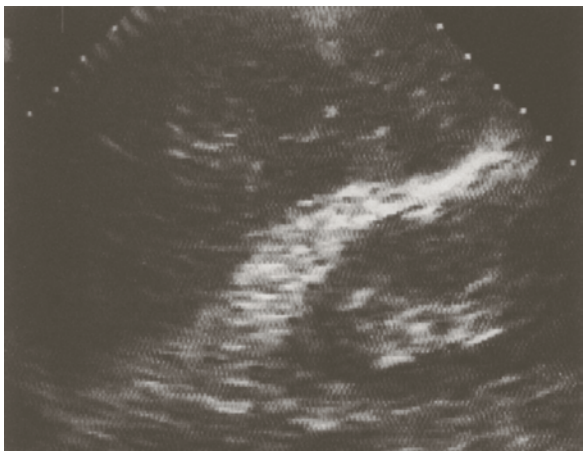

Fig. 10.4 Hypoechoic and heterogeneous splenomegaly in a septic patient. Surgery revealed stercoral peritonitis with hemorrhagic suppuration of the spleen

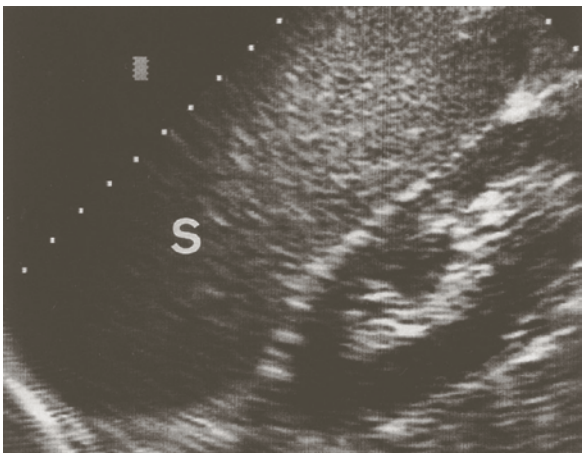

Fig. 10.6 Splenomegaly. This homogeneous 16-cm long spleen (*S*) covers the kidney. Longitudinal scan of the left hypochondrium

Perisplenic effusion (see Fig. 5.3), a traumatic rupture of the spleen (irregular intraparenchymatous image, with capsular hematoma), and a splenic infarction (regular pyramidal hypoechoic image) can be diagnosed (Fig. 10.7). More relevant in daily practice is the possibility of locating the spleen before any left thoracentesis (see Fig. 15.6 page 134).

Splenic artery rupture, although rare, is really a diagnosis for beginners. It basically yields a peritoneal effusion, prompting immediate laparotomy in a shocked patient with abdominal pain.

Interventional ultrasound at the spleen can be envisaged. Percutaneous drainage of splenic abscesses is an alternative to surgery [1–3]. The mortality of a splenic abscess without invasive therapy is 100%. After surgery, the mortality is 7.8% [4]. After percutaneous procedures, in spite of hemorrhageous or infectious complications, the mortality is only 2.4% [3]. Some authors propose a simple therapeutic aspiration with an 18-gauge needle as a first line of treatment. Antibiotics can possibly be injected in situ [3]. With a 21-gauge needle, we could diagnose

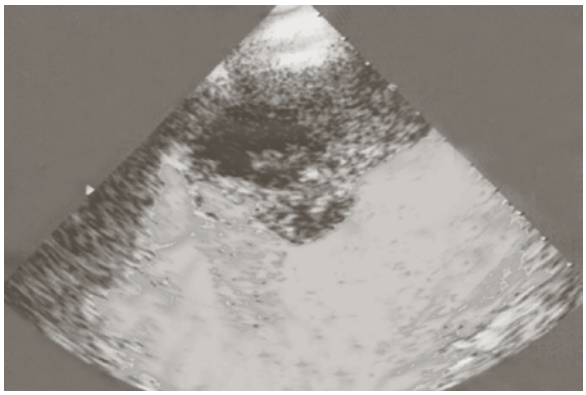

Fig. 10.7 Splenic infarction. Roughly pyramidal hypoechoic image with peripheral base. Image quality also typical from a cardiac machine with phased-array probe

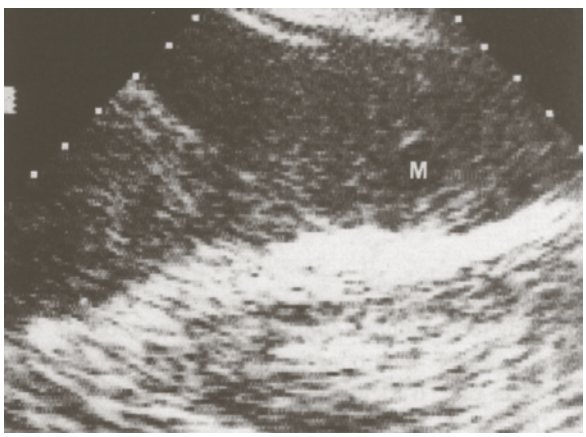

Fig. 10.8 Sequel of Fig. 10.1 after evacuation of the abscess. The target is significantly reduced

Staphylococcus abscess (Fig. 10.1) and subsequently aspirate it (Fig. 10.8) without hemorrhagic or infectious complications.

Adrenals

Imaging the adrenals in emergency situations may appear of limited value, yet it is a potential target. Some intensivists believe that corticosteroid therapy can be useful in selected cases of septic shock, whilst others do not. For the former, we propose a simple approach that requires some skill: bedside visual analysis of the adrenals. The reward will be, if carefully validated, the possibility of detecting anomalies that are able to prompt corticosteroid therapy in adequate setting. The adrenal, surrounded by fat covering the kidney, is usually not visible, but the adrenal space is clearly delimited (see Fig. 4.8 page 30 or Fig. 5.3 page 34). A nice routine would be to systematically look at the adrenal area when looking at the kidneys in whole-body examinations. Ultrasound signs of the acute adrenal failure have been described insufficiently in the literature. In the case of bilateral hemorrhagic necrosis, an echoic mass has been described [5, 6].

In a patient admitted for severe hypertensive crisis, the search for an adrenal mass will make an argument for an endocrine origin. Pheochromocytoma can yield a voluminous mass.

Pancreas

Not too much energy should be devoted to this organ by the intensivist who has not full mastery of priority targets (lungs, veins, basic heart, etc.). Experts in imaging should be liberally called in this setting. For those who cannot benefit from these experts 24/24, here are basic notions. The 17-cm range of our probe is sufficient for analyzing this retroperitoneal organ. Precisely localized using the vascular landmarks (see Fig. 4.3 page 28), it can be hard to detect when there is meteorism [7]. In favorable cases, gas collections can be mobilized, the stomach can be filled with fluid in order to create an acoustic window. The gland appears, and the main pancreatic duct and the bile ducts can be observed (Fig. 10.9).

Acute pancreatitis is a familiar field for radiologists [8]. The organ has usually increased size, with a hypoechoic heterogeneous pattern. Necrotic roads can be observed in the peripancreatic space (Fig. 10.10) or at a distance. Rarely, the pattern seems normal [9]. CT is usually indicated in first-line investigations for the positive diagnosis of acute pancreatitis (the Balthazar score currently enriching Ranson or Glasgow scores). Ultrasound is interesting for monitoring after an initial CT. Iterative ultrasound scans detect the appearance of fluid within the pancreas, surrounding it, or from a distance. A collection can be simple necrosis or infectious abscess (Fig. 10.11). Ultrasound can answer the question by tapping the collection, provided there is no

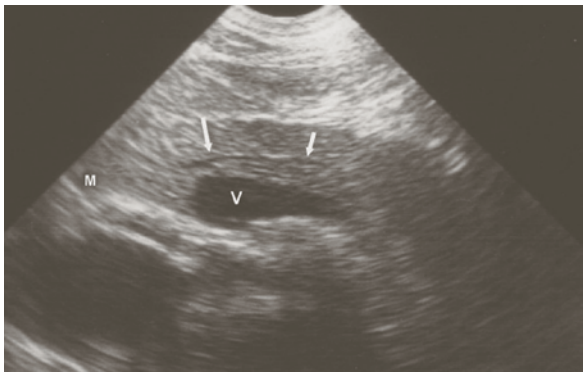

Fig. 10.9 Normal pancreas. In this transverse epigastric scan, the parenchyma is perfectly identified, homogeneous, with a well-defined main pancreatic duct (*arrows*), end of the common bile duct (*M*) and confluence of the portal and mesenteric superior veins (*V*)

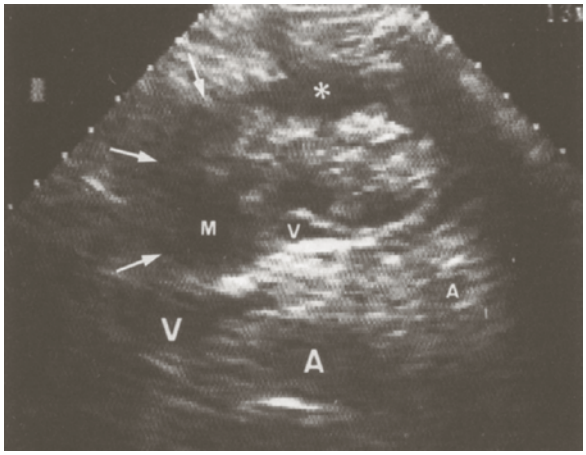

Fig. 10.10 Hemorrhagic necrotizing acute pancreatitis. The head and body of the pancreas are enlarged (*arrows*) and heterogeneous. Hypoechoic collections can be distinguished within the head (*M*), and anterior to the body in the pancreatic space (*asterisk*). *A* aorta, *small A* superior mesenteric artery, *V* inferior vena cava, *v* splenic vein. Transverse scan

bowel or vascular interposition, and provided a false aneurism is ruled out (see Chap. 25 page 255). An evacuation procedure requires large, invasive material since the collection can contain large debris. Some authors recommend surgery for central collections, and percutaneous procedures for peripheral ones [10]. Venous thrombosis (splenic or superior mesenteric veins) is accessible (see Fig. 6.17 page 50). False aneurysms (mainly at the superior mesenteric artery) can be detected. The detection of strategically located gallstones is probably the field of CT.

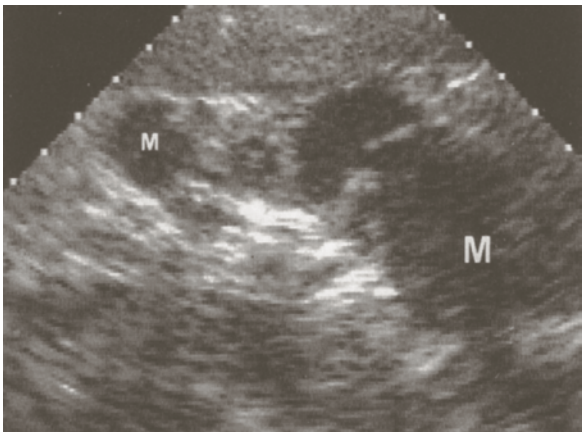

Fig. 10.11 Hemorrhagic necrotizing acute pancreatitis, transverse scan. The pancreas was identified only using the vascular landmarks (not featuring at this level). Numerous hypoechoic collections along the head (*m*) and the body (*M*)

A pancreatic pseudocyst produces a well-defined, anechoic image with a thin, regular wall. Echoes within this image suggest superinfection.

One word about CT – not always a magic wand. We heard of an interesting story of abdominal pain in a 45-year-old man without history, where CT, immediately performed, classified the patient in grade E pancreatitis. Everything was clear, from the hemoglobin – which was low (normal for a haemorrhagic pancreatitis), the enzymes – which were not elevated (precisely indicating some extremely severe cases), the patient's state – which worsened hour after hour in the ICU: there was an academic explanation for each of these points. The only test which was lacking in the file was an ultrasound, which was not performed in the ER. This man was eventually saved thanks to a laparotomy, decided in the face of extreme hemodynamic instability (fortunately in open hours), and the finding of a ruptured splenic arteric aneurism. A basic sonointensivist would have performed routine ultrasound 1 min after physical examination, would have found fluid in the abdomen (which was shown also by CT, but CT had labeled the patient as having pancreatitis, making doctors afraid of inserting a needle – the infernal machine closed with subtlety on this patient) would not have feared to puncture it, and would have found blood, prompting for immediate surgical management. This is not a rare story, because it has one common point with countless others: they can all have a rendezvous with a critical care physician. In our institution,

we see two or three times a month one of these rarities, which are, using critical ultrasound, immediately defused (see the endnote of Chap. 29 page 279).

Enlarged Lymph Nodes

The diagnosis raises no difficulty: round or egg-shaped, tissular mass, located along vascular axes (see Fig. 12.3 page 90). They can sometimes create acute obstructions (respiratory tract, bile tract). Usually, such findings are not of interest in the critically ill, but should be kept in mind for the post-intensive period. Among the multitude of uses of general ultrasound in the non-critical subject, early detection of pathologic lymph nodes is a promising field.

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Aorta

11

Aortic aneurism is a time bomb that has consigned countless victims to the corridors of ERs over the years, and to CT rooms in recent times. Defusing this bomb has been possible from around 1982, in the routine examination of any thoracoabdominal pain, since excellent 40-cm wide machines with wheels became available at this time. A few seconds were usually sufficient, beginning by the abdominal aorta.

Our 5-MHz microconvex probe with its 17 cm of maximal range gives the best conditions for studying the thoracic and abdominal aorta, as well as the retroperitoneum in most patients in our institutions.

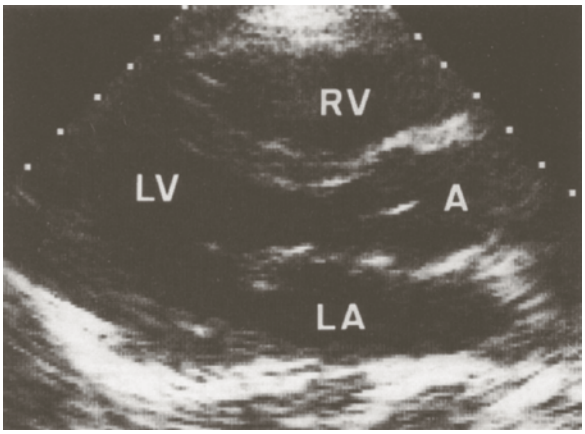

Fig. 11.1 Initial aorta. Cardiac parasternal long-axis scan. The aorta (*A)* is seen between the left auricle (*LA*) and right ventricle (*RV*). *LV* left ventricle. This scan follows the conventions in cardiac imaging for once (head of the patient at the right of the image)

Thoracic Aorta

The perfect ergonomy and resolution of our microconvex probe for supraclavicular or suprasternal approaches may make one reconsider the usual approaches (TEE, CT, RMI) for immediate assessment of the thoracic aorta. Clearly, we do not have 100% success, mostly depending on the patient's morphotype, but all favorable morphotypes can benefit from precious minutes using early diagnosis.

The thoracic aorta can, to a various extent, be visualized by surface ultrasound.

1. The initial aorta is usually visible via the left parasternal route (Fig. 11.1).
2. The ascending aorta is sometimes visible by the supraclavicular route (Fig. 11.2).
3. The aortic arch and the three supra-aortic trunks are sometimes well visible via the suprasternal route (Fig. 11.3). Any pathologic enlargement increases the acoustic window and increases the success rate of our approach.

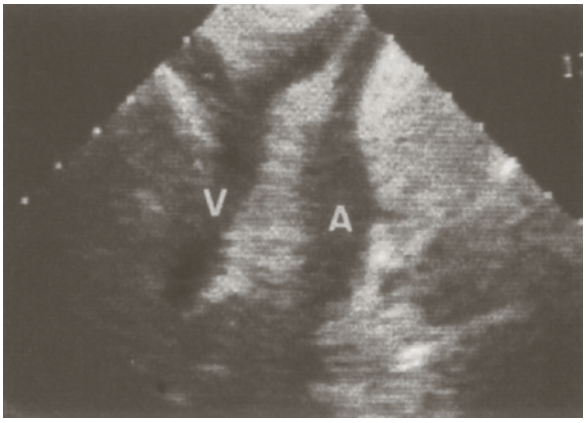

Fig. 11.2 Ascending aorta (*A*), inside the superior vena cava (*V*). Right supraclavicular approach. The origin of the brachiocephalic artery can be seen

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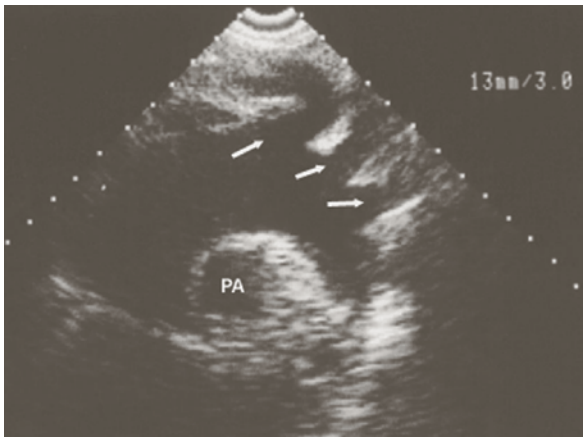

Fig. 11.3 Aortic arch. Exposure in a young woman with a favorable morphotype, suprasternal approach, microconvex probe. The origin of the supra-aortic trunks (*arrows*) and a transverse section of the right pulmonary artery (*PA*) are exposed in detail

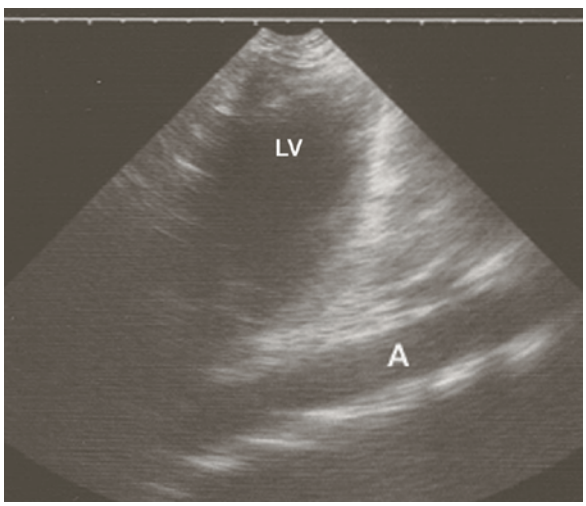

Fig. 11.4 The descending thoracic aorta. It is exposed over 12 cm in this scan, which exploits the cardiac window (apical scan of the heart). *LV* left ventricle

4. The isthmus is usually not well accessible – this is a limitation in the traumatized patient, since this segment is of strategic importance.
5. The descending thoracic aorta is visible over several centimeters, behind the heart, via the cardiac apical route (Fig. 11.4). A posterior approach is usually futile because of the lung interposition. In pathologic conditions, however, a left pleural effusion (a hemothorax in the case of aneurysm leakage) provides a correct posterior acoustic window (see Fig.15.10 page 135).

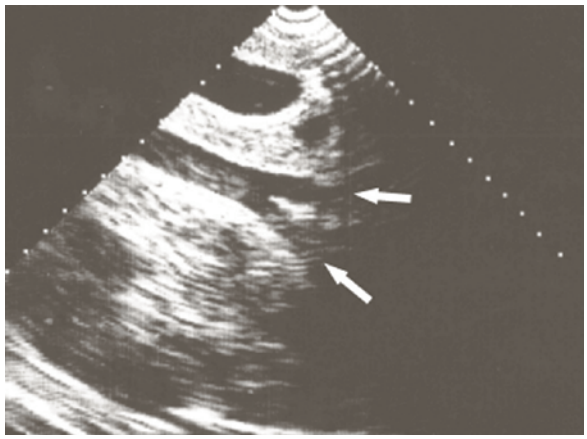

Fig. 11.5 Terminal aorta, longitudinal section. *Arrows* origin of the iliac arteries. This type of image can replace invasive modalities such as CT or angiography in emergency situations. The bright linear echo within the aortic lumen is typical of a ghost artifact: straight and motionless, like a ghost in real time – see the bright surroundings

The abdominal aorta is then followed via the abdominal route up to its bifurcation (Fig. 11.5).

Thoracic Aortic Dissection

This disease can give misleading presentations, meaning that any physician will from time to time (by mistake so to speak) face this kind of patient. A routine ultrasound examination of any thoracic pain can immediately rectify the diagnosis.

The diagnosis of thoracic aortic dissection can be fully accessible to a simple approach, with the restrictions written above. We observe the following signs:

- The aortic lumen is enlarged (Fig. 11.6).
- The intimal flap is recognized using these signs:
  - This is an echoic structure within an anechoic lumen.
  - This structure is never perfectly straight or regular, as would be a tangential artifact (these artifacts are usually located in a geometric axis, i.e., horizontal or vertical). It has anatomic shapes.
  - Its dynamic is relative with respect to the vessel dynamic. This relativity can be printed on M-mode in the favorable cases, but can also be just visualized.
- A hemopericardium is often present (Fig. 11.7).

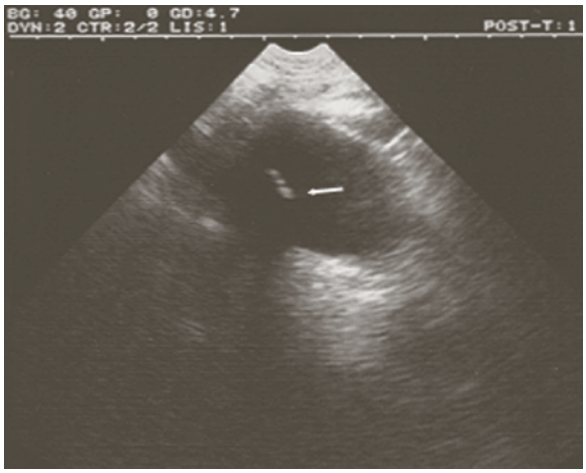

Fig. 11.6 Dissection of the thoracic aorta. Intense chest pain in a 77-year-old female. A suprasternal scan demonstrating an enlarged aortic lumen (45 mm) with an internal image that is irregular, nonartifactual (neither horizontal nor vertical nor parallel to strongly echoic external structures), and mobile, indicating intimal flap (*arrow*). Such images are highly more characteristic in real time than in this single view (see Fig. 11.16)

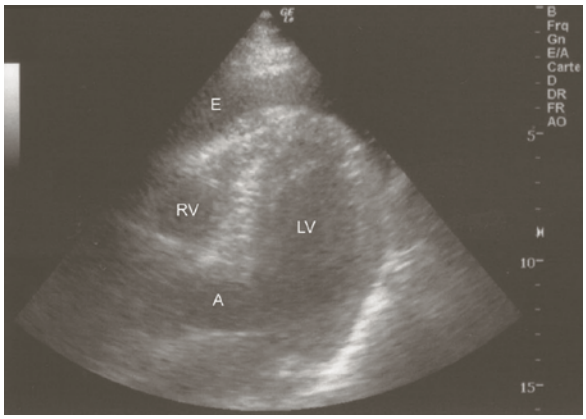

Fig. 11.7 Hemopericardium. Usual appearance in patients with aortic dissection. Note the echoic pattern (this is blood). The small size of the right ventricle should prompt immediate management. This image is one among two already featuring in this book, but such easy-to-diagnose and easy-to-manage life-threatening conditions symbolize the whole meaning of critical ultrasound. *E* pericardial effusion

When these signs are present, the diagnosis can be obvious to the point that it becomes risky to refer such patients to confirmation tests like CT.

Figure 11.5 provides an example of a ghost artifact that may mimic an intimal flap for the very inexperienced user.

Thoracic Aortic Aneurism

A thoracic aortic aneurysm yields a large mediastinal mass accessible to a microconvex probe. The walls of the aorta generally have a sacciform pattern. The content can show massive thrombosis and then appear as a tissular mass (Fig. 11.8). However, this mass will contain a central lumen, with a stratified periphery. Often, the most central layers of the thrombosis are still mobile, and one can see them driven back to the periphery a few millimeters in each systole.

The supra-aortic vessels can be followed to various lengths, but this has rare applications, at least in medical ICU use (see Chap. 25).

Abdominal Aortic Aneurism

Aortic analysis is routine in any abdominal pain. Studying the aorta diameter should not yield particular difficulties in thin patients without gas. As for the others (who are often the ones who actually have the disease), subtle maneuvers are usually efficient. The anterior barriers (fat, gas) can be drawn away by pressure – here, the pressure should be done gently, in order to avoid any uncontrolled consequences (pain, deleterious hyperpressure). We use one hand to hold the microconvex probe and our other hand to spread the pressure. See Fig. 11.9 page 86 for how to gently hide gas. If the fat/gas barrier is too substantial, we do not persist and

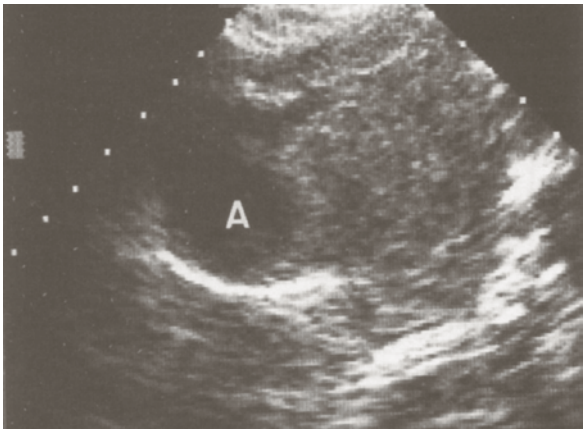

Fig. 11.8 Thoracic aorta aneurysm. A suprasternal scan of a patient with thoracic pain and shock. Note the substantial thrombosis, with regular layers. *A* circulating lumen of the aorta

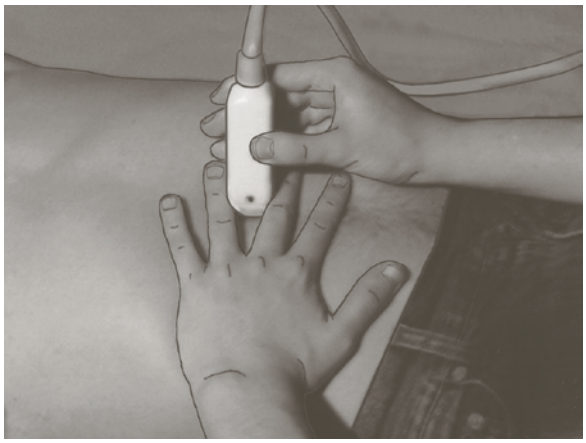

Fig. 11.9 The free hand is spread over the abdomen and the microconvex probe is inserted as shown. The free hand gently controls the pressure, and even makes the clinical work of palpation

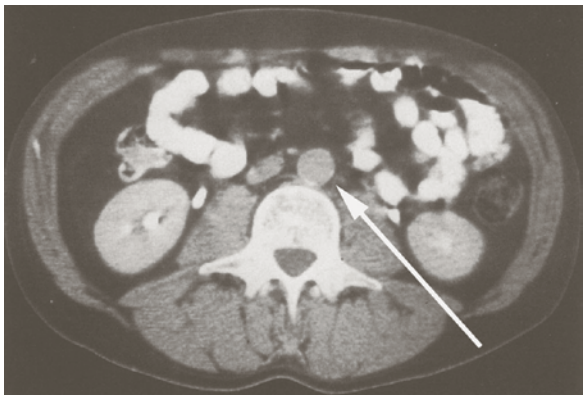

Fig. 11.10 CT scan of the abdomen, showing that in case of anterior gas interposition, a translumbar approach is available for analyzing the abdominal aorta (*arrow*), using a short probe

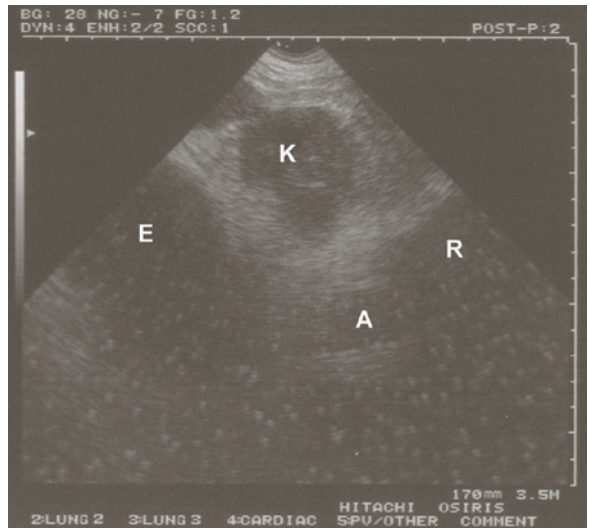

Fig. 11.11 Translumbar approach to the aorta. The probe is placed like the *arrow* in Fig. 11.10 (in fact through the kidney, *K*). Fine movements allow the aorta (*A*) to be exposed, against the rachis (*R*). Note in the bottom of this figure, multiple snow artifacts, called K-lines, due to sectorial interference

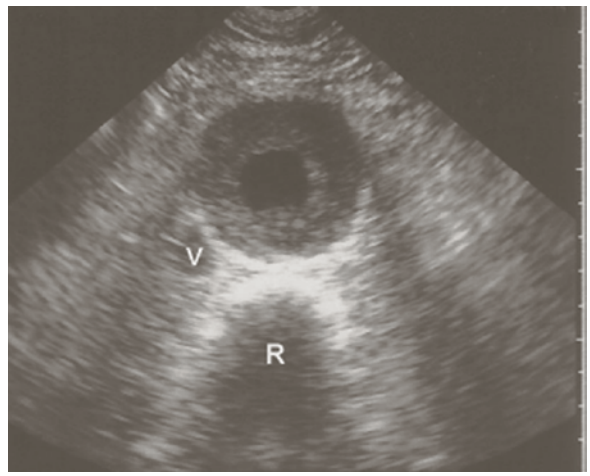

Fig. 11.12 Aortic aneurism. Transverse scan of the epigastric area. The aorta is recognized by its location anterior to the rachis (*R*), at the left of the inferior vena cava (*V*). A substantial enlargement of the caliper (5 cm) is immediately noted. A large, regular thrombosis within the aneurysm yields a quasi-normal caliper of the lumen (a standard aortography would underestimate this aneurysm)

shift to a translumbar approach (Figs. 11.10 and 11.11).

We know that the longitudinal approach is advocated by some. Scanning the abdominal aorta via a transversal approach allows immediate location. The Carmen maneuver makes everything more evident and provides equivalent information to longitudinal scans. The diagnosis is usually basic, showing an enlarged aorta (Fig. 11.12), loss of parallelism of the aortic wall, with a fusiform or, less often, sacciform shape (Fig. 11.13).

The basic signs of abdominal aortic aneurysm are a loss of parallelism of the aorta walls with a fusiform or, less often, sacciform shape (Fig. 11.13). When local conditions are favorable, ultrasound provides, like CT, a global overview of the lumen, thrombosis, wall thickness (increased in the case of inflammation) and main collateral vessels. The diagnosis of aneurism is usually done for a caliper >3 cm. In the case of leakage, a collection is found in the left retroperitoneal space (Fig. 11.14). Serendipitous cases show a precise area of whirling, in rhythm with heart frequency, within the hematic effusion.

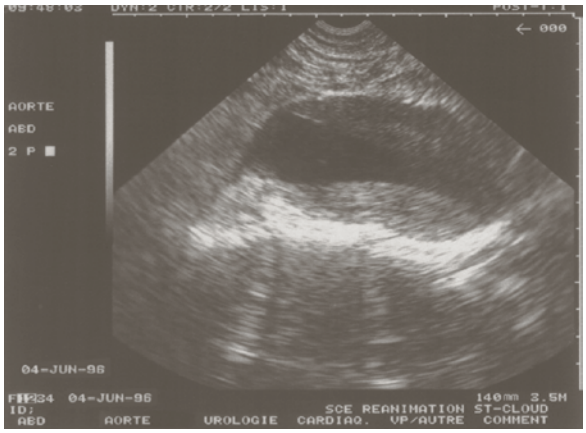

Fig. 11.13 Aortic aneurism. This scan specifies the 10-cm extension of the aneurism of Fig. 11.12

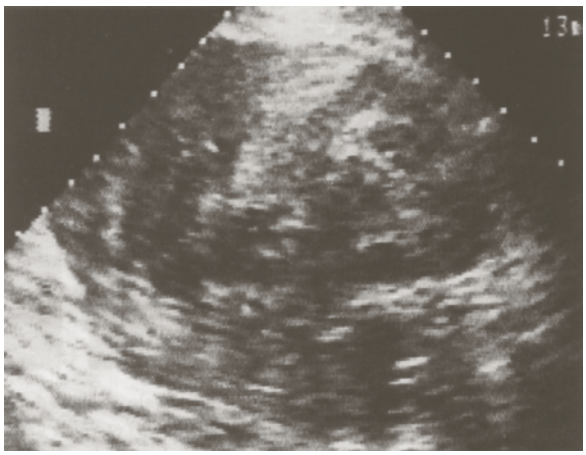

Fig. 11.14 Retroperitoneal hematoma. Patient in shock with abdominal pain. Huge, roughly rounded mass with anterior contact (transversal scan, left flank approach). The echoic heterogeneous pattern indicates early clotting

This dynamic pattern obviously indicated the location of the leakage and indicated extremely urgent surgery.

Fortuitous discovery of incipient aneurysm can occur in the medical ICU and should prompt further investigations. An atherosclerotic aorta with irregular borders simply indicates that the patient may have diffuse potential arterial damage.

Abdominal Aortic Dissection

A dissection of the abdominal aorta (or extended to it) yields enlarged lumen with an intimal flap separating

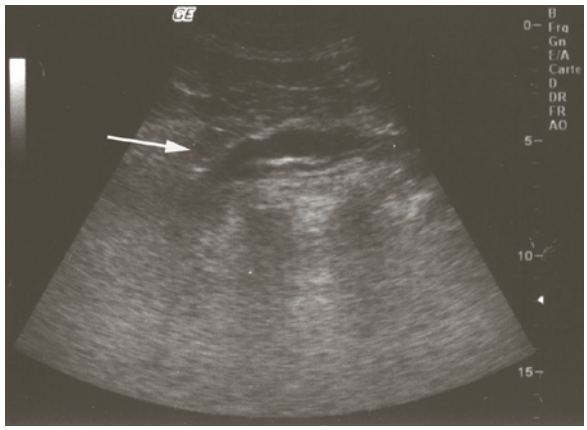

Fig. 11.15 Aortic dissection. Epigastric longitudinal view of a patient in shock with thoracoabdominal pain. Within the abdominal aorta (*arrow*), a long intimal flap is clearly visible, with characteristic static signs (sinuous shape). See Fig. 11.16 for the dynamic description

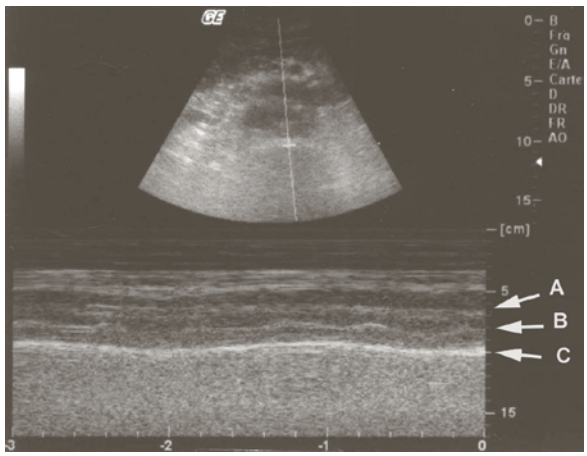

Fig. 11.16 Aortic dissection, sequel of Fig. 11.15. M-mode on a transversal scan of the abdominal aorta. *A* and *C* are the proximal and distal walls of the aorta, *B* is the intimal flap. The relative dynamic of *B* when compared with the walls, *A* and *C*, is characteristic, as demonstrated on this frozen image

two channels. The flap is easy to identify, with these major criteria.

1. It appears echoic within an anechoic surrounding (Fig. 11.15).
2. This image is anatomic, not strictly straight, as some artifacts appear (see Fig. 13.7 page 103).
3. The visualization of an intrinsic dynamic at the flap level is characteristic (Fig. 11.16).

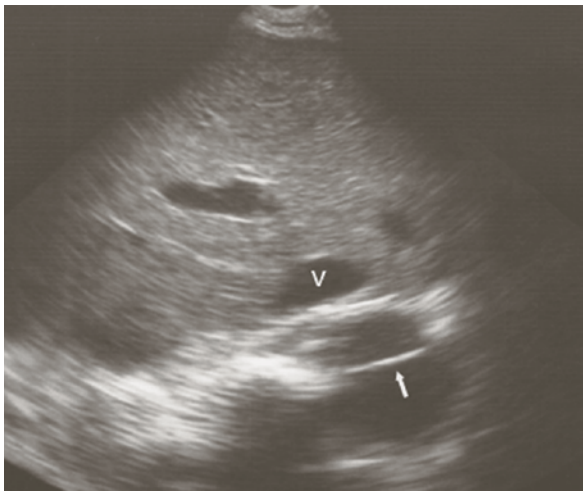

Fig. 11.17 Aortic dissection. Within the aorta, the intimal flap is clearly visible (*arrow*) in this transversal scan. In real-time, this flap has an intrinsic movement (unlike any artifact)

Such patterns must prompt for a search for thoracic aortic dissection.

When the aorta can be followed to its bifurcation, the progressive disappearance of one channel can be noted (Fig. 11.17).

Retroperitoneal Hematoma and Other Disorders

The mass is usually voluminous, heterogeneous, often with a dependent zone that is rather echoic and that corresponds to blood clots, and a nondependent area that is rather poorly echoic, and that corresponds to the serum. This area can be rich in septations due to fibrin deposits (Fig. 11.14). It is possible to follow this hematoma up to the insertion of the psoas muscle. Peritoneal blood effusion can be associated with contiguity and should not be misleading.

A posterior translumbar approach is logical, but an extensive hematoma generally comes in contact with the anterior abdominal wall (clinically detectable). The differential diagnosis with a parietal hematoma, whose treatment is different, will be resolved by studying the linking angles.

When a superinfection is suspected, a diagnostic ultrasound-guided tap is possible.

Retropneumoperitoneum should theoretically yield a characteristic image, since air stops the ultrasound beam.

Principles of Examination of the Deep Veins in the Critically Ill

12

First Application: Ultrasound-Assisted Central Venous Access

Vascular probes are not fully suitable for vascular assessment in the critically ill.

We now leave the abdomen for a critical target in the critically ill approach: the venous network. The main applications in the critically ill are:

Help in venous catheterization, including ultrasound-guided canulation (the present chapter).

Diagnosing venous thrombosis (Chap. 13).

Hemodynamic assessment in the critically ill (Chap. 23).

We open the venous study with this small chapter on venous access to give more homogeneity in the next chapters (from 13 to 21), in direct connection with the BLUE protocol. In this chapter, the user will see how to assess the venous patency, in order not to make a futile procedure. In the critically ill, we have developed 10 technical features that oppose our approach to traditional venous ultrasound. Chapter 13, devoted to the BLUE protocol, develops them in detail, but the first seven must be known at this point.

1. We use one single probe for the whole body – it gives appropriate information.
2. We do not use traditional vascular probes: they limit the user to investigation of only linear areas and only superficial veins. They lack suppleness.
3. We analyze all sites, not just the cervical or groin area.
4. For initial vessel detection, we use cross-sectional scans and avoid axial scans (see Fig. 1.4 page 6).
5. We do not use Doppler.
6. We do not use compression systematically.
7. When we use a compression maneuver, it is moderate.
8. We use the escape sign, which is not to our knowledge in the textbooks.
9. Only the anterior approach in a supine patient can be routinely used.
10. We do not use gel: our alternative contact product allows a major gain of time for whole venous system assessment.

Although it is of little use to experts who have mastered blind central venous access, this chapter will be very helpful to those who want to provide the maximal safety and comfort to their critically ill patients, approaching the zero fault level. In addition, these methods will save time and costs. We will show how we search for a vein in the aim of catheterizing it, focusing on the subclavian access. Then we will show the long-axis shooting method, which we have used since 1989 and was defined in 1992 as a standardized approach in critical care [1]. As self-taught sono-intensivists, we suspect that the same tradition that did not accept the lung in the court of the ultrasound domain also did not make optimized use of venous ultrasound in the critically ill.

Our 5-MHz microconvex probe is perfect for deep venous access.

Before Beginning: How We Hold and Move the Probe for Venous Analysis

This aspect is so important that we begin with some advice.

1. We apply the probe on the skin like a fountain pen, i.e., with just enough pressure to have an image on the screen (see Fig. 1.2). A slight pressure can collapse an internal jugular vein and make it invisible. Remember

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that an external operator must be able to withdraw the probe from the operator's hand without effort.

2. We use a microconvex probe. It can be applied everywhere, including nonlinear areas (subclavian, popliteal, superior caval vein) and deep veins (inferior vena cava). Vascular probes are linear, which means that they are appropriate for *some* veins (femoral, jugular), and in *some* views according to the landscape (axial *or* cross-sectional approach), at a certain depth. In other words, vascular probes are not suitable for studying vessels (we are not studying ambulatory chronic venous insufficiency).
3. Aiming at keeping ultrasound a simple discipline, we keep the probe perpendicular to the skin, i.e., exactly above the region of interest (avoiding those sophisticated oblique, recurrent approaches), as shown in Fig. 1.2 but not as in Fig. 12.8.
4. The Carmen maneuver is a permanent movement that we exert. At the first static appliance of the probe, the vascular couple may not be obvious to detect. Using the Carmen maneuver (scanning with the probe up and down, as described in Chap. 1 page 5) makes the detection of the couple immediate. Then we keep the target at a standstill.

First Step: Recognizing the Vascular Couple

Each vein (apart from rarities: saphenous veins, some cerebral veins, etc.) is accompanied by an artery (Figs. 12.1 and 12.2). As opposed to axial scans, cross-sectional scans immediately show this couple and make critical ultrasound easy. Searching for this double tubular structure, the hand scans the area, making large use of the Carmen maneuver (see page 5). Veins or arteries are tubular and have no end, as opposed to cysts, hematomas or enlarged lymph nodes (Fig. 12.3): the Carmen maneuver makes them promptly disappear. Doppler is not mandatory for this simple distinction. Muscles (sternocleidomastoidian for the internal jugular vein) are usually flat, not tubular. A simple scan will demonstrate the muscular nature of such image.

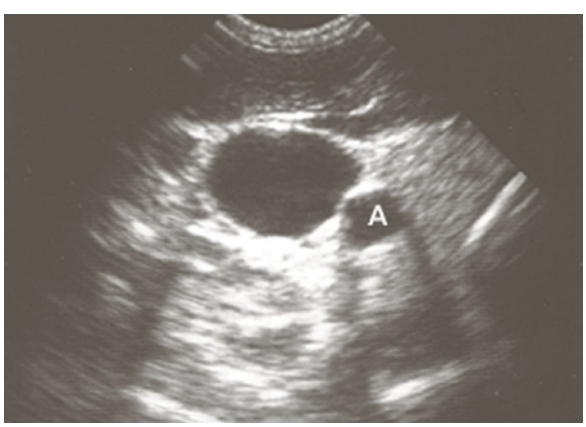

Fig. 12.1 A normal right internal jugular vein, cross-sectional scan. The vein is located outside the artery (*A*), has a round shape, a caliper of 13 × 20 mm, and an anechoic content. Note the vagus nerve behind the angle between the two vessels

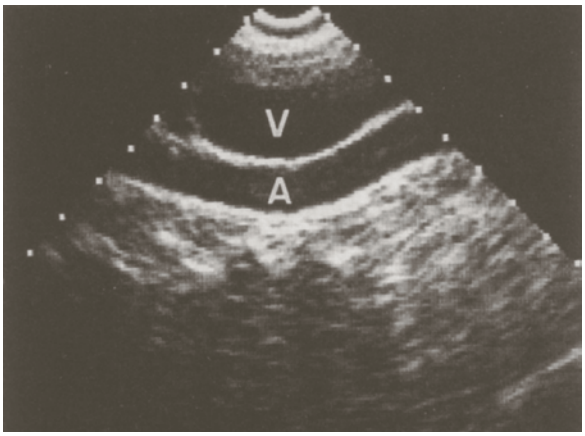

Fig. 12.2 A normal internal jugular vein (*V*) in a longitudinal scan of the neck. In this scan, the vein lies anterior to the artery (*A*) – not a rare finding

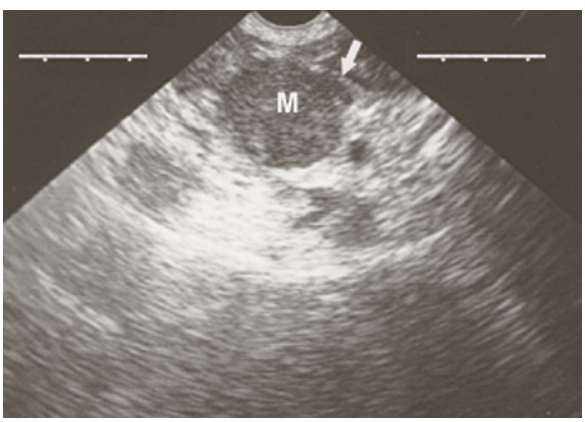

Fig. 12.3 Lymph node. Transverse scan of the neck. A tissue-like mass (*M*) is detected outside the artery. This is an enlarged lymph node, egg-shaped when scanned (Carmen maneuver). In a single scan, venous thrombosis may have the same pattern. The *arrow* designates the shifted and flattened internal jugular vein

How We Distinguish the Vein from the Artery

The user has now just to distinguish the vein from the artery. Here again, Doppler is of limited interest. Here are real-time criteria for this distinction. With a few of them, the distinction is usually immediate.

1. The artery has perfectly round cross sections (local aneurisms are rarities). A vein can be slightly or frankly ovoid, triangular, or even collapsed. Only rarely is it perfectly round.
2. In an axial scan, the borders of the artery are strictly parallel, whereas those of a vein are almost never parallel.
3. The vein is usually larger than the artery (venous volume is 65% of the total blood volume).
4. The artery shows systolic movements, whereas the dynamic changes of the vein vary, from wide movements in rhythm with the respiration cycle (with possible superimposed cardiac rhythm in case of tricuspid regurgitation) to standstill.
5. The vein lumen can show valvulae (Fig. 12.4), whereas the artery wall shows calcifications.
6. Usual anatomic location.
7. Spontaneous flow can sometimes be observed within veins.
8. Pathologic images within a vein (thromboses) are not seen within an artery.
9. The dynamic maneuver shows that a mild pressure is sufficient to collapse a patent vein, whereas an artery needs arterial pressure to collapse (a maneuver we like to avoid).

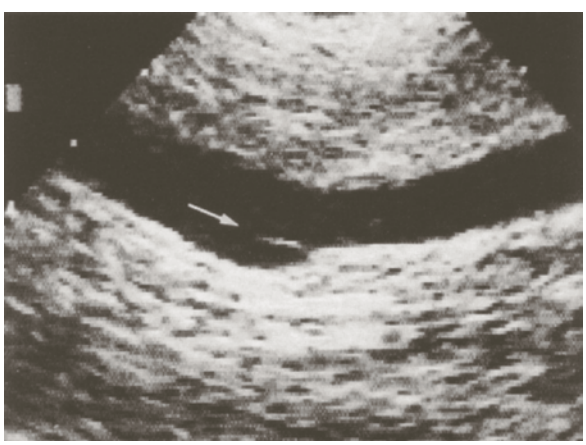

Fig. 12.4 Common femoral vein, axial scan. The *arrow* designates a valvule

Before Puncturing: How We Recognize the Patency of the Vein

Patency of the vein must be checked. The ultrasound analysis of most veins can be separated into two steps (the first including two parts):

Static Approach

The probe is applied over the vein and the operator simply observes.

Static Patterns

Simple observation is the basis of our approach. Exactly like a weather report, depending on the local conditions, the sky can be perfectly clear (blue) or obscured by diffuse clouds. Similarly, a free vein can be full black or black-gray, depending on the surrounding echoes, but always homogeneous. Like some microclimates throughout the world, some areas always have a favorable surrounding— an internal jugular vein in particular. In these cases, the static approach can be considered a gold standard: black means free. Subclavian and femoro-popliteal veins are usually black-gray. A thrombosis has characteristic features, with a tissular echogenicity and irregular shape (like a cumulus), when not occlusive. Conversely, a normal vein has a characteristic anechoic pattern (black or black-gray). *Ghost artifacts* are encountered on occasion. They are rather cirrhus-shaped (i.e., linear) and are inert (i.e., they do not move with the other anatomic structures when mobilizing the probe). See Figs. 11.5 page 84 and 13.7 page 103. It is possible to study the venous area, search for asymmetric caliper between the right and left vein and confirm the presence of a catheter (Fig. 12.5).

Dynamic Patterns

This step indicates the variations in venous caliper, as well as the behavior of a venous thrombosis in the lumen. Any central vein has respiratory changes: inspiratory flattening (up to the collapse) in spontaneous ventilation, inspiratory enlargement in mechanical ventilation. From the iliac to the calf veins, we do not observe spontaneous movements.

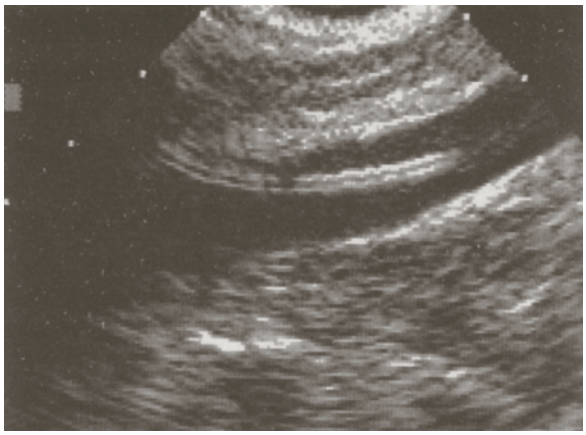

Fig. 12.5 Catheter within the venous lumen. Any catheter displays this characteristic pattern (two strictly parallel hyperechoic lines). The route through the soft tissues is also visible. The technology is of 1982

Dynamic Approach: Compression Maneuver

The compression maneuver is a popular technique at the lower extremity veins (Fig. 12.6). Our smart microconvex probe can be inserted everywhere (see Fig. 13.8 and corresponding text). We call for a policy of *controlled* pressure. What we define as controlled compression means either no compression or *mild* compression. When a static analysis has detected a venous thrombosis, this answered the question; the compression technique is of no interest and therefore possibly dangerous for no benefit. Four basic reasons advocate for a mild compression.

1. A mild pressure is more than enough to collapse a normal vein.
2. A strong pressure can compress a fresh thrombus (and conclude a normal test).
3. A strong pressure can collapse an artery, especially if the blood pressure is low.
4. A strong pressure will dislodge a thrombus [2].

Ultrasound must remain a safe procedure. We estimate that it is wise (and sufficient) to limit pressure to the reasonable value of 0.5–1 kg/cm^2. This basic notion will be recalled in Chap. 13.

As a rule, we compress first very softly. If the vein just initiates a collapse, we slightly increase our pressure, resulting in a complete collapse of the vein using mild pressure. By operating slowly, one can see the distal wall driven back toward the proximal wall, which remains in place. Then both walls get closer and eventually slap against each other, resulting in a complete collapse of the lumen. The operator should be accustomed to feeling the necessary pressure to obtain this result. The belief that Doppler is not mandatory is shared by others in the literature [3,4] and increasingly by teams in daily practice.

The examination will be made difficult by parietal emphysema, local dressings, a tracheostomy, cervical collars, and massive hypovolemia.

We compress, taking care to remain in the very axis of the probe (especially at deep areas: subclavian, iliac areas), in order to avoid off-plane effects.

The outlook of a thrombosed vein is described in Chap. 13.

Recognition of an occluded vein renders any catheterization futile (reminder).

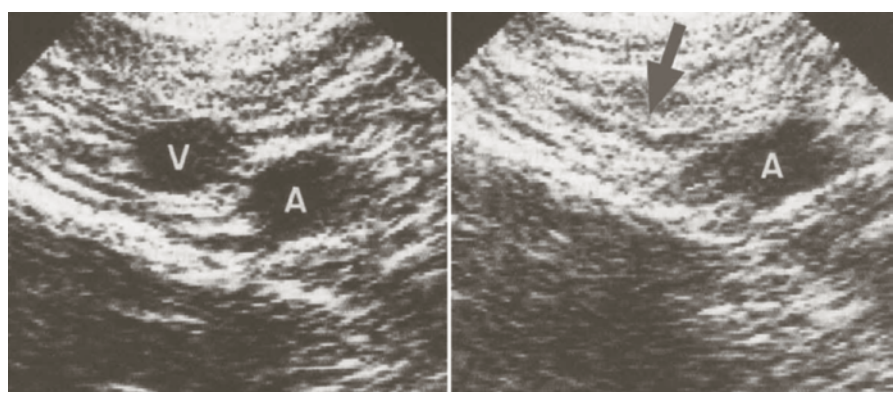

Fig.12.6 Compression maneuver. The left image shows how the subclavian couple immediately appears on a longitudinal scan of the thorax below the clavicula. The right image shows the complete collapse of this vein when pressure is exerted by a probe (*arrowhead*). Cross-sectional scan of the subclavian vein (*V*), with the satellite artery (*A*)

Ultrasound-Enlightened Catheterization

This procedure allows selection of the most adequate site of insertion. It has been proven since 1994 that large and free veins are easier to catheterize than small ones [5]. This conclusion has raised some smiles, but yielded pragmatic outcomes: one application among 100 justified in itself the purchase of simple ultrasound units in each ICU since 1994.

Asymmetry (defined as twice or more the surface) is the rule at the internal jugular level. Asymmetry is present in 62% of cases, to the benefit of the right side in only 68% of cases [6]. It is sometimes caricatural. The same study highlighted that 23% of the internal jugular veins had, at admission in the ICU in the supine position, a cross-sectional area less than 0.4 cm^2. By systematic use of the right side, a small vein will be encountered in a quarter of cases, which is a high rate. Such a small area, only slightly increased by the Trendelenburg maneuver, predicts difficulties in blind emergency catheterization.

A rapid look at the vein before puncture can prevent some unfortunate experiences:

1. Thrombosed vein.
2. Aberrant location of the vein related to the artery, which affects 8.5% of cases at the jugular level [7].
3. Inspiratory venous collapse. This feature is highlighted if zero-pressure ultrasound is applied. No experimental studies are required to predict that the conditions for gas embolism are present. This characterizes nonsedated patients. In sedated patients, the increase in inspiratory caliper is always correlated with a centrifuge flow of venous blood during disconnection of the syringe. The subclavian vein has the reputation of having constant dimensions even in hypovolemic patients. Ultrasound shows the opposite (at least at the external half).
4. Permanent complete venous collapse. No vein is visible. This is often seen at the internal jugular vein. Subtle maneuvers are required if one wishes to see the vein anyway. More simple than the Trendelenbourg or Valsalva maneuver, compressing the neck just above the clavicula usually makes a shy vein, less than 3 mm, appear. Such a dimension should discourage an attempt at catheterization.

Making a skin landmark at the area of the jugular internal vein, switching off the ultrasound unit, and inserting the needle is possible. Ultimately, this method is valid only if the caliper of the vein is large enough; this kind of vein has been proven to be easily catheterized using blind methods [5]. For the subclavian vein, which is deeper and usually smaller, this maneuver is more hazardous, as a small error in angulation will result in a greater failure rate. In spite of this poor methodology, studies have concluded that ultrasound is of no benefit in this setting, which is in our opinion a hasty conclusion [8].

Before the Next, Invasive Step: How to Train Safely

Our method for simulating parenchymas for cheap, allowing safe training using our probe and the axial approach are described in Chap. 26. We think that any physician able to write has the required skill. The coordination required to write the letter "O," for instance, requires remarkable control of agonist/antagonist muscles, but is done unconsciously by everyone.

Subclavian Vein, Normal Pattern

We locate the cross-sectional axis of the subclavian vein (probe longitudinally under the clavicle) (Fig. 12.6). Very near the vein (too near for some blind operators) is the lung: a hyperechoic horizontal structure with a dynamic pattern (lung sliding), surrounded by ribs, and followed by air artifacts (see Chaps. 14–21). The external half is easier to expose and to compress.

Our simple protocol allows us to easily collapse a nonthrombosed vein (Fig. 12.6), by gentle probe pressure, under the clavicle, with the free hand of the operator making pressure above the clavicle (a variant of the "Doppler hand," see Chap. 13 page 110). The proximal end of the subclavian vein, near the sternum, cannot be compressed. In this area, visualizing spontaneously moving valvule (the free subclavian valvule sign), a spontaneous respiratory change in dimensions, or a spontaneously visible flow indicate venous patency (Fig. 12.7).

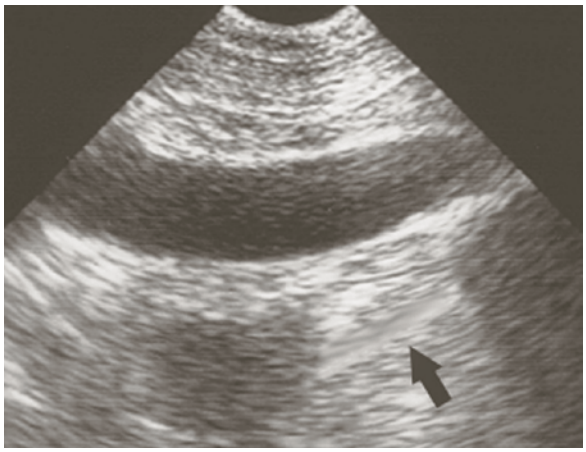

Fig. 12.7 Right subclavian vein, long axis. Transverse scan of the thorax. This vein is free. Its large caliper is favorable to catheterization. Such an exposition is common with a microconvex probe. Note the lung surface (*arrow*) nearby

As already written, a microconvex probe is not only perfect but also mandatory, since we are here facing one of the less linear areas of the human being.

Ultrasound-Guided Catheterization of the Subclavian Vein

This method will be appreciated only by those physicians who sometimes encounter technical difficulties (and have experienced dramatic night anecdotes with blind attempts) and prefer a visual guidance to a blind approach for ensuring the zero fault.

Blind insertion of an internal jugular or subclavian catheter fails in 10–19% of cases, and complications occur in 5–11% of cases [9]. The failure rate increases with the degree of the emergency, up to 38% in case of cardiac arrest [10]. Paradoxically, during the entire procedure, the patient is not easily accessible; the physician must finish the procedure before being able to correct an unstability.

In our experience, the only drawback of the ultrasound-guided procedure is its simplicity. The ability to find any vein in a few seconds in any patient (thin or stout, large or small) is a reason to have a unit in each ICU. The advantages of ultrasound have been demonstrated recently [11,12], and we can see now an explosion of publications, but the "music" is roughly the same, advocating ultrasound use. However, we have here again adapted this traditional music.

How Do We Proceed?

Basic details of interventional procedures are provided in Chap. 26. Asepsis must be absolute. A simple sterile glove surrounding the probe is not acceptable. We must have the needle, probe, and ultrasound unit in the same visual axis. The unit behind us in (unlike Fig. 12.8) is a poor option. After short local study, the probe is applied just proximal (1–2 cm free space) to the site of needle insertion. The probe identifies the vascular couple in its cross-sectional axis and is then located axially, targeting on the vein using the Anke maneuver (see page 6 in Chap. 1).

Longitudinal or Transversal Approach?

Since we began our intuitive technique (before having knowledge that ultrasound use had been described), we used an axial approach. This allowed us to see the needle through its entire length, i.e., also the areas traversed by the needle before reaching the vein. Cross-sectional approaches seem highly popular nowadays. They visualize the artery near the vein, but they see only a part of the needle. Therefore, the user does not know whether the end or the body of the needle, is observed, and has no idea of which

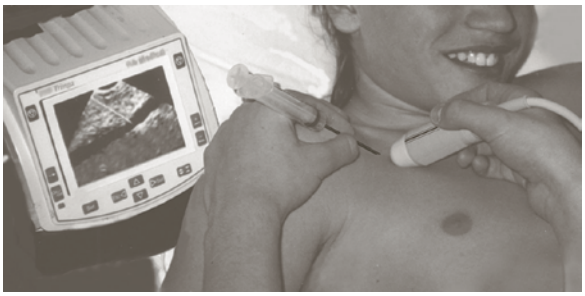

Fig. 12.8 The point of this figure is to show that the probe, needle, and screen are at the same location of the visual field of the operator. Do not pay attention to the probe inclination, which is not an example to follow when using simple ultrasound. Figure 12.10 provides additional details

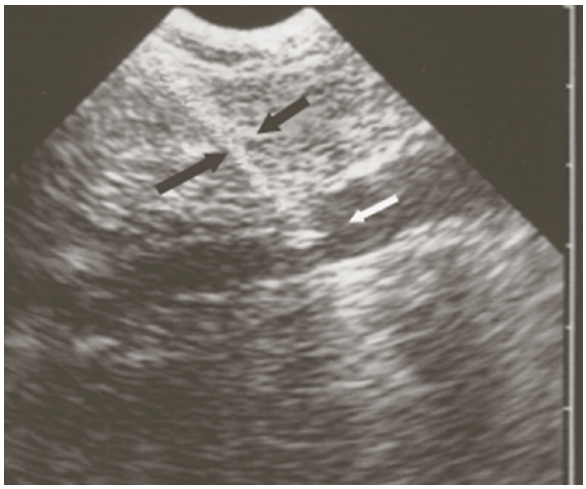

Fig. 12.9 Subclavian venous catheterization. The body of the needle is visible in this scan (hardly, but a figure does not reflect the real-time pattern) through the superficial layers (*black arrows*) and the tip of the needle has reached the venous lumen (*white arrow*)

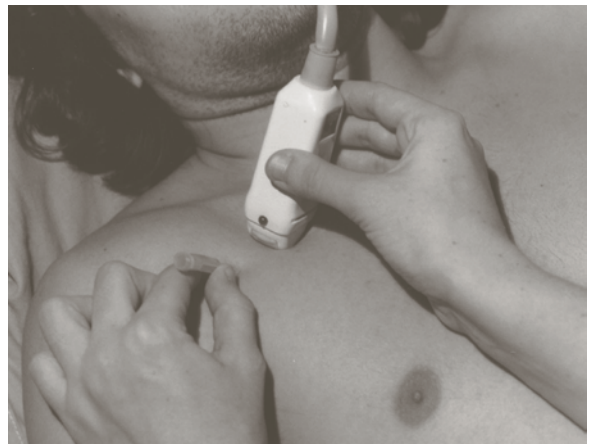

Fig. 12.10 This simple figure provides *nine* pieces of information. The right hand holds a microconvex probe – ideal for this nonlinear area (subclavian vein). Note the available space due to the probe's small footprint. The probe is applied quietly, with minimal pressure, by a hand firmly lying on the thorax. The probe is applied tangential to the thorax (90°): just above the region of interest. The probe exposes the vein on an axial view. The left hand holds the needle quietly, with no crispation, since vacuum of the syringe is not required here. The needle is applied at 45° on the thorax. Roughly 2 cm separate the needle from the probe head extremity (up to 1 cm is correct). The needle quietly aims at the landmark of the probe (note this intelligent landmark, easy to locate). There is no sophisticated device attaching the needle to the probe. For simplifying the image, the syringe is not featured and sterile material is not set up in this ficticious procedure

structures are currently traversed, before and after the target (lung, mainly). Using the axial approach and a slight Carmen maneuver, we know where the artery and the end of the needle are (Fig. 12.9). An artery not visible on the screen *cannot* be in the route of the needle when the needle is inserted in the axis of the probe. The needle traverses only the planes that are visible on the screen. A fortuitous encounter with the artery is not possible.

In fact, with traditional vascular probes we assume that it is difficult to introduce the axial approach with such cumbersome probes. This is, for sure, the historical reason for the development of the cross-sectional approach with these large probes.

A piece of useful advice: When stabilizing our gunsight to the vein, we like to move off the artery by 1–2 mm, but no more. The principle of this maneuver is to increase the safety to a point where we will be able to retire from the intensive care profession without ever having touched any artery.

The probe is now stuck through the long axis of the vein, tangential to the skin (90°), and the needle is applied facing the probe landmark, with a 45° angle (Fig. 12.10). The distance between probe head and needle tip is usually 2 (±1) cm. The needle remains in the exact axis determined by the probe landmark.

How to Handle the Needle: A Critical Detail

In the blind techniques, the users progress making the vacuum and need their two hands. This allows the withdrawal of low-pressure blood and to know (but too late) if a pneumothorax or an arterial puncture occurred. With ultrasound, one hand must hold the probe, but this is not a problem: the needle is taken like a pen and penetrates on visual guidance. There is no need for vacuum and no need for two hands.

What Do We See?

In the axial approach, we usually see the needle traversing the soft tissues, touching the proximal venous wall, pushing this wall, then penetrating the vein. Sometimes the proximal and distal walls are pressed against one another, and the needle penetrates both walls.

The needle is not visualized during its penetration in roughly 15–20% of cases. The problem is of minor importance once the needle is in the probe axis. One has just to follow the procedure. If the vein remains on the screen and if the needle is on the probe axis, the needle is on the right way. Eventually, the tip of the needle is seen touching the proximal wall of the vein, shifting it, traversing the vein, etc.

The shell phenomenon is a very rare event, which we have met only in a couple of nonsedated young females. In case of initial difficulty (or bad progression of the wire), the vein is no longer visible. Maybe a vasospasm is the mechanism or a hematoma (a few milliliters are sufficient for collapsing a vein).

When the Procedure Is Over

A routine ultrasound check shows that there is no pneumothorax (an unlikely event) and that the guide does not use the jugular route (see Fig. 26.5 page 267). Note that if the point of insertion of the needle is chosen rather distal to the medial line, the risk of ectopic positioning in the jugular vein decreases, as does, theoretically, any risk of subclavian pinch-off syndrome.

We like to make this check when still under a sterile environment and apply the sterile material in order to assess the subclavian *and* neck area. If radiography is asked to check for the absence of pneumothorax, ultrasound has already answered this question with better accuracy (see Chap. 18). If the question is ectopic positioning at the internal jugular vein, ultrasound has answered this question. If the question is where is the end of the catheter with respect to the right auricle, the answer comes from simple good sense: inserting a reasonable quantity of catheter within the patient seems highly sufficient. There is no need for long academic studies or TEE for this.

Malposition of the catheter within small vessels like the internal mammary vein seems anecdotical. Poor outflow when aspiring blood through the syringe is a valuable clinical sign of insertion into a small-caliper vessel. This condition is hard to imagine if the catheter has been inserted with ultrasound guidance. Only for these exceptional situations, the traditional radiograph could be made on the next day, in order to reduce cumulative irradiation and costs. In practice, we no longer request check radiographs. Other authors prefer ultrasound [13]. It is again possible to inject bubbles of echoic material to detect the end of the catheter, but in our opinion it complicates a simple situation.

Ultrasound guidance at the subclavian vein is mentioned by other teams [14], but studies conducted in the intensive care setting seem rare.

Why the Subclavian Vein Rather Than the Internal Jugular

We can observe around us a certain reluctance for the subclavian access, which we hardly understand. The unsuitable ergonomy of the vascular probes may explain this mistake.

The subclavian access is an elegant site for avoiding the infections – it is the cleanest site [15]. Provided we have a visual access, we do not find any reason for keeping on with the internal jugular vein. The remote infectious complications are decreased [16]. The risk of lung or arterial puncture is invalidated thanks to the visual control.

Some want to “keep” this vein for further possible chronic hemodialysis. The intention is laudable, but is it good for the patient? Are subsequent needs for hemodialysis so frequent for justifying this attitude? Note in this open debate that ultrasound guidance is likely to provide minimal damage to the vein.

We found a much lower rate of catheter-linked venous thromboses using the subclavian route compared with the internal jugular. Maybe the flow in this vein is superior (draining the whole arm) to the internal jugular vein (half a head) which would be a partial explanation.

The patient’s comfort is enhanced.

The classical contraindications (impaired hemostasis, impaired contralateral lung, obesity, history of kyphoscoliosis or bone fracture, etc.) disappear if visual guidance is used. The patient benefits from all the advantages of the subclavian route with no drawbacks.

In a study of 50 consecutive procedures carried out in subclavian veins in ventilated patients, with no selection (which will never be submitted for lack of time), we had a success rate of 100% [17]. In 72% of cases, success (frank flow within the syringe) was obtained in less than 20 s; in 16% of cases, it was obtained in less than 1 min. Twelve percent of cases were considered

long, but success was nonetheless obtained in less than 5 min. In other words, ultrasound has accustomed us to immediate success. Basically, all patients were *consecutive,* meaning that the usual factors of reluctance were not considered. Thirteen patients were plethoric (with distance from the skin to the subclavian vein >30 mm). The procedure was immediate in 11 of these 13 obese patients.

Philosophic Considerations and Others

The practice of ultrasound-guided puncture does not help to progress in the blind technique, since the landmarks are different. We cannot answer a critical question: should these blind approaches be forgotten? This should make the operator dependent on the ultrasound machine, but how to select the patients who will benefit from this "refresher" technique is an ethical issue without solution.

Countless systems have been designed for complicating the procedure. A system of servocontrol to the probe is restrictive rather than liberating in our opinion, since it prevents any adaptation during the procedure. Sly manufacturers have created machines devoted to this sole use, usually of limited quality but high cost. We consider that it is wise to invest slightly more money and have "real" whole-body multipurpose machines. Doppler systems have been advocated for guiding the procedure. We do not see the interest – a shared opinion [18].

When should we proceed to ultrasound-guided catheterization? In our opinion, each time the physician wishes to avoid any risk, lost time or discomfort to the patient: i.e., every time. Other arguments are extracted in the literature:

1. After failure of a blind attempt.
2. In official contraindications to the blind technique.
3. If costs must be controlled, since ultrasound uses 40% less material than blind techniques [19].

How What About the Other Sites?

The internal jugular vein benefits from a high level of success [20] (Figs. 12.1 and 12.2). For those who prefer to use this site, it is not forbidden to use the previous technique, the rules are the same. Choosing the internal jugular vein requires facing *hair* falls, *nasal* secretions, *eye* tears, *mouth* secretions, *ear* miasmas, leakage from a *tracheostomy*, plus the frequent detachment of the transparent dressing because of *sweating*. Provided we have the system that gives a visual look inside the human body, we have a clear preference for the subclavian route.

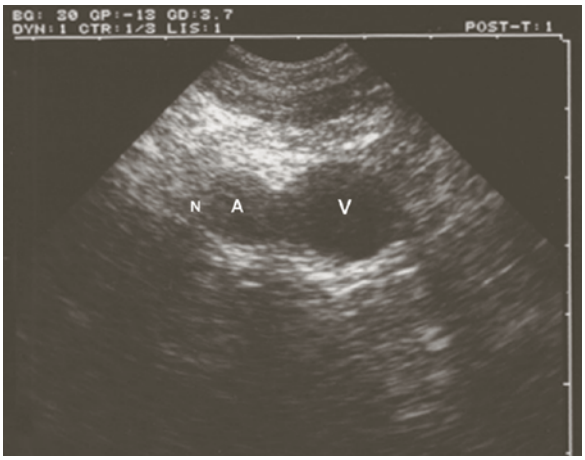

Fig. 12.11 Common femoral vessels. Cross-sectional scan at the groin. The absence of apparent separation between artery (*A*) and vein (*V*) is due to a tangency artifact, hence this peanut pattern. We heard about the sign of a Mickey Mouse head in the near area, an image which would be of interest for very young students. For those interested in nerve blockade, one nerve (*N*) is featured

Ultrasound can be used at the femoral area if the pulse is missing and if there is no alternative – again bearing in mind that it is not the cleanest site (Figs. 12.4 and 12.11).

As a note, after using our procedure upon a piece of tofu as a training exercise (see Fig. 26.5 page 267), we can on occasion catheterize peripheral veins, less spectacular than central ones but maybe as efficient.

Emergency Life-Saving Insertion of a Short Central Endovenous Catheter

This life-saving maneuver (abbreviated as ELSISCEC), used in extreme emergencies, is detailed in Chap. 26. Under sonographic guidance, we insert a multipurpose 60-mm, 16-gauge catheter in a central vein (see Fig. 26.2 page 265). This method can be done without asepsis faults. It is not fully academic but is fully

life-saving. The problem of central venous access can be solved in a few instants, avoiding spectacular alternatives such as transosseous access.

Five main points in conclusion:

1. Vascular probes are not fully suitable for vascular access.
2. The simple label "vascular," linked to linear probes, makes the doctor believe that this material is adapted for the vessels.
3. A vascular probe usually prevents catheterization of the subclavian vein.
4. It is difficult to insert a vascular probe within a sterile sheath because of its large size.
5. Our microconvex probe can be applied on any vein of the body, providing accurate clinical information and allowing canulation.

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Principles of Examination of the Deep Veins in the Critically Ill

13

Second Application, Deep Venous Thrombosis in the Critically Ill: the BLUE Protocol, Venous Part

This is a long chapter, but is a procedure that can be done in a couple of minutes once mastered.

Deep venous thrombosis in the critically ill patient is not the classical deep venous thrombosis seen in the emergency room or in chronic valvular insufficiency. The logic of the approach is completely opposed. We suspect that this field has not been fully exploited by the experts, in the same way the same experts proclaimed lung ultrasound unfeasible (see Chaps. 14–23). In the BLUE protocol, the venous approach is possibly the most important step.

Venous thrombosis in the critically ill patient in the ICU is rather an arid field. Deprived of a solid "gold standard" (especially at the bedside), we did not extensively publish on it. We describe at the end of this chapter why we believe that simple ultrasound is precisely the accurate gold standard, why we do not believe in venography, and why Duplex sonography is not for us the appropriate reference. It is difficult to compare our experience with that obtained using Doppler with vascular probes, restricted to the femoral veins, in nonsevere patients, even if they seem to have good accuracy [1].

Our venous scanning can be used outside the BLUE protocol, i.e., extrapolated in patients just seen in the emergency room (or the private practice) or just severe patients ventilated in the ICU with the particularity that exactly the same procedures, without any difference, can be used. Only the setting differs. This detail (and many others) explains the minimal thinness of this textbook.

The routine use of simple ultrasound allows us to face the old problem of pulmonary embolism, which includes the notorious insufficiences of the clinical data [2, 3], the deadly risks of undiagnosed cases (40% risk of mortality), the risk of the usual diagnostic tools [4], and the risk of usual therapies – 11% risk of major bleeding and a lethal risk of between 0.7% and 1.8% [5–7], a pity if not appropriately given. We would like to share the satisfaction of never being surprised by this disorder, and we no longer ask the question of whether such ultrasound examination should be ordered. We just do it as part of our routine examination. Regularly, ultrasound clarifies in a few instants situations that appeared complex (usually conditions mimicking septic shock).

Our 5-MHz microconvex probe is perfect for the search for deep venous thrombosis at all areas, especially the subclavian, iliac, popliteal, and calf veins. In the BLUE protocol, such a probe is a requirement, since it will be used for any vein and the lung without any delay.

The 10 Peculiarities of Venous Ultrasound in the BLUE Protocol

The BLUE protocol follows 10 points *that are in full opposition with the traditional approaches*. We repeat them on purpose.

1. We use a single probe suitable for the whole body, which allows major time and cost saving.
2. We do not use vascular probes: they condemn the user to investigate only linear areas and only superficial veins, whereas our microconvex probe makes a universal assessment. The subclavian vein, superior caval vein, inferior caval vein, and calf veins are targets out of reach of a vascular probe.
3. We do not use axial scans (see Fig. 1.4 page 6). Axial scans are difficult, like a violin. A slight movement or too ample breathing of the physician can make the vein disappear from the screen – and even create an off-plane effect, mimicking for the most inexperienced operators a positive compression maneuver. Cross-sectional scans are easy, like

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a guitar: the vein is always promptly visible on the screen. We do bilateral and comparative cross-sectional scans of the veins.

4. We do not use Doppler, even in areas that are supposedly not compressible.
5. We do not use compression, not systematically.
6. When we decide on a compression maneuver, it is moderate.
7. We use the escape sign, which is not to our knowledge in the textbooks.
8. We do not limit our protocol to the femoro-popliteal veins. The whole of the venous system is accessible (Fig. 13.1). Our protocol is extended to the calf and the upper extremity. As a major principle that is central to the BLUE protocol, when suspecting massive pulmonary embolism, the expected remaining thrombosis will be small (see below, the miasma sign). The traditional femoral two-point protocols are irrelevant. For once, subtle signs should be sought for in a critically ill patient.
9. We do not use the traditional posterior approaches. Only the anterior approach in a supine patient can be routinely used. Traditional material (i.e., long linear probes) are unsuitable for many areas in the supine patient, mainly the popliteal fossa and calf. Traditional maneuvers (prone positioning, Valsalva maneuvers, etc.) are irrelevant in the critically ill patient. Our short microconvex probe makes ultrasound easy.
10. We do not use gel. Our contact product allows major gain of time for whole venous system assessment (and increased comfort to all).

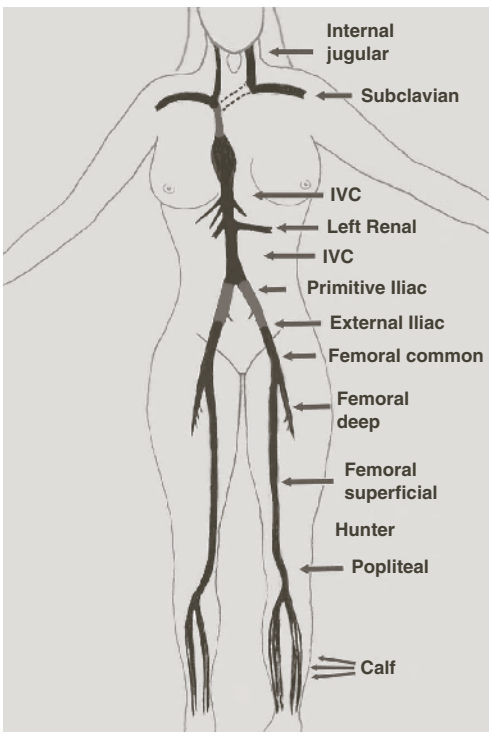

Fig. 13.1 The venous network. This figure shows the deep venous axes that are accessible to ultrasound. The superior caval vein and the primitive iliac veins, inconstantly exposed, are in *gray*. The brachiocephalic trunk, sometimes hard to detect, is indicated with *dotted lines*

Following these 10 points allows us to make, as we have proposed since 1992, a fast and accurate protocol. The search for venous thrombosis is achieved in less than 3 min in expert hands (usually one-quarter of the time for the upper axes, three-quarters for the lower axes, inferior vena cava included) and is part of the lung-vein analysis in the BLUE protocol.

The Principle of the Venous Exploration in the BLUE Protocol

The BLUE protocol orders venous analysis in a patient with acute respiratory failure, each time there is a normal anterior lung surface. Pulmonary embolism is a priority diagnosis, since the patient is at high risk of suddenly dying.

The BLUE protocol invites the physician to do the examination, since the radiologist may not be immediately present, accustomed to this kind of patient, or fully aware of some strategic areas. This means that a critical care physician should learn these rules as a priority. This may appear as an adventure, with the outward difficulty that veins run all along the whole body, each area slightly differing from the others. For mastering this field, the user can refresh anatomic notions, or more simply follow the veins step by step.

How to recognize the vascular couple, then the vein, then the venous patency were studied in Chap. 12.

The Diagnosis of Venous Thrombosis. Step 1: Simple Observation

Simple ultrasound is such a performing tool that we advocate it as the gold standard. For a reminder on the

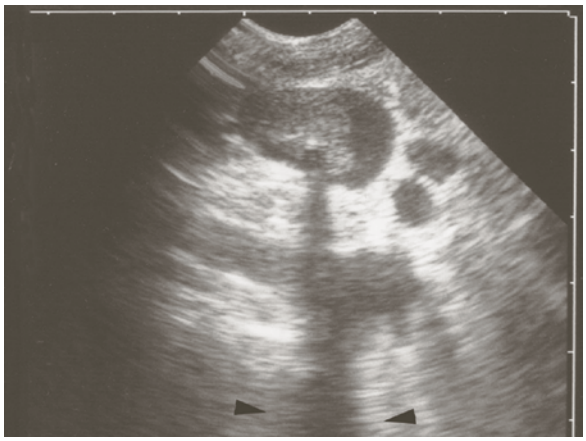

Fig. 13.2 Venous thrombosis. Typical thrombosis of the jugular internal vein, developing around a venous catheter. The catheter is detected by direct vision, or by observing its blatant acoustic shadow (*arrows*)

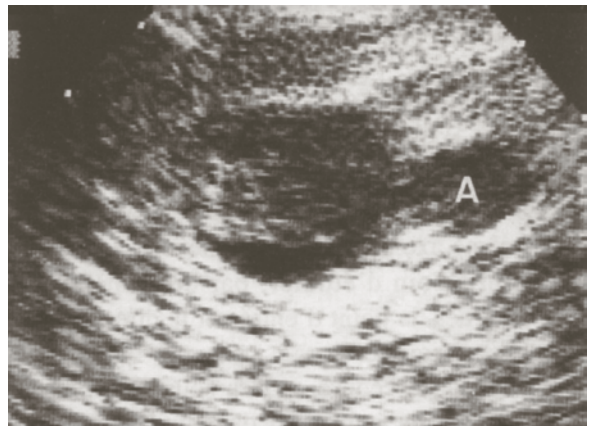

Fig. 13.4 Subocclusive thrombosis. Echoic image indicating a thrombosis of the jugular internal vein. The free lumen is reduced to an anechoic moon shape. A slight compression maneuver should first make this free lumen disappear, an increased compression should initiate an escape sign. Cross-sectional scan of the cervical vessels (*A* artery)

way we hold the probe, locate the vascular couple, and locate the vein, please refer to Chap. 12.

We briefly recall the main points of Step 1: The probe is applied like a fountain pen with zero pressure and the venous segment is observed. The thrombosed vein is filled with an echoic, tissue-like material, which has an anatomic shape, somewhat cumulus- or cauliflower-like (Fig. 13.2), or blood sausage-like (Fig. 13.3) unless the thrombosis is subocclusive (Fig. 13.4) or occlusive (Fig. 13.5). The operator must appreciate that the local conditions are good for this basic observation, i.e., a nonclouded sky. This is the case nearly always at the internal jugular vein, where there is a favorable microclimate. At this superficial segment, peripheral structures never cloud the image. As a rule, a black internal jugular vein is a normal, patent vein, making the compression not even necessary. Any tissular pattern is immediately detected within the lumen of the internal jugular vein. For the

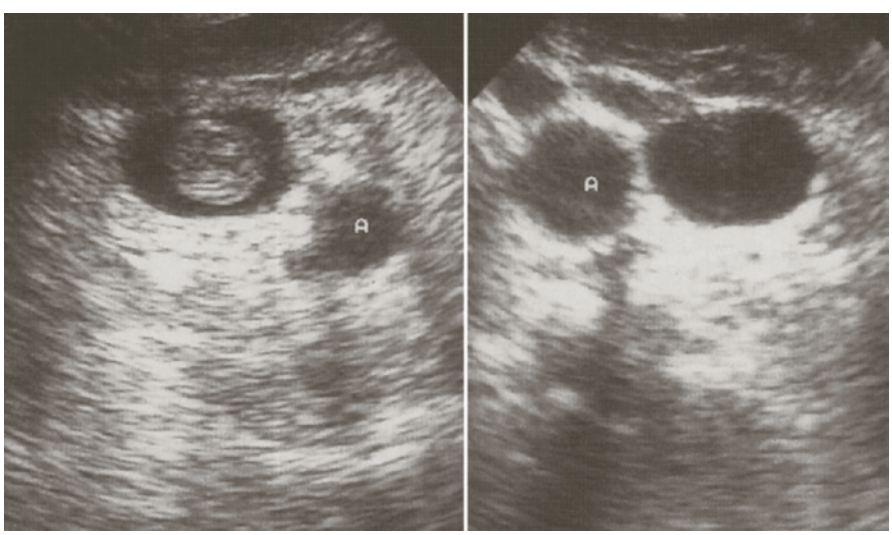

Fig. 13.3 Blatant thrombosis of the internal jugular vein and comparative look. This figure is the reprint of a reprint (original not found). In spite of the degradation, this image demonstrates what has been possible to observe at the bedside since 1992. Any physician using a correct ultrasound material will acknowledge that, for a thrombosis visible in the middle of a jugular vein, or floating like a snake within an iliac vein, or a frank escape sign, it should be time for considering gray-scale ultrasound as an appropriate gold standard

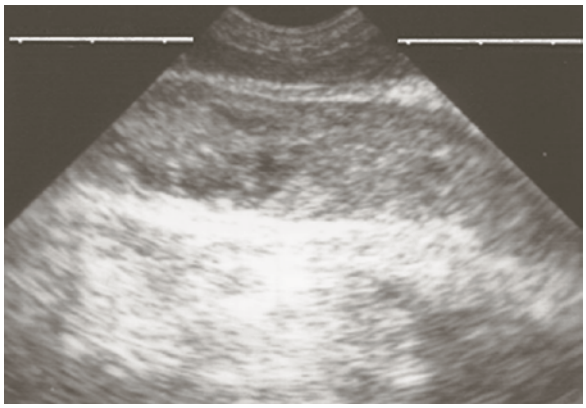

Fig. 13.5 Occlusive internal jugular venous thrombosis. Long axis. We can measure at least a 6-cm extension

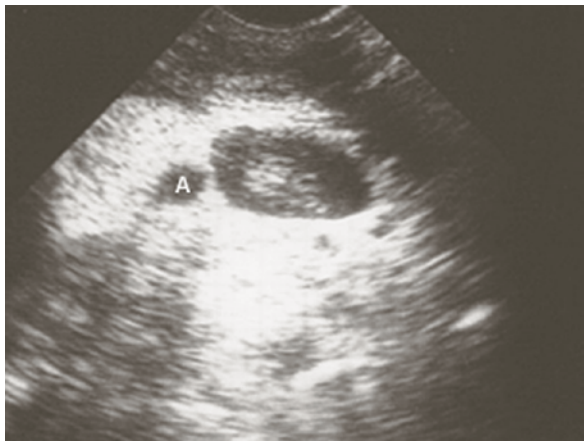

Fig. 13.7 Ghost artifact. This echoic image, in the lumen of the left internal jugular vein, has hyperechoic pattern and regular shape. Mild pressure of the probe pushes this image outside and completely collapses the lumen. This is a ghost. Left carotid artery (*A*) at the *left* of the vein. Note the oblique course of this artifact (created by strongly reflecting surrounding structures)

other veins, it depends on local "clouds," which can be abdominal gas, thigh fat, etc. As a rule, below the groin, the surrounding tissues create an echogenicity that prevents direct visualization of the thrombus, hence a compression maneuver more quickly done.

Patent upper veins (internal jugular, subclavian) have usually ample movements, especially in free breathing (negative inspiratory pressure). The motionlessness of an upper vein suggests thrombosis (Fig. 13.6).

Pitfalls. The confusion with other structures is easily avoided:

- Ghosts (Fig. 13.7). These erratic ghosts are created by the hyperechoic surrounding structures. There is no need for sophisticated ghost detectors: a ghost artifact has a regular, hyperechoic structure, in a geometric axis (usually horizontal, sometimes following the surrounding structures, like in Fig. 13.7). It looks like a cirrhus (i.e., simple lines) and never

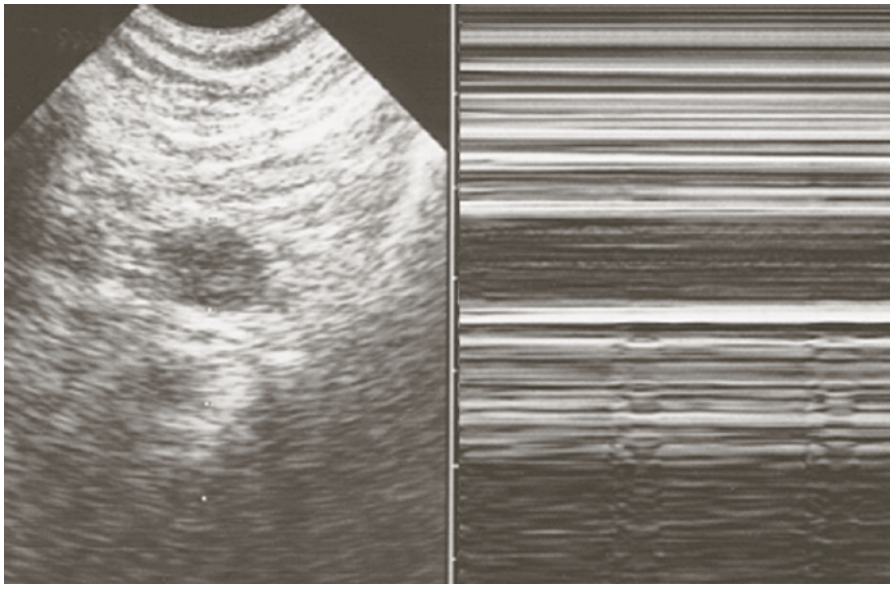

Fig. 13.6 Occlusive thrombosis of the subclavian vein, short axis. The vein is incompressible. The *right figure*, in time-motion, depicts a sensitive sign of occlusive thrombosis: complete absence of respiratory dynamics of the vein

like a cumulus (or a cauliflower). In case of persistent doubt, a slight compression will quietly compress the vein, and the ghost will quietly evaporate, without any escape sign, yielding complete collapse of the vein with minimal pressure (the Anna's ghost sign, from Rio).

- Endovenous tumor: this would be a differential diagnosis, but so rare that we have still no experience with it (and in addition believe that anticoagulation may not be a major error here).

The Diagnosis of Venous Thrombosis. Step 2: The Dynamic Controlled Compression Maneuver

We briefly recall the main points of Step 2, which should be done only if Step 1 has not answered the question. It can be used at any level (see Fig. 12.6). A small microconvex probe has the perfect design for controlled compression. To herald that noncompressibility is a sign that venous thrombosis is not satisfactory, since this does not inform on the intensity of the pressure. The following scene should not be observed: finding the vein and immediately crushing it with uncontrolled strength, without time (2 s) for initial static assessment. The vein will not suddenly run away. This is usually the case with novice operators. We must take time to locate the vein in the gunsight, aim, then shoot without exaggerated haste (in war time, time to identify enemy aircrafts takes *far* less than 2 s and avoids collateral losses).

At the lower extremity, we spend less time on the first observational step because, first, the ground noise makes a clouded sky and, second, the small venous caliper is less appropriate for detecting thrombosis. A floating thrombosis is often seen at the iliac or caval segment, but quite never at the femoral area.

Compression should be applied gently for the four basic reasons exposed in page 92 of Chap. 12. We recall here the consequences of uncontrolled pressure:

1. The pressure in the venous system is low. A mild pressure is more than enough to collapse a normal vein.
2. A strong pressure can crash a fresh thrombus (and conclude to a normal test).
3. A strong pressure is the best way for dislodging an unstable thrombus. A chest pain during a venous compression is a sign of pulmonary embolism.
4. A strong pressure can collapse an artery, especially if the blood pressure is low.

To keep ultrasound as a safe procedure, we advise limiting the pressure to 0.5–1 kg/cm^2. The behavior of the patent vein is described in Chap. 12.

Technique

The compression maneuver is done with one or two hands, depending of the anatomy. One hand is sufficient for the internal jugular vein, the inferior vena cava, the iliac veins, the four-fifths upper part of the femoral vein, the popliteal vein. We use two hands when there is no bone behind the vein: subclavian, calf, lower femoral vein. The Hunter canal is an area where the compression maneuver is reputed to be ineffective. This belief has delighted the manufacturers who sold a lot of Doppler equipment. Considering that we have two hands, we just use our unoccupied hand as a counterpressure applied at the opposed part to the probe. The compression maneuver is then made really easy (Fig. 13.8). Please read under the heading "Lower femoral vein." At the subclavian vein, our small probe is located under the clavicula, and the fingers of the free hand are above the clavicula, making a synchronized movement. At the calf, the free hand takes the posterior calf muscles.

Results

A major sign of venous thrombosis, constant in our observations, is the association of an absence of collapsibility of the vein *under mild pressure* with the escape sign.

Result 1: Noncompressibility

This sign does not require extensive description.

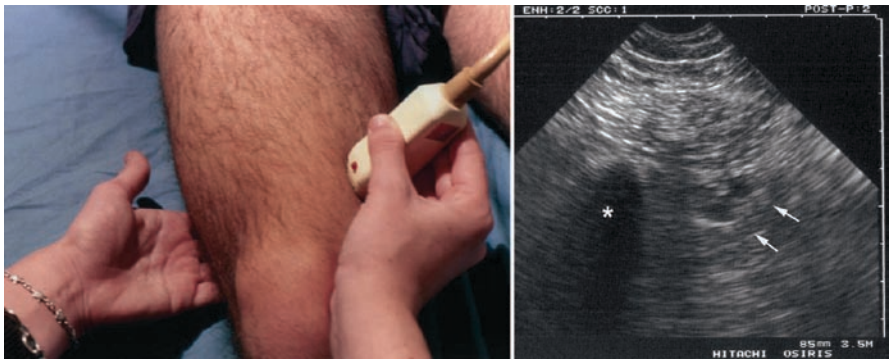

Fig.13.8 The Doppler hand and the V-point. This figure shows how the lower femoral vein is easily studied using a two-handed compression, making Doppler useless. The microconvex probe has an ideal shape for this use. See how it can be applied everywhere, in any incidence. Note how the hand gently holds the probe, while firmly resting on the leg. At the right, the ultrasound image (transversal scan of lower thigh). The femur generates frank shadow (*star*). The femoral vessels are seen within the femur (*arrows*). Which one is the vein? The compression will tell (among other signs)

Result 2: The Escape Sign

This is a subtle sign. The escape sign means that instead of observing the distal wall moving toward the proximal wall (normal vein), the operator observes the proximal and distal walls staying in constant dimensions (no compressibility), whereas the surrounding soft tissues are moving, compressed by the probe. This means that the pressure exerted by the doctor is sufficient for moving the vein (relative to surrounding tissues), but insufficient for collapsing it: the venous pressure is superior to the pressure of the soft tissues. The thrombosed vein behaves like a sausage (a blood sausage, so to speak).

A slight probe pressure is sufficient to initiate the escape sign. With experience, this is sufficient for the diagnosis. The escape sign makes us interrupt the compression maneuver. Any additional pressure intensifies and confirms the escape sign, but also increases the risk of dislodgement. In a partial occlusion, the slight compression maneuver easily collapses the free lumen (Fig. 13.4), and then initiates an escape sign. It should be emphasized and repeated that a moderate probe pressure is necessary and sufficient to collapse a normal vein.

The escape sign is rarely of use at the upper extremity, mainly because compression is not really useful (especially internal jugular vein). Only static analysis is sufficient.

The Diagnosis of Venous Thrombosis: Additional Patterns

The occlusion can be partial (Fig. 13.4) or complete (Fig. 13.5), extensive (Fig. 13.5), floating within a large lumen (Fig. 13.9) or suspended. Detecting extensive thrombosis has a prognosis meaning. Detecting very small thrombosis (the miasma sign) has major diagnostic relevance in massive embolism. A sign of minor help is venous enlargment [8, 9].

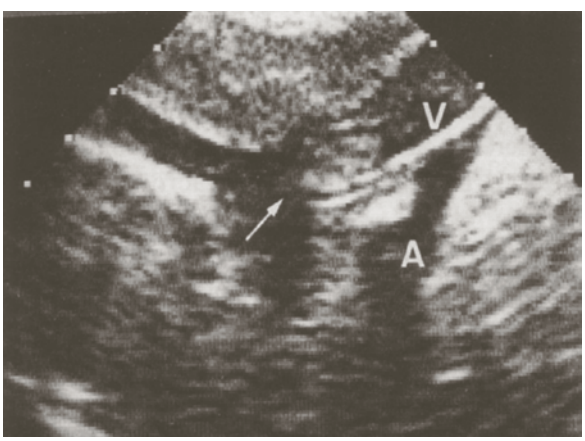

Fig. 13.9 High-degree floating thrombosis. Internal jugular vein (*V*) in an axial scan, probe applied in the supraclavicular fossa. A thrombosis is detected. The *arrow* designates its caudal end, just at the Pirogoff confluent. In real-time, this thrombosis has worrying halting dynamics in rhythm with the heart cycle. Negative progression. *A,* arterial vessels

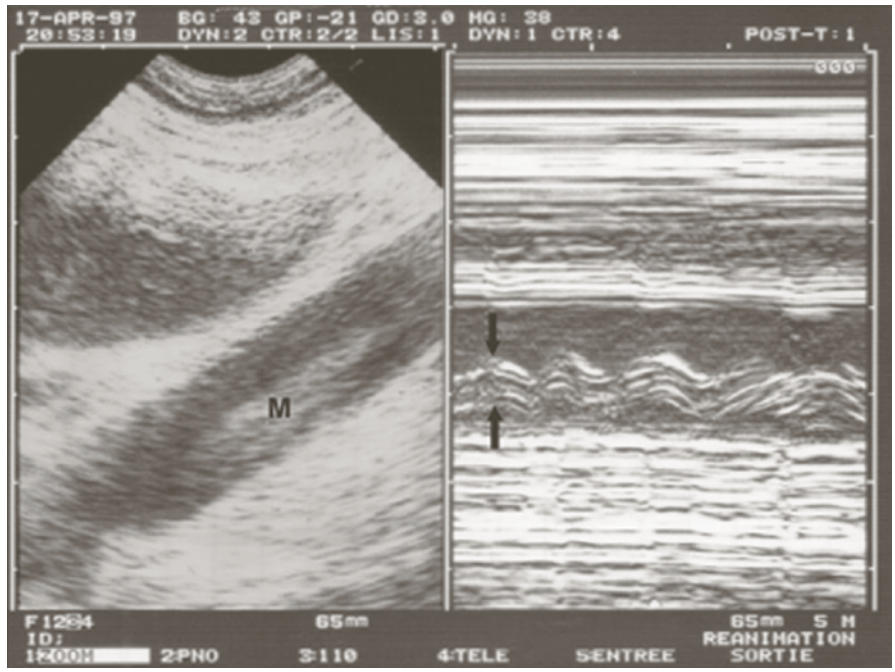

Fig. 13.10 Floating iliac thrombosis (*M*). The floating character is demonstrated using the M-mode, at the right: characteristic sinusoid ondulations (*arrows*). If compression of such a structure is attempted, one can calculate a volume of at least 7 × 7 × 40 mm of embolus dropped toward the lung

Bilateral thombosis. Usually, one suggestive sign of thrombosis is the unilaterallity (compressible at one side, not at the other). This is of help in patients who require more than the usual pressure (firm soft tissues, habitus, etc.). In exceptional cases, a bilateral, symmetric thrombosis exists. Each time, in our experience, the diagnosis was obvious using Steps 1 and 2.

Floating thrombosis. Better than any other test (especially venography), ultrasound has the strength to provide immediately this real-time characteristic pattern. This should make ultrasound the gold standard (Fig. 13.10). Sometimes, the thrombus has halting movements, in rhythm with the heart cycle: the floating thrombus seems to be attracted by the right heart. We deeply consider that such highly unstable thromboses deserve aggressive therapy.

Incipient thrombosis. Between blood and clot, there is a short transient step that is soft. The vein therefore can be flattened by the probe pressure, but we hesitate to compress, especially since it can be accessible to Step 1 analysis at the jugular level (read about the CLOT protocol, page 285 of Chap. 29). A kind of diaphanous image is visible within the venous lumen, partly fixed against the wall, partly freely floating, nearly dancing (Fig. 13.11). At this step, we assume the vein to be totally compressible (we have never tried). A day later, a complete, blood sausage-like thrombosis is usually present.

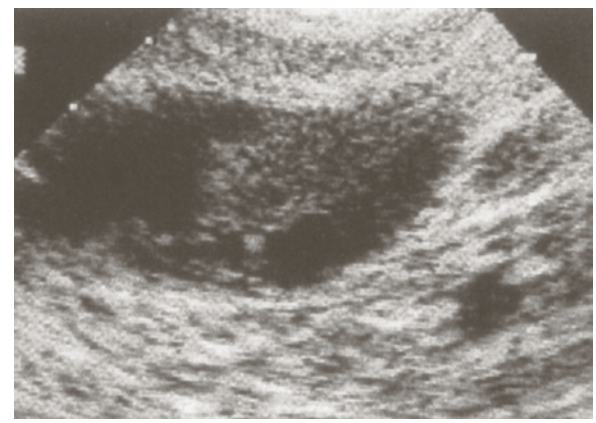

Fig. 13.11 Incipient thrombosis. Diaphanous curls are freely floating in the lumen of this internal jugular vein. A part of this image is fixed against the wall. This pattern is possibly the first step of a rising venous thrombosis

Thrombophlebitis. A pattern that is no longer tissue-like (gray) but hyperechoic (white) is obviously due to massive gas within the thrombosis, i.e., severe infection (Fig. 13.12). A thickened wall is often observed (phlebitis). Septic thrombophlebitis is observed preferentially at the internal jugular site,

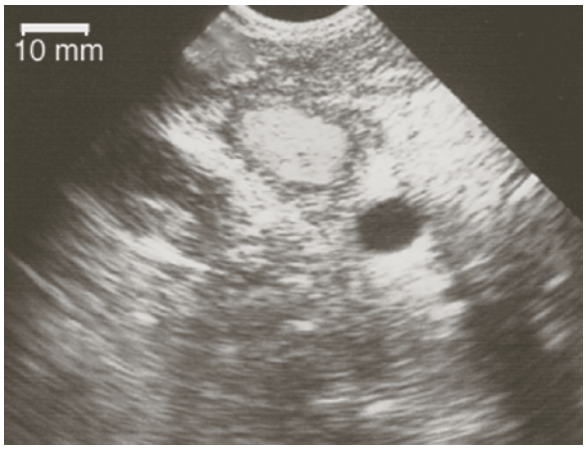

Fig. 13.12 Suppurative thrombophlebitis. Note the markedly echoic pattern and the thickened wall. Complete thrombosis of the right internal jugular vein, transverse scan. Note: we assume such a thrombosis to be compressible

which favors superinfection from the skin. Another sign of infected thrombosis is the isolation of a microbe within the thrombosis, using an aspiration of a minute quantity of the thrombus under ultrasound guidance, in expert hands. Some teams have attempted this procedure [10]. Rightly or wrongly, we have not yet proposed such a study to our ethics committee. Spontaneous venous thromboses (i.e., without previous catheterization or trauma) have no reason to be superinfected.

What to Begin With: The Bulldozer Technique or the Butterfly Technique?

Two approaches are possible.

1. The bulldozer technique, i.e., comprehensive visiting from the head to the feet, i.e., internal jugular veins, then subclavian, caval, iliac, femoral, popliteal, then three-point calf vein analysis. This technique is rapid – less than 3 min. If the inferior caval vein is difficult to expose (gas), the operator, not losing time, bypasses this area, and jumps to the lower area. This jumping maneuver pays off when a thrombosis is located there. In the other case, the operator comes back at the inferior vena cava, making more subtle maneuvers for hiding the gas, etc. The bulldozer technique is indicated when there is no clinical location.
2. The butterfly technique is an adapted approach that has the advantage of being even faster. It is directed by history. A notion of right leg pain indicates beginning at the right femoral segment. In an ambulatory patient coming from home (or an airplane etc.) without suggestive location, the lower extremities should be visited first. Not provocatively, we begin at the Hunter area using the Doppler hand maneuver (see addendum). In patients ventilated in the ICU for several days, we rather apply the probe at the internal jugular and iliac segments, i.e., on downstream of areas that benefited from catheterism. This approach, called the CLOT protocol, favors rapidity. The role of the CLOT protocol for diagnosing pulmonary embolism in ARDS is described in Chap. 29 page 285.

From the very moment a venous thrombosis is detected, the BLUE protocol is finished (see Chap. 20). This does not prevent continuing comprehensive venous analysis, but this is done for other purposes, not changing the immediate therapeutic decision.

Internal Jugular Vein Thrombosis

At the internal jugular vein (see Chap. 12 for its recognition), we use only Step 1, which usually is sufficient (Figs. 13.3 and 13.4).

Routine screening at the jugular veins of our critically ill patients has shown a high rate of thrombosis, usually after a recent local catheterization or attempt at such (Fig. 13.2). In rare cases, the thrombosis is not related with a local procedure. Rare studies in the ICU suggest an occurrence of 70% [11, 12]. Fewer studies have evaluated the risk of pulmonary embolism as well as septic consequences [11]. Pulmonary embolism from upper-extremity veins is estimated as nonexisting for some (corridor talks) and as occuring in 10–12% of cases, including a subclavian source, for others [13, 14]. In both cases, the methodology is unfortunately not optimal. We have evidence that such thromboses are eventually dislodged.

Subclavian Venous Thrombosis

This is sometimes easily identified using the static approach alone (Fig. 13.6). Sometimes a dynamic maneuver with the Doppler hand is required.

The frequency of subclavian venous thromboses (after catheterism) seems strikingly lower than internal jugular thromboses.

Superior Caval Vein

Applying our microconvex probe (again this probe, and no other probe may achieve this task) against the neck (see Fig. 23.8 page 234), we have the opportunity to expose, in more than three-quarters of cases, at the bedside and without invasion, this whole venous segment. One can see the right pulmonary artery passing posterior to it, the right auricle at the bottom of the image, the ascending aorta inside the vein. Sometimes, the lung prevents this visualization.

No compression maneuver can be done here. Doppler could be helpful, but before using it, we will point out some clues. First, isolated venous thrombosis is exceptional (not yet seen in our experience). Indirect signs indicate patency: inspiratory collapse (in a spontaneously breathing patient) of the subclavian or jugular veins [15, 16] indicates absence of an obstacle at the superior caval vein. The sniff test (sudden inspiration by the nose) [15] should normally yield jugular and subclavian collapse, but is not realistic in critically ill patients, and we are not keen on sudden maneuvers in these fragile patients. They would dislodge a thrombosis that was until then stable.

Right atelectasis, not a rare situation in the ICU, attracts the mediastinum and makes it accessible using a parasternal approach. A floating thrombosis in the superior caval vein can be diagnosed (Fig. 13.13).

In case of necessity, in a ventilated patient, a transesophageal examination could diagnose superior caval obstruction, but this rare application should not in itself prompt for the purchase of a TEE unit. What we see from time to time are oncologic patients with *known* superior caval obstruction who are coming in for another problem or a complication of this problem. There is consequently no diagnostic problem.

Chapter 23 shows the role of investigating this vein for hemodynamic assessment of critically ill patients.

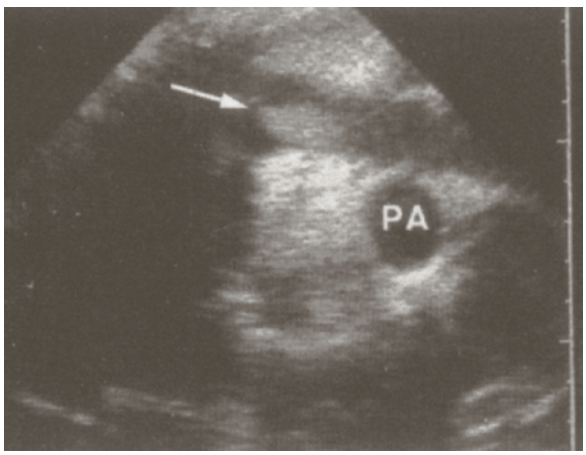

Fig. 13.13 Superior caval vein thrombosis. Patient with right lung atelectasis. Right longitudinal parasternal route. The thrombus is visible (*arrow*) within the venous lumen, and is floating in real time. The only immediate thing one can do (apart from immediate fibrinolytic therapy, if possible) is to position this patient on the right lateral decubitus, hoping that the thrombus, when dislodged, will choose the right lung, more dependent. *PA* right branch of the pulmonary artery. An idle observer could take prolonged observation for eventually seeing the thrombus dislodgement, followed a few seconds later by the embolus visible through PA, the pulmonary artery (if lucky, since there are two pulmonary arteries)

Left Brachiocephalic Vein

This is sometimes visible anterior to the aortic cross using a suprasternal route and the microconvex probe. This segment is not easy to compress. If a local thrombosis is suspected (e.g., a large left arm), only static analysis will be contributive: direct detection of the thrombosis, absence of spontaneous collapse, absence of the free valvule sign. Doppler may be useful, but such a location, *isolated without* any jugular internal or subclavian extension, is more than exceptional.

The Inferior Caval Vein

Draining half of the systemic blood toward the heart and the crossroad of lower-extremity thromboses, this vessel has a strategic situation. In the previous edition, a whole chapter was devoted. For various reasons, we have dispatched its content into search for thrombosis (here) and assessing patient's hemodynamics (see Chap. 23). Again, the notion of supra- and infrarenal portions of our previous editions resulted in useless complication. Basically, the vein begins at the umbilic and ends at the xyphoid point (see Fig. 4.2 page 28).

We routinely use a two-hand technique. We apply our free hand with spread fingers on the abdominal wall (see Fig 11.9 page 86), insert the probe between two fingers of the free hand, and apply a more or less important pressure with the free hand in order to gently drive away the gas, if any. A substantial compression by the probe alone would possibly harm the probe and the patient. Most often, the gas barrier is suddenly bypassed, yielding a clear visibility of the target. Let us not forget that the compression would result in decreasing the caliper of the vein.

A spontaneous echoic flow, possibly due to agglomerated blood cells, is observed in privileged cases (Fig. 13.14). The flow hesitates on mechanical inspiration or even moves backward – making cheap diagnosis of flow analysis without Doppler. The venous caliper is modified by respiratory and cardiac rhythms, usually with inspiratory collapse in spontaneously breathing subjects. Visible flow variations in caliper are signs of venous patency.

A compression maneuver against the rachis, *in the absence of obvious image of thrombosis,* is often able to collapse the inferior caval vein, depending on the morphotype. In a segment so near to the heart, one imagines the consequences of an inappropriate compression – if a thrombosis has been seen. Note that a complete venous compression does not affect the real-time blood pressure (immediate derivation through an azygos system is a possible explanation).

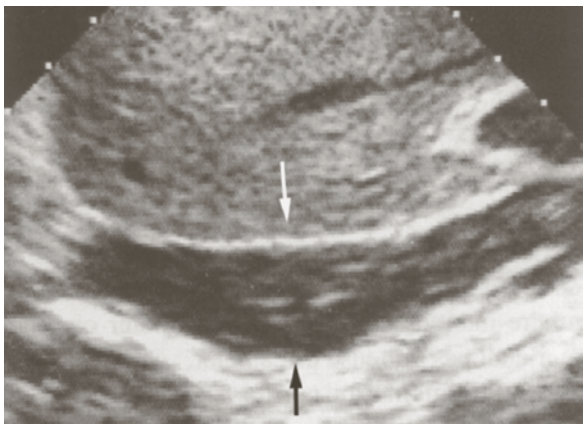

Fig. 13.14 Inferior caval vein. In this longitudinal scan, an echoic flow with visible particles goes toward the right cavities. Note the bulge in the upper portion of the vein (*arrows*), a frequent normal variant (saber profile). Note that a measurement of the vein caliper at this level would yield misleading information in predicting central venous pressure

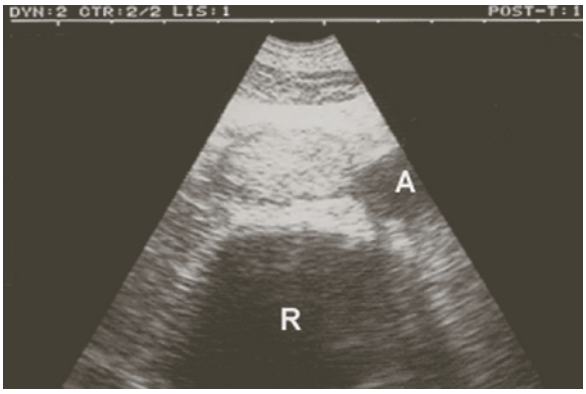

Fig. 13.15 Massive thrombosis of the inferior caval vein. Transverse scan of the umbilical area (infrarenal portion). Anterior to the rachis (*R*) and at the right of the aorta (*A*), the venous lumen of the inferior caval vein is filled with echoic material. This recent thrombus is still soft. Hence, a compression maneuver may collapse the venous lumen, with doubtful consequences. Young patient with multiple trauma

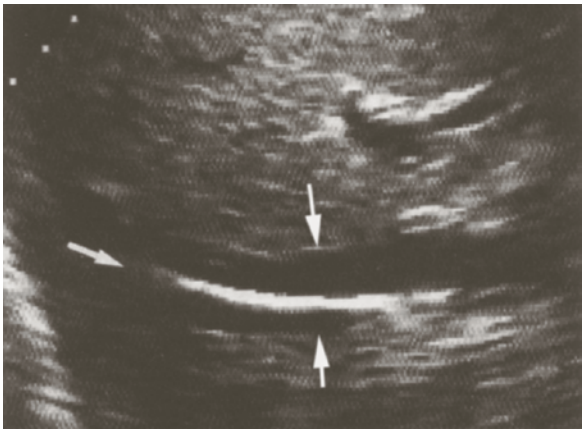

Fig. 13.16 Catheter (*arrow*) within the inferior caval vein lumen

The signs of caval thrombosis have no peculiarity (Fig. 13.15). Extensive, floating patterns are favored by the large size of this vein. Detection hypertrophy of an azygos system, for example, is a matter for specialists. Extrinsic obstacles, catheters, or caval filters can be observed (Fig. 13.16).

The Iliac Segment

Iliac veins are difficult to assess with cumbersome abdominal probes, when gas is profuse, and with some

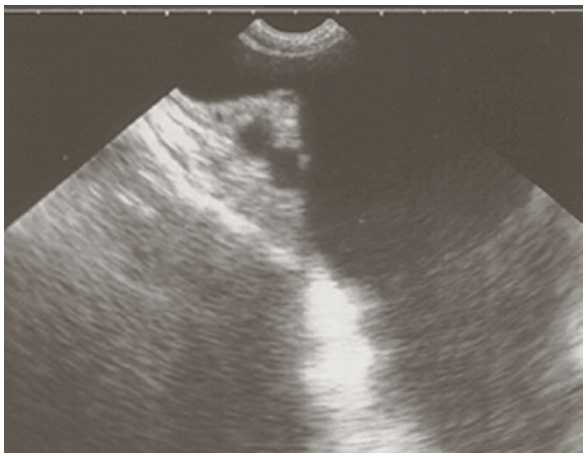

Fig. 13.17 Through a peritoneal effusion, these right iliac vessels are clearly outlined

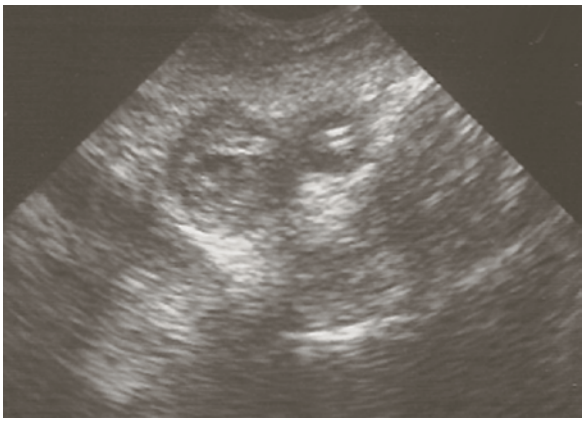

Fig. 13.18 Left external iliac thrombosis. In this cross-sectional scan, slightly over the groin, the external iliac vein is enlarged by an echoic heterogeneous occlusive material. This sole pattern renders the compression technique redundant. Hence, the risk-to - benefit ratio of this maneuver is inverted. Note at the *right* of the image an arterial catheter (two parallel hyperechoic lines)

morphotypes. Our microconvex probe provides better focused pressure. In most cases, iliac veins can be followed and compressed over a more or less long segment. We differentiate primitive from external iliac veins. The external iliac vein is usually always accessible. The gas can be easily compressed and the vein can again be compressed. The primitive iliac vein detection is more chancy. We use the same two-handed technique at the inferior vena cava level (see Fig. 11.9). A peritoneal effusion can isolate the vascular axes from the bowel (Fig 13.17). The Carmen maneuver is the most efficient way to see immediately the vascular couple among the GI tract. A rectilinear segment of GI tract locating at the same axis should not mislead. It is single (not a vascular couple), large and has visible peristalsis, among many signs, making Doppler alone useless for this task. An echoic flow with dynamic particles can at times be seen, indicating venous patency. Valsalva or sniff-test maneuvers are irrealistic in our tired patients (they should either increase or collapse the iliac lumen, ruling out at least complete obstruction downstream).

Floating thrombosis is often clearly detected at these large areas (Figs. 13.10 and 13.18).

The compression of the primitive iliac vein is chancy: effective here, uneffective there; we still do not know why. Yet the usual contrast makes this maneuver of minor interest, like at the internal jugular area (see again Figs. 13.3 and 13.18).

Isolated iliac thromboses are reputed to be exceptional, more often visible in an obstetrical or trauma setting [2, 17]. The usual studies are not done in ICUs. Here, thromboses are usually seen after femoral catheterization. The common femoral vein can be normal, with the thrombosis developing downward, at the iliac vein. For the reasons described above, when the external iliac vein is assessed but not the primitive iliac vein, we assume that the clinical problem is minor. Doppler should not be the solution, because gas are a hindrance for Doppler too. Here is a place for a CT scan (or more exceptionally venography) if really the clinical setting is suggestive.

The Femoral Vein: Upper Three-Quarters

The common femoral vein lies outside the femoral pulse. Figure 12.11 details some of its characteristics. The deep femoral vein leaves the main axis, goes toward the femur, whereas the superficial femoral vein goes, vertical, inside the femur, up to the knee. The femoral superficial vein is rarely duplicated, yielding two venous channels surrounding the artery.

The femoral vein is a familiar target. Everything regarding this area was already said above. The femoral thrombosis occupies a traditional relevance, since it should be implied in 95% of cases [17] and is reputed to often be extensive [18]. Yet following the central idea of the BLUE protocol, in a massive pulmonary embolism we do not expect to see large areas of thrombosis there.

The static approach is rarely contributive, as written above. In some instances, an echoic heterogeneous pattern is recognized within the enlarged lumen, making the compression maneuver useless (Fig. 13.18). Floating patterns are rarely found (there is too little space). The dynamic maneuver usually makes the diagnosis. Since the superficial femoral vein is the longest (roughly 30 cm), we split it in seven parts (this including the lower quarter studied below), making an acceptable balance between accuracy and speed. Using cross-sectional scans and a direct, slight compression maneuver, this makes 21 s per side.

The Femoral Vein: Lower Quarter

We find this area really interesting. It was always reputed to be noncompressible. This short paragraph will indicate that it is useless to buy Doppler technology only for this belief. The "Doppler hand" is an unexpensive tool able to make immediate diagnosis of Hunter thrombosis – a strategic area. Using our Ecolight system, the user always works with two (gel-free) hands, and does not lose more than 3 s for this maneuver (Fig. 13.8). The operator has just to find the "V-point," i.e., the point where a slight probe pressure, or the slight counterpressure of the free hand (usually only the middle finger), or both, makes the free vein completely and easily collapse. Short training allows easy detection of the V-point. Our friends Marcio and Bianca Rodriguez, from Porto Alegre, cleverly called the free hand the "Doppler hand." The Doppler hand shows that critical ultrasound is performed with both hands, permanently, like a physical examination.

The Popliteal Approach in the Critically Ill

The whole spirit of the BLUE protocol (and whole-body ultrasound in the critically ill) can be appreciated here. This analysis is hardly possible using traditional materials in supine patients. The vein is now posterior in a patient who cannot be easily turned (Fig. 13.19). Our microconvex probe with its 8-cm length solves this issue. We just have to slightly bend the knee. For those who feel lost by this unusual approach, the probe applied onto the anterior knee with the landmark to the right of the patient should be simply shifted without changing anything, at the posterior aspect. With this simple maneuver, the landmark is successively at the right of the supine patient, then looking at the ceiling, then located to the left of the patient when the probe is behind the knee.

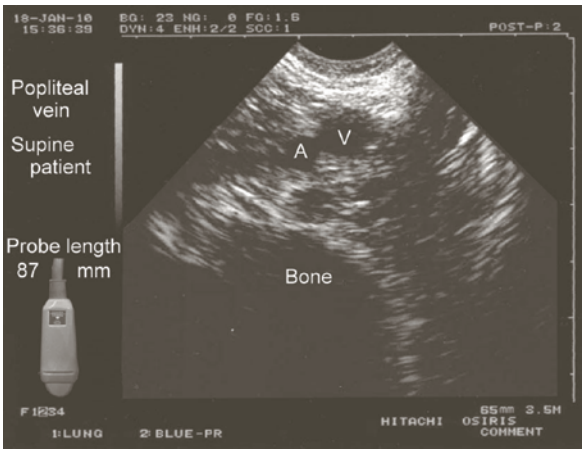

Fig. 13.19 Popliteal vein. Posterior cross-sectional approach of the popliteal fossa, showing the vein (*V*), generally single, and the artery (*A*). Supine patient, Short probe

The Calf Case

The community usually neglects this area, traditionally considered difficult. We think the detection of calf thrombosis in a critically ill patient is a major finding, originating from the 81% sensitivity and 99% specificity of the BLUE protocol for the diagnosis of pulmonary embolism (see Chap. 20). It is true that these 12 veins (two per artery in each leg) make a small world. The physicians who consider this area of little clinical interest can omit the reading of this section, but will deprive themselves of a key element in 20% of the cases of massive pulmonary embolism – where this location appears isolated (unpublished data).

Once again, some basic adaptation made ultrasound easy, even at this area.

Indication

This analysis is determinant in the case of negative examination of the main axes.

Technique

The technique available in the literature supposes a posterior approach in a patient in the prone position: not applicable to the critically ill. We describe an adapted anterior method. Our microconvex probe is ideal for being inserted transversally at the anterior aspect of the leg, between tibia and fibula. Insertion of a rubber tourniquet above the knee (at the V-point, assuming absence of local thrombosis) increases the size of the calf veins. In a *transverse* scan, both bones are easily recognized, as well as the interosseous membrane. The anterior tibial group, passing just anterior to the membrane, is reputed to be slightly or not emboligenic, and can perhaps be occulted (making four remaining veins on six per side). Posterior to the membrane, through the posterior tibial muscle, one can observe the fibular group outside and the tibial posterior group inside (Fig. 13.20). The Carmen maneuver (see Chap. 1 page 5) is the point that makes the venous location easy. There is little place for a static approach. The Doppler hand (free hand of the operator) then holds the calf in front of the probe for the compression maneuver. Sometimes, only the dynamic approach makes it possible to recognize normal veins: small structures that collapse under pressure are veins – normal veins. If this approach does not answer the question, we make a lateral approach just posterior to the tibia, or sometimes to the fibula (Fig.13.21). Here again, Doppler is not used. Using a classical posterior approach (in noncritically ill patients), the use of only compression resulted in an 85% sensitivity [19].

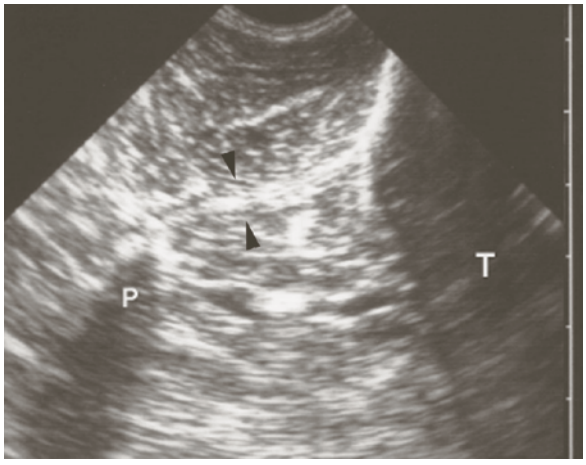

Fig. 13.20 Calf veins. Right transverse scan, anterior approach. Interosseous membrane is straight between the two bones (*arrowheads*). About 2 cm posterior, through the rectangular posterior tibial muscle, the tibial posterior, and fibular veins are visible, inside the location of the letters *P* and *T*: *P* shadow of the fibula, *T* shadow of the tibia

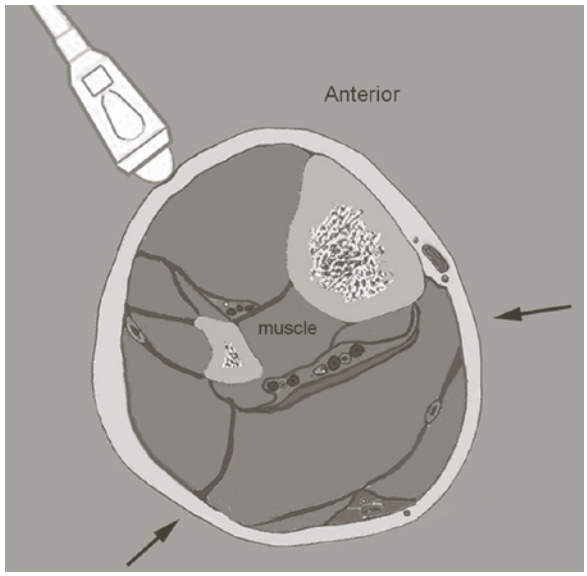

Fig. 13.21 Anatomy of the calf area. This section, inspired from H. Rouvières' textbook of anatomy (Masson, Paris, 1974) is used to show the location of the main vascular groups, posterior to the posterior tibial muscle (French term). This figure shows the main landmarks, i.e., the two bones, the interosseous membrane and the venous couples. The *arrow*s show how a small probe can approach the calf not only anteriorly but laterally with interesting bone counterpressure

Results

Basically, three scenarios are possible:

1. The venous groups are identified. They are compressible. A one-point compression is done in a few seconds, and immediately rules out local calf thrombosis. The probability of thrombosis decreases with the multiplication of measurements. However, aiming at a comprehensive analysis would be time-consuming, with the risk of not reaching the 100% of volume scanned. Here, we agree for making reasonable three-point protocols (traditional protocols use two points at the femoral area). The ultrasound report will describe a calf venous system free in at least one, two or three points.
2. A pathological structure is identified: tubular, noncompressible, echoic, enlarged (suggestive if larger than 5 mm), yielding an escape sign (Fig. 13.22), and a sequel sign (a sign of ours): this image is

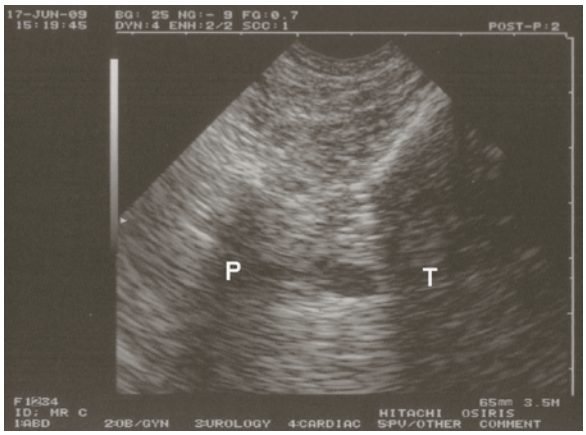

Fig. 13.22 Calf venous thrombosis. In this transverse anterior scan, an enlarged structure is visible, at the normal place of a posterior tibial vein. This structure is tubular on dynamic scanning, and not compressible using the Doppler hand, as opposed to the contralateral one. The letters labeling the bone shadows (*P* Fibula and *T* Tibia) are located at the level of the veins

prolonged downstream by an image clearly identified as a patent vein. Calf thrombosis is quasicertain.

3. No tubular group is identified. It sometimes happens, preventing us from reaching a conclusion. It is possibly that there are fibrous changes, or it is already a sign of isoechoic thrombosis. Devoid of a gold standard, we still cannot reach a conclusion (the venography is no longer used, and the radiologists rarely explore this segment using their material in ICU patients).

Prognosis Interest of the Calf Veins Analysis

This seems a minor problem. Calf venous thromboses do not embolize [20]. Fatal cases of pulmonary embolism do not come from isolated calf thrombosis [21–25] but from the iliofemoral areas [26–28]. We are sure that no doctor is worried by isolated calf vein thromboses. The more segments that are free, the lower the probability of deadly surprises according to the Grotowski law. This law speculates that a noncritically ill patient who has a slight suspicion of embolism and no thrombosis detected using our simple method, including the calf area in *at least* one point, is *not* at risk of sudden death. Therefore, searching for pulmonary embolism by the traditional way (spiral CT) would do more harm than good. We suggest using simple scintigraphy in a semi-emergency.

There are ways to minimize the problem of an undetected calf thrombosis in long-staying patients (i.e., not exactly the spirit of the BLUE protocol, but nearer to the CLOT protocol, see page 285). Calf thrombosis extends to the femoral veins in 20% of cases [25]. This extension always occurs before pulmonary embolism [25]. Taking this notion into account, when the calf analysis is unsatisfactory, we monitor the V-point (just above the knee) at regular intervals (every 24 h). A few seconds are required. If thrombosis is detected by such monitoring (which we called the V-protocol), it is time for curative treatment.

The Place of Simplified Venous Protocols

We have heard of those protocols checking only two points at the femoro-popliteal veins. They are spreading in the ERs. Such protocols are possibly a providence in the overcrowded ER, where a main goal is to relief this chronic pressure. Yet this does not work in critically ill patients (see above). In the critically ill, the Grotowski law forbids such speculation. Furthermore, provided we correctly understood, if these methods have a 97% negative predictive value, we worry about the remaining 3% of patients who will come home. We hope that these protocols are temporary.

The Management of a Noncritically Ill Patient Suspected of Mild Pulmonary Embolism with Negative Venous Ultrasound Scanning

This situation is a daily occurrence in the emergency room. Chapter 13 refers only to critically ill patients (we are in the BLUE protocol). In order to make a homogeneous textbook, the present situation will be detailed in Chap. 29 page 285.

Limitations of Ultrasound of Deep Venous Thrombosis in the Critically Ill

The dressing of the catheter, the trachostomy cord, orthopedic materials in trauma, and an abundance of digestive gas are hindrances.

Femoral veins are more difficult to recognize when there is a high degree of obesity or hypovolemia. Chronic

thrombosis can be isoechoic to the surrounding tissues [23], but the Carmen maneuver can usually recognize a tubular structure, even isoechoic, beside the artery.

In the trauma patient, the compression maneuver can be harmful.

Venography, Angio-CT, Doppler, ARM: Which Gold Standard?

Venous ultrasound is a validated field [32], yet our approach can create new perspectives.

Venography

It is assumed to provide an objective document. Certain teams still favor it, especially with young traumatized patients. It also has limitations, which we have classified, beginning by the worst:

- Venography transgresses (like bedside chest X-rays) the golden rule of plane imaging: analyzing any structure in two perpendicular planes. Partial thromboses can be missed in a single view.
- Several areas cannot be opacified: deep femorals, gastrocnemial veins, etc.
- The interpretation is operator-dependent. Divergences from 10% to 35% between observers are reported [29], and our experience shows a high rate of errors (with ultrasound as reference). This is compounded if 20% [30] to 30% [31] of venographies are classified normal in pulmonary embolism. It can, therefore, not be accepted as a gold standard.
- It requires transportation of a critically ill patient, pelvic irradiation, iodine allergy, cost, possible dislogement of thromboses, and needle insertion on the back of the foot (an unpleasant procedure).

Venography (like chest radiography) is a limited tool. The only gold standard that we would accept would be complete venography using *both* front *and* profile incidences (not ready to be seen in our institutions).

Doppler

Many reasons are advocated for requiring Doppler. Few resist analysis. Knowing the direction and the speed [30] of the flow: We guess that venous flow comes from the tissues. Immediate recognition of the vascular couple: We do not need Doppler. Distinguishing the vein from the artery: We have enough real-time arguments. Knowing the extent of the thrombosis [1]: Real-time shows it as well. Reinforcing the diagnosis based on noncompressibility: A role of Doppler should mean that real-time ultrasound is not sufficient. If both tests disagree, will the user believe in Doppler or in real-time ultrasound? Diagnosing iliac venous thrombosis: Gas is a hindrance for real-time as well as Doppler. For other issues with Doppler, see page 296 of Chap. 30.

Doppler can be advantageous in trauma, since the compression maneuver may be harmful.

Angio-CT

For doctors who are not self-confident, angio-CT is a kind of solution, like angio magnetic resonance (ARM). Yet apart from the lack of elegance of using these methods (which are detailed in Chap. 19), this is not envisageable for critically ill patients.

Therapeutic Ultrasound in Deep Venous Thrombosis

See in Chap. 26 the role of ultrasound when a caval filter is envisaged.

Considerations About the Outcome of Catheter-Linked Venous Thromboses

The internal jugular vein is a privilegiated target for these thromboses. Some issues are not solved.

In our observations (unpublished), the mortality seems to be increased in patients with such thromboses, apart from a possible bias (thrombosis may occur in the most severely ill patients). Since death is a daily occurrence in the ICU, concerning 20–30% of patients admitted, all possible factors should be carefully scrutinized. We hypothetize that jugular thrombosis in the long-staying critically ill creates small emboli, likely occult. If they happen repeatedly, they can yield issues: perhaps not sudden death, but more occult issues like delayed discharge, difficult weaning, unclear and transient dysadaptation episodes, subacute fatigue of the

patient or even so-called nosocomial pneumonia. Like a banderilla sunk at the bull's back, maybe these repeated aggressions exhaust the patient, before the death-blow, so to speak.

When thrombosis is generated by a catheter, there is a direct communication with the skin. This may explain fever (of "unknown" origin), but also septic pulmonary embolism. Should such thromboses be considered systematically infected?

A catheter surrounded by thrombosis is a frequent finding. What to do when we intend to withdraw the catheter? We advise the delicate users not to see what happens (using ultrasound) during this maneuver.

Is the "first inspiration" safe? Apart from the real first inspiration (that occurs at birth) and bad evolution, all ventilated and sedated patients are eventually desedated. At one moment, the positive inspiratory pressure is replaced by a negative inspiratory pressure. How about a floating thrombosis when suddenly the pressures are inverted in the bloodstream?

Should heparintherapy in critically ill patients (receving jugular or femoral catheters) make more harm than good?

We envisage a solution for these problems: avoiding the internal jugular route. Please read page 96 of Chap. 12 for discussion about our interest for the subclavian route.

We conclude by summarizing the 10 main points of this chapter:

The search in extreme emergency for a venous thrombosis is a raison d'être for the BLUE protocol.

Only the described material (one small unit with immediate switch-on, only one probe for lungs, veins, heart, etc.) is suitable for an efficient 3-min scanning.

Our unique multipurpose probe is probably the most precious tool, since it can explore any area.

Simple protocols can be described at any area, including popliteal, calf, superior caval vein, etc.

The simple analysis of the venous content is often sufficient.

The compression must be done only if there is no visible thrombosis, and with minimal pressure.

Doppler is not mandatory.

Progressing one's territory step by step makes an efficient whole-body approach.

Large venous thromboses are easily detected, until the moment they are suddenly no longer visible.

Finding a small area of venous thrombosis has major relevance when massive pulmonary embolism is suspected.

Simple venous ultrasound should be recognized as the gold standard.

Addendum

Observations under submission indicate that nearly half of the cases of massive embolism reveal a positive search at the V-point. Following this sequence, the BLUE-protocol allows in nearly half cases the diagnosis in less than one minute, facing an A-profile at the lung area and a positive V-point.

The following step, based not on the logic but on the best compromise, is the common femoral vein, involved in 20% of remaining cases.

The following step is the calf analysis (one or two points) showing a positive test in *half of* remaining patients.

If this simple sequence is negative, we resume the examination at the upper veins (jugular, subclavian), showing positive in 20% of remaining cases.

Spending energy searching for iliocaval thrombosis when massive pulmonary embolism has occured does not seem to pay off.

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Introduction to Lung Ultrasound

14

The previous chapters dealt with admitted targets (with slight personal adjustments, especially at the venous chapters). They did not cover all of the interests of critical ultrasound. We now deal with the main vital organ, which has been a little overlooked, maybe because it contains air. Considering the lung as part of the ultrasound discipline gives full meaning to the term critical ultrasound. As opposed to what is taught, ultrasound beams are smart. They can cross both bones and air (see Fig. 29.5 page 287). Ultrasound allows an accurate demonstration of nearly all acute disorders involving the lung.

The story of lung ultrasound deserves a book of its own. In the coming chapters, we will remain as technical as possible. After introduction of a normal examination, in order to begin "slowly" we will introduce the field by a rather admitted application: fluid pleural effusion.

Our 5-MHz microconvex probe is perfect for investigation of the lung.

Basic Terminology

Words, locutions, and abbreviations are used to increase the speed of communication. Lung ultrasound was a free field, not occupied by the specialists of imaging. Therefore, a whole terminology had to be created for making the lung transparent. This language was based on a maximal use of logic, avoiding confusion as much as possible (although any language contains some mistakes, e.g., the French "plus" can mean more, or no longer). A-lines, B-lines, etc., up to Z-lines have been chosen on purpose, each with a precise idea to help memorization. We checked that bat sign, seashore sign, lung sliding, quad sign, sinusoid sign, tissue-like sign, shred sign, lung rockets, stratosphere sign, lung point, etc., did not yield confusion in the medical terminology.

Basic Technique: The Seven Principles of Lung Ultrasound

Following seven principles allows standardization of the method.

1. A simple, two-dimensional apparatus is the most appropriate for lung ultrasound.
2. The thorax is an area where air and water are intimately mingled.
3. The lung is the largest organ in the human body.
4. All signs arise from the pleural line.
5. Lung signs are mainly based on the analysis of artifacts.
6. The lung is a vital organ. Most signs are dynamic.
7. Nearly all acute disorders of the thorax come in contact with the surface. This explains the potential of lung ultrasound, which is paradoxical only at first view.

Development of the First Principle: Simplicity of the Unit

The most sophisticated units – usually devoted for cardiac explorations – are not ideal. The usual size, image resolution, start-up time, probe shape, complexity of the technology and high cost are all hindrances.

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The machine that we have used since 1992 is still manufactured, with updates regarding only the external aspect (the manufacturer did not have to improve the resolution quality, which was already optimal). It is perfect for lung – and whole-body – analysis. It is important to provide a figure allowing the reader to compare our 1992 resolution with recent laptop models from the 21st century (see Fig. 30.4 page 300). Figure 2.1 on page 12 illustrates one of the main reasons why lung ultrasound development was delayed in many ICUs, and can still appear obscure to some.

Development of the Second Principle: Understanding the Air-to-Fluid Ratio and Respecting the Sky–Earth Axis

Air and fluids coexist in the lung. Air rises, fluids sink. Lung ultrasound requires precision on the patient's position with respect to the sky-earth axis, and the area where the probe is applied. Pneumothorax is nondependent, interstitial syndrome is usually nondependent, alveolar consolidation is usually dependent, and fluid pleural effusion is fully dependent.

The critically ill patient can be examined supine, semirecumbent, or sometimes laterally, rarely in an armchair, and on occasion in the prone position. Dependent disorders can become nondependent in the prone position.

The mingling between air and fluids generates the artifacts because of the high acoustic impedance gradient. Air completely stops the ultrasound beam (acoustic barrier), fluid is an excellent medium that facilitates its transmission. The air-to-fluid ratio differs completely from one disease to another. We use this to describe the disorders from pure fluid to pure air. That is, pleural effusion (pure fluid), alveolar consolidation, from atelectasis (mostly fluid) to pneumonia (some air), interstitial syndrome (mostly air), the normal lung (slightly hydrated), and pneumothorax (pure air) (Fig. 14.1).

In pleural effusion, the air-to-fluid ratio is 0.

In alveolar consolidation, the air-to-fluid ratio is very low, roughly 0.1 (due to some air bronchograms).

In interstitial syndrome, the air-to-fluid ratio is very high, roughly 0.95 (air is mingled with minute interstitial edema).

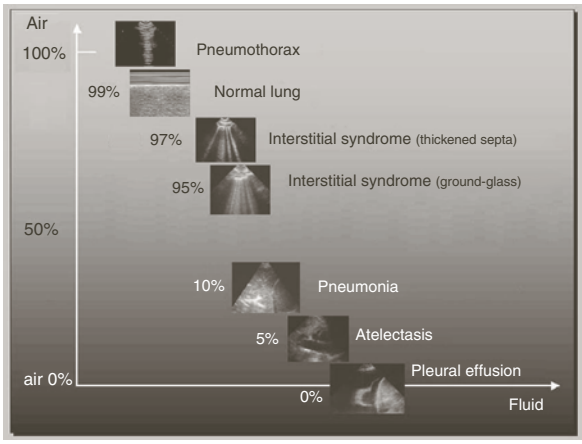

Fig. 14.1 The air-to-fluid ratio. The main disorders – and the normal lung – feature between pure air and pure fluid. Note: between pneumothorax and interstitial syndrome, the position of the normal lung. In order not to complicate this graph, we did not feature anaerobic empyema, which contain minute amounts of gas (and have echoic content)

In decompensated COPD or asthma, air is the major component and the ratio is higher, roughly 0.98.

The normal lung should logically be located here, the air-to-fluid ratio being roughly the same, 0.98.

In pneumothorax, the air-to-fluid ratio is 1.

Development of the Third Principle: Locating the Lung and Defining Areas of Investigation

The lung is the most voluminous organ: about 1,500 cm^2 in surface area, 17% of the body skin projection. Where should one apply the probe? This seems to be an issue. We could answer simply but not efficiently, "At the same places as the stethoscope." Yet in critical settings, questions include whether there is a pulmonary edema, a pleural effusion, a pneumonia, a pneumothorax, etc.? A basic approach has allowed us to define standardized areas of interest: the BLUE points. The BLUE points allow to answer each question in a few seconds. Other uses need comprehensive scanning.

Like for the nine areas that partition the abdomen, or the six electrodes that are placed at strictly defined areas for the EKG, a partitioning of the thorax will allow standardized work for reproducible results.

The anterior zone is limited by the "BLUE hands": two hands (without the thumbs) are applied together

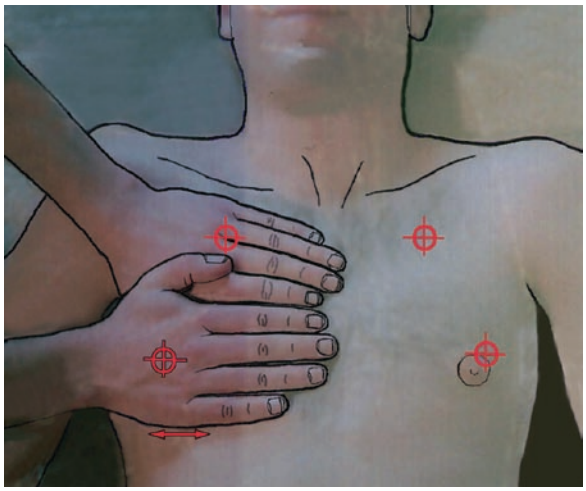

Fig. 14.2 The BLUE points. The upper hand is applied with the little finger against the lower border of the clavicula (in its long axis). The finger tips touch the midline. The lower hand is applied below the first one. The thumbs do not count. The upper BLUE point is at the root of the middle and ring fingers of the upper hand (*upper cross*). The lower BLUE point is in the middle of the palm of the lower hand (*lower cross*). In this subject, the lower BLUE point is near the nipple. This definition makes a symmetric analysis, usually avoiding the heart. The lower edge of the lower hand roughly indicates the phrenic line (*arrow*), i.e., the end of the lung. Note that the shape of the hands has been studied in order to correct the obliquity of the clavicula, yielding a roughly transversal phrenic line. See Fig. 1.2 page 4, which shows an examination at the lower BLUE point, in a supine patient at earth level, defining a Stage 1 examination (1′ in actual fact, since the subject is semirecumbent)

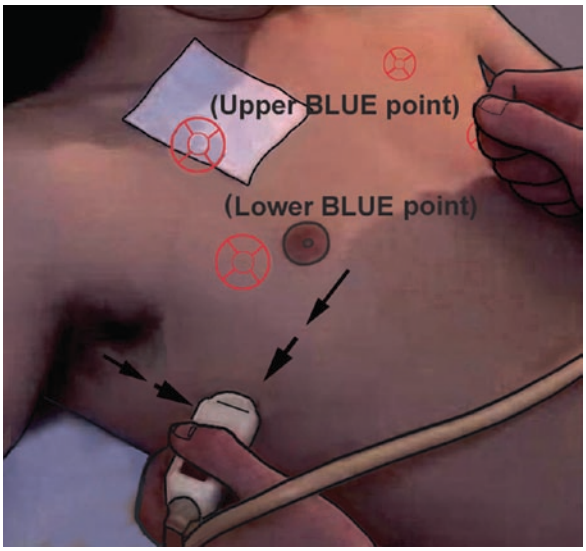

Fig. 14.3 The phrenic point. This figure shows a Stage 2 examination, i.e., a lateral continuation of the Stage 1. The probe is here at the intersection between the middle axillary line (*vertical arrow*) and the phrenic line (*horizontal arrow*): the phrenic point

(Fig. 14.2), with upper little finger against the lower border of the clavicula. Nails are at the midline. The lower little finger indicates the lower anterior border of the lung (phrenic line). The wrist articulation is usually at the anterior axillary line, separating anterior from lateral wall. The physician has previously evaluated the size of the patient (the term "BLUE hands" refers to the patient's hands). Between 1.65 and 1.85 m, the difference is insignificant. The anterior lung is therefore located.

Previous concepts: We defined the lower lung border in the adult at between zero and two to three fingers below the nipple line. This landmark was valuable only in adults, had too wide a range, and was difficult to imagine in the case of large breasts. Young people have a phrenic line rather three fingers below the nipple line. In the neonate, the nipple is located high (five fingers). The BLUE hands are valuable at any age. Our previous division of the anterior wall into four quadrants, like the breast, is used less often.

The lateral zone (Fig. 14.3) extends from the anterior to the posterior axillary lines (lower border limited by a horizontal extension of the phrenic line). The posterior limit, at the posterior axillary line, is thus explored with the probe at bed level in a supine patient. The bed prevents long probes from exploring more posteriorly.

The posterior zone extends from the posterior axillary line to the rachis, and may appear inaccessible in supine patients. This twilight zone can be reduced by using a short and small probe.

The anterolateral location of the diaphragm is a basic step for locating the lung. Not following the scale can make young users confused between pleural and peritoneal effusions, between alveolar consolidations and normal abdominal structures, and, for those who believe the lung to be lower than it is, with the liver-kidney interface, which can mimic a diaphragm (see Figs. 4.1 and 4.8 page 30). Chapter 4 provided a traditional approach for the cupola. Using intercostal scans, the probe is perpendicular to the thorax, offering a different visualization. The anterior insertion of the diaphragm is located with respect to the lowest finger of the BLUE hands, defining the phrenic line. One main point to understand with our perpendicular approach is that we do not search to see the diaphragm, but rather for its location (and dynamic). The

diaphragm insertion is the location where the image displays a thoracic image at the left of the screen (i.e., air barrier, or pleural or alveolar disorders), and an image of the liver (or spleen) at the right of the screen.

Definition of Stages of Investigation by Combining the Lung Areas and the Sky-Earth Axis

Stage 1 investigates the anterior wall in supine patients. In addition, Stage 1 specifies that the finding is done at earth level, as a kind of tribute to Scott Dulchavski, who investigates astronauts (with Andrew Kirkpatrick, among others).

Stage 2 adds the lateral wall, from anterior to posterior axillary line.

Stage 3 adds the external part of the posterior wall (zone "3"). Critically ill, ventilated, traumatized patients are supine. One mandatory condition to explore the posterior lung is to have a short probe. Our microconvex probe is 8-cm long. The probe is inserted as far as possible at the posterior wall. The probe head must point as far as possible to the sky, as if the operator wishes to shoot at the lung (probe being considered like a gun) and not the parietal layers. One understands that a long probe will be a major hindrance to this maneuver, i.e., to the practice of lung ultrasonography in the critically ill. During Stage 3, the operator has no visual control of the probe and must hold it by the whole hand (i.e., not as advised in Fig. 1.2 page 4). The hand depresses the bed to gain precious centimeters, the index and thumb hold the probe head like the orbital walls protect an eye. This ensures a soft contact between the probe and patient's skin, avoiding damage and harm (to the probe also). When the conditions prevent correct exposition, installing the ispilateral elbow anteriorly toward the midline is sufficient for gaining precious centimeters (Fig. 14.4). Stage 3 provides major information with minimal mobilization.

In *Stage 4*, the patient must be positioned laterally or seated in order to comprehensively study the posterior chest wall. Stage 4 also includes the apex. Only a microconvex probe can efficiently do this. Stage 4 offers information that makes ultrasound nearly as competitive as CT.

Standardization of a Lung Examination: The BLUE Points

The concept of the BLUE points should help users when they apply their probe on the largest organ of the body (Figs. 14.2 and 14.3).

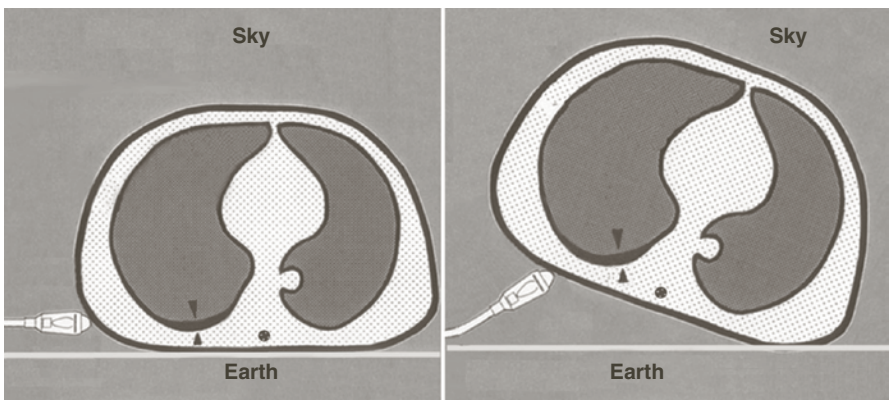

Fig. 14.4 The lateralization maneuver. *Left:* The probe explores the lateral zone up to bed level. The bed prevents the probe from scanning further. Using this horizontal axis, the detection of this small effusion is not obtained. *Right:* The back of the patient has been slightly raised (lateralization maneuver). The probe gains precious centimeters of exploration and is now pointing to the sky at a PLAPS point. Minimal effusion or posterior consolidation can be diagnosed. Note that the effusion has slightly moved toward the medial line (the *arrows* indicate the maximal thickness, the *circle* the medial line), indicating also that the maneuver of turning the patient should be minimal (a wider maneuver could result in locating this effusion at the mediastinal wall)

- The upper BLUE point is defined between the third and fourth finger of the upper BLUE hand, at their palmar insertion.
- The lower BLUE point is defined at the middle of the palm of the lower BLUE hand. This allows avoidance of the heart in most cases, while having a symmetric definition. The lower BLUE point is near to the nipple in the adult, far below in the neonate, but works at any age.
- The little finger of the lower BLUE hand indicates the phrenic line (Fig. 14.3). The continuation of this line and its intersection with the middle axillary line defines the phrenic point, locating the usual lateral place of the cupola (which can vary if there is atelectasis or lung overdistension).
- The PLAPS point is posterior (Fig. 14.5). PLAPS is a practical abbreviation for posterior and/or lateral alveolar and/or pleural syndrome. It is sought in a Stage 3 examination, i.e., in a *supine* patient. The PLAPS point is designed for detecting most alveolar or pleural disorders (see the BLUE protocol design page 200).

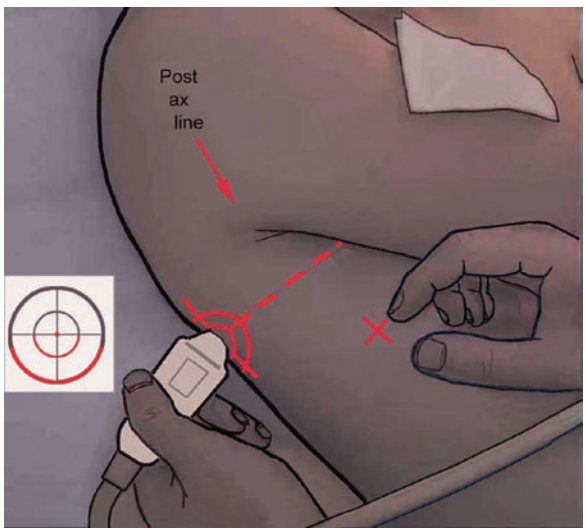

Fig. 14.5 The PLAPS point (PLAPS: posterolateral alveolar and/or pleural syndrome). This is Stage 3, which adds this external part of the posterior area, using a short probe, here with minimal turning of the patient to the left. The probe is applied at the PLAPS point, i.e., the intersection between the transversal line continuing the lower BLUE point (*dotted line*), and the longitudinal posterior axillary line (*arrow*), or, as seen here, as far as possible behind. This will immediately detect small and large pleural effusions (and 90% of cases of alveolar consolidations in the critically ill patient). The target to the left indicates the down extensions of the PLAPS point. Using the PLAPS point, the probe is slightly above the diaphragm, i.e., in full lung area. The right index points on the phrenic point (*cross*)

The native description of the PLAPS point is simple: the intersection between the posterior axillary line and the transversal line continuing posteriorly to the lower BLUE point. Yet for maximal accuracy, one must use variable geometry.

As regards for its horizontal component, the short probe should be inserted as far as possible behind the posterior axillary line, depending on the body habitus, the possibility to slightly turn the patient's back. The shorter the probe, the better the PLAPS point.

For its vertical component, a negative finding for PLAPS makes the investigation already superior to radiography, in terms of diagnostic accuracy. Yet to achieve results akin to CT, a rapid extension to one intercostal space below is wise, defining an extended PLAPS point—or if still negative, to the next intercostal space (super-extended PLAPS point), which usually shows the cupola. The operator aims at the PLAPS point, then, if needed, a lower level, and again if necessary (Fig. 14.5). The maneuver will show (if any) very small lesions above the cupola.

Philosophy of the BLUE points: Specifically designed for the BLUE protocol, the BLUE points make lung ultrasound simple. They are standardized and therefore reproducible, associating clinical efficiency and ease of use. They integrate the notion that pneumothorax, interstitial syndrome and pleural effusion have a wide projection. Yet the operator is free to insert the probe at will. If a BLUE point is not accessible (dressing, subcutaneous device), the probe will be applied beside. The PLAPS point was carefully studied for optimizing the search for pleural or alveolar disorder, even small. The aim of the PLAPS point is to have the probe located at the thorax. Too cranial would miss small juxta-phrenic lesions, too podal would result in application of the probe at the abdomen, showing structures difficult to describe, usually fat, mimicking alveolar images. It is easier to avoid these structures than to try to explain why they are not thoracic. Using the notion of extended PLAPS point, the operator will descend and detect the diaphragmatic insertion easily. The bottom of the scapula as a landmark was not found to be practical enough. The principle of this flexible approach allows the PLAPS point to be defined with maximal accuracy and minimal explanation.

The label *upper* or *lower* BLUE point assumes a Stage 1 or 1′ analysis (if not, position has to be specified).

BLUE Points and Clinical Information

The upper and lower BLUE points immediately indicate anterior interstitial syndrome.

The upper BLUE point immediately indicates pneumothorax in a Stage 1′ examination (dyspneic patient).

The lower BLUE point immediately indicates pneumothorax in a Stage 1 examination (ventilated patient).

The PLAPS point immediately indicates the huge majority of pleural effusions, whatever their size, and 90% of locations of acute alveolar consolidations. Obviously, substantial effusions or consolidations are detected at the phrenic point, very substantial cases can approach anterior BLUE points.

The phrenic point immediately indicates one lung intubation, esophageal intubation, phrenic palsy, etc.

Location of the Lung in Challenging Patients

The organs are the same in thin and overweight people, but it can be difficult to locate the lung. The BLUE hands are of great help for initiating the point of research. For the PLAPS point, one can hesitate. We use some principles inspired from air navigation. If there is a doubt about the diaphragm, the user will scan podally and identify a large mass below (i.e., to the feet) that may also look ill-defined. This tissular mass is supposedly the spleen, but may be an alveolar consolidation. If the user goes on scanning downward and detects an organ that is also ill-defined but looking, even from afar like a kidney, the probability of a kidney surrounded by a spleen is major and the phrenic location is confidently determined.

The Case of the Patient in the Prone Position

The simplest way we found eventually was to consider the scapula (the point just inside the internal border at halfway) as an equivalent of the upper BLUE point (upper prone point?). The point at the lower end of the scapula would fit for the lower BLUE point (lower prone point?). A horizontal line drawn from one or two fingers above the point where the lower rib reaches the rachis usually indicates the diaphragm, at least in young adults (Fig. 14.6).

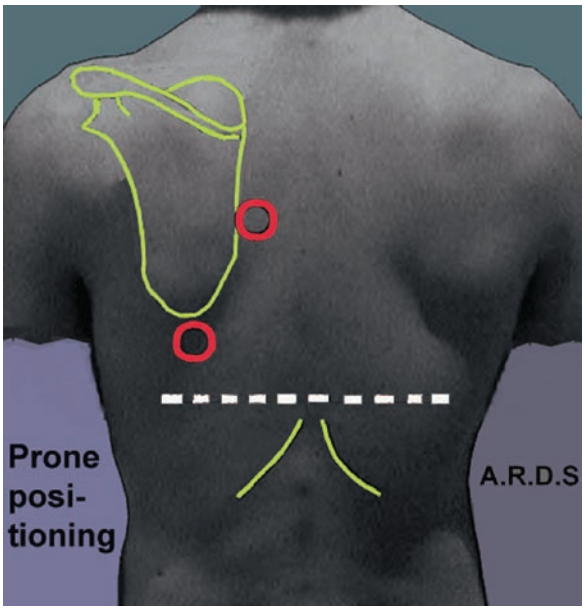

Fig. 14.6 The prone points. Patient in the prone position. The upper prone point is located just inside the middle of the scapula. The lower prone point is just below the scapula. We determine the junction between lung and abdomen, in young adults, at 1 or 2 cm above the point where the last ribs reach the rachis

Aside Note

Of little interest to the intensivist, the upper BLUE point is roughly located at the upper lobe or culmen, the lower BLUE point at the middle lobe or lingula, and the PLAPS point at the lower lobe. In the prone position, one can correlate the upper third to the upper lobe, the middle to the Fowler segment of the lower lobe, and the lower third to the basal pyramid of the lower lobe.

Development of the Fourth Principle: Defining the Pleural Line

Now it is time to take the probe. Figures 1.2 and 1.3 page 4 show correct and incorrect ways to hold it. The probe

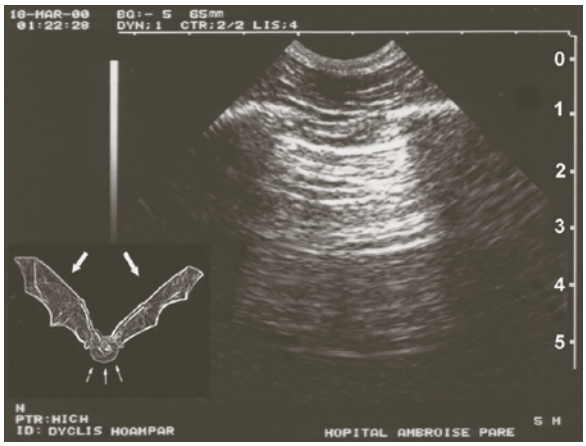

Fig. 14.7 The bat sign and the normal lung surface. The *right vertical scale* is in centimeters. The ribs (1 cm) are recognized by their arciform shape with frank posterior acoustic shadow. A horizontal line below the ribs line (1/2 cm in the adult) is highlighted (1.5 cm). This is the pleural line, which basically indicates the lung surface. The upper rib/pleural line/lower rib profile shapes a kind of bat flying toward us, hence the bat sign, a basic landmark in lung ultrasonography. The horizontal lines arising from the pleural line are repetitions of the pleural line, called A-lines (3.5 and 5 cm), and located at a precise distance: the distance between the skin (0 cm) and the pleural line. These A-lines are large. The pleural line and the A-lines cannot be confused with other horizontal lines located above or below. See Fig. 14.10, for more details

is perpendicular to the anterior chest wall (Stage 1), and tries to be perpendicular in Stage 3.

We do not use the traditional subcostal approach. This route, from the old school, can be misleading (see Fig. 15.1 page 129). Our microconvex probe allows a direct intercostal approach.

We do not use transversal scans. Slight movements create large changes of the image, making ultrasound difficult (see Fig. 1.4 page 6).

A first step is the recognition of the rib and its acoustic shadow in a longitudinal scan (Fig. 14.7). Neglecting this step can cause serious mistakes. In normal adults, the rib makes a roughly 2-cm arciform hyperechoic structure. Ribs are roughly 2 cm apart from each other.

The rib line is a virtual line passing by the top (on the screen) of two ribs.

Half a centimeter below the rib line (in the adult), a hyperechoic, roughly horizontal line is always visible: the pleural line (Fig. 14.7). The pattern created by the upper rib, the pleural line, and the lower rib has been labeled the bat sign. The bat sign is the basic step in any lung ultrasound, allowing one to precisely locate the lung surface using a permanent, stable landmark. Using longitudinal scans, the pleural line is always under control, even in agitated patients or a shaky environment.

The concept of the bat sign avoids confusion with all other horizontal hyperechoic lines, i.e., superficial aponevroses or deep repetition lines (A-lines, A′-lines, see below).

The visible length of the pleural line, between two rib shadows, is roughly 2.5 cm (since the concept of a sectorial scan makes a triangular image) in the adult.

In the neonate, the bat sign has exactly the same proportions (see Fig. 21.2 page 205). At any age, the pleural line is located at roughly a quarter to a third of the distance between the two rib borders.

The pleural line indicates the interface between the soft tissues (rich in water) of the wall and the lung tissue (rich in air), i.e., the lung-wall interface, that shows the parietal pleura in all cases, and the visceral pleura, i.e., the lung surface, only when there is no pneumothorax (nor pulmonectomy). The pleural line makes the parietal and visceral pleuras one line. The pleural cavity is normally virtual. With our 5-MHz probe we do not distinguish the two layers, which is not a problem. All signs arise at the very level of the pleural line (Fig. 14.8). When the pleural layers are separated, the visceral pleura is hidden by air in the case of a pneumothorax. It is perfectly visible in the case of a pleural effusion.

Variant of the bat sign: the "young bat sign." If the probe is applied near the sternum, the cartilage generates an ovoid structure that is traversed by the beam. We associated this pattern to the image of the young bat (with the idea that the bones are not yet calcified).

Technical note: Beginners, in workshops, often recognize the pleural line thanks to the lung sliding. We do not advise this way, because they will be confused in critical settings, where lung sliding can be absent. The pleural line should be recognized without any dynamic reference, only using the bat sign.

Development of the Fifth Principle: Dealing with the Artifact Which Defines the Normal Lung: The A-Line

Once a probe is applied on an intercostal space, it is true that only artifacts (from bones and air) are visible. These artifacts were always considered undesirable. We will discuss them here. We will define Merlin's

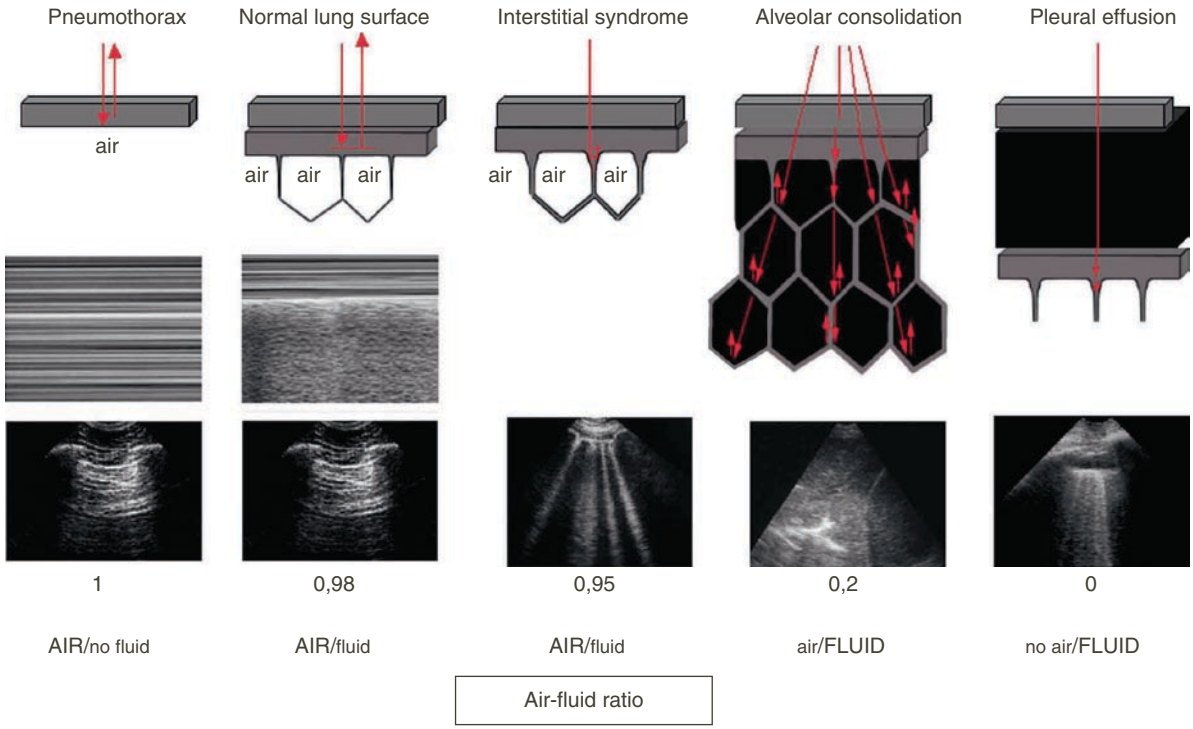

Fig. 14.8 This figure demonstrates the basis of lung ultrasound according to the air-to-fluid ratio. *Pneumothorax*: The pleural line is drawn by only the parietal pleura. Pure air abuts the pleural line. This yields A-lines. The absence of visceral pleura yields abolition of lung sliding. *Normal lung surface*: The dynamics of the visceral pleura generates lung sliding. The normal interlobular septa are too fine for generating B-lines. The visceral pleura contains a layer of cells with minimal hydric content (this generates a structure able to create lung sliding). *Interstitial edema*: These subpleural interlobular septa are thickened and surrounded by alveolar gas. The beam penetrates this small mixed system, is trapped after less than 1 mm, tries to come back at the probe head, but is trapped again; this results in persistent to-and-fro movements, generating one small line at each movement, resulting all in all, at the speed of 1,540 m/s, in a long, vertical hyperechoic line, the B-line (a fluid-air artifact). Although enlarged, the septum is still too small to be visualized directly. *Alveolar consolidation*: Numerous alveoli are filled with fluid (transudate, exudate, etc.). The (deep) interlobular septa are now not only thickened, but surrounded by fluid elements. The correct term should therefore be alveolar-interstitial syndrome. There is no place here for the generation of comet-tail artifact. The thickened interlobular septa generate multiple interfaces, resulting in a tissue-like pattern. *Pleural effusion*: The two layers of the pleura are separated by fluid – resulting in a homogeneous pattern (traditionally anechoic, except for the critical causes: empyema, hemothorax), which is enclosed by four regular borders, especially the lower one: the lung line

space as the space located between the pleural line, the shadow of the ribs and the lower border of the screen (from a question of Elisabeth Merlin, from a CEURF session). Merlin's space is occupied by air artifacts or anatomic disorders.

For the sake of rapid communication, the artifacts arising from the pleural line were given short names using an alphabetic classification (we describe 12 of them at the pleural line: A-, B-, C-, F-, I-, J-, N-, O-, P-, T-, X-, and Z-lines). This is simpler than it appears at first view. Other artifacts are described above the pleural line (E, S, W-line), in other parts of the body (G-, R-, and U-lines), or outside the body (H- and K-lines). Most are either horizontally or vertically oriented. In this introductory chapter, only the main normal artifact will be described.

The Main Normal Artifact: The A-Line

The normal artifact is the repetition of the pleural line, a roughly horizontal hyperechoic line parallel to the pleural line (Fig. 14.7). We called this artifact the A-line, following the alphabetic logic. Air blocks the ultrasound beam, which comes back to the central unit, yielding this regular artifact. The distance between the

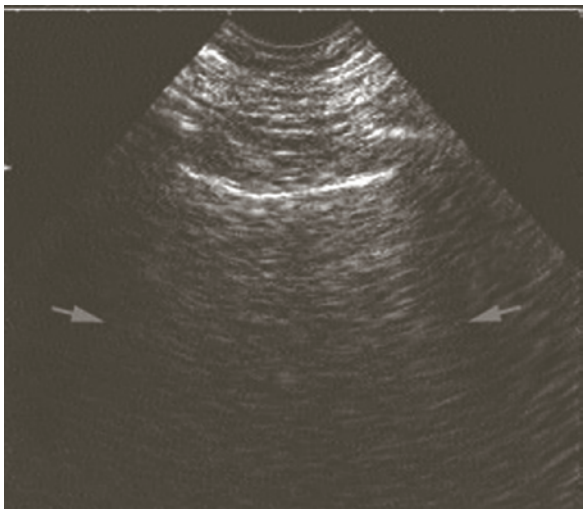

Fig. 14.9 An O-line. Merlin's space is completely homogeneous here, without any anatomic image. This is an elementary air artifact without generation of A-line (the *arrows* delineate their expected location). As opposed to endless zoologic discussions about the zebra's coat, this figure proves that the natural tone of air is dark on ultrasound. Normal and pathologic air (pneumothorax) can yield O-lines

pleural line and the A-line is equal to the skin-pleural line distance. Several equidistant A-lines can be visible. They can be called A1-lines, A2-lines, etc., according to the number of observed lines. Horizontal artifacts are sometimes seen between two A-lines, and are called A′-lines or A′′-lines (see Fig. 18.9).

The A-line is usually as long as the pleural line (slightly longer, given the sectorial image), but can be shorter, or even not visible (Figs. 14.9 and 1.5 page 7). In this case, the Merlin space is homogeneous. Slight Carmen maneuvers can make the A-lines appear, but this is not a clinical problem, provided there is no visible B-line (see Fig. 17.1 or 17.2 page 153). This absence of any artifact is called the O-line (O for non-A, non-B), or again A° line, if one calls the first visible A-line the "A1-line." In other words, to see the complete absence of any artifact arising from the pleural line has the clinical meaning of the A-line: just *air*. The O-line concept allows demonstration of the real tone of air. Fluid-air artifacts (the B-lines) give hyperechoic patterns, up to a completely white diffuse pattern (the Birolleau variant, see Fig. 17.7 page 155). We conclude that fluids, traditionally described as anechoic, yield hyperechoic tone, when minute and surrounded by air. We also conclude that the natural tone of the pure air is, in the ultrasound world, dark.

Note

The A-line is the normal artifact, yet it is also one of the signs of pneumothorax. What should be understood is that A-lines indicate air, i.e., quasi-pure (normal lung surface) or pure (pneumothorax) air. A third kind of air is encountered: the air of the ICU room. A probe on its stand shows horizontal lines, the H-lines (see Fig. 18.4 page 167). Air yields horizontal lines.

Other Artifacts

The main other artifact is the vertical B-line. Its description raises a didactic issue because it is pathological but some locations are found in the normal lung. See Chap. 17 page 158, normal variants. The Z-line is a parasitic artifact (i.e., it yields no clinical information), see Fig. 17.8 page 156.

Development of the Sixth Principle: Defining the Dynamic Characteristic of the Normal Lung: Lung Sliding

Like any vital organ, the lung permanently moves from birth to death without interruption. Lung sliding, the basic dynamic sign arising from the pleural line, indicates the inspiratory descent of the visceral pleura against the parietal pleura, and the expiratory ascent. Ultrasound has been able to detect this fine movement since at least 1982. We could see that previous pantographic systems were able to demonstrate this dynamic, at least using M-mode. Observation of the pleural line shows this to-and-fro dynamic (glittering, shimmering, sparkling, twinkling).

The lung is a craniocaudal piston. Lung sliding is more easily seen using longitudinal scans. This is one of the many reasons why we advocate them. The dynamic of the lung must be studied with a motionless hand, steadily applied. Movements of the operator would generate fatigue and make ultrasound a difficult exercise. Like a *sniper*, once having got the best image of the bat sign, the operator stops any movement and quietly watches at the pleural line (see Figs. 1.2 and 1.3 page 4).

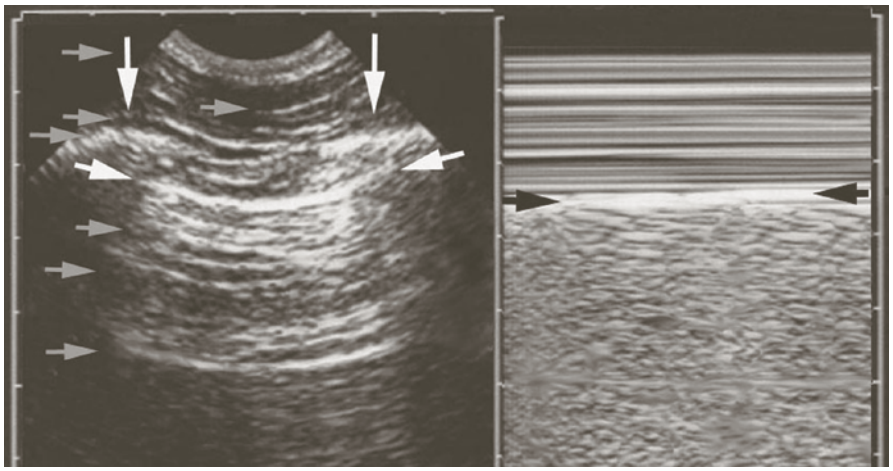

Fig. 14.10 The seashore sign and other details. *Left*: Real-time image. The vertical *arrows* show the ribs. The horizontal white lines show the pleural line, clearly defined by the bat sign. *Gray horizontal arrows* show some of the numerous horizontal lines that should not be confused with the pleural line. They indicate, from top to bottom: the skin, some aponevroses, a rib, minor air reflections below the pleural line (called A′-lines), and (*lower gray arrow*), an A-line. *Right*: M-mode. A marked difference appears on either side of the pleural line (*arrows*). The motionless superficial layers generate horizontal lines (waves). Lung sliding generates the sandy pattern. This whole, called the seashore sign, demonstrates the lung sliding on a static view. Note a critical detail: both images are strictly at the same horizontal level. This allows immediate location of the pleural line on the M-mode image, without any confusion possible: a keypoint in extreme emergencies (compare with Fig. 18.1 page 165)

The M-mode is useful, not for demonstrating lung sliding, but for data recording. The characteristic pattern recalls a seashore and is called the seashore sign (Fig. 14.10). "Beach sign" was a little short for such a basic sign. The M-mode provides dynamic information, unlike a frozen image. Not only is an M-mode figure easier to insert in a medical file than a videotape (or was for many years), but this mode helps the beginner to better understand lung sliding. The parietal tissues are motionless, or there is a slight diffuse movement. This slight movement is unavoidable because both the patient and the doctor are alive, generating minute dynamics on the screen. This "background noise" does not appear on an M-mode image, which allows the seashore sign to appear, strikingly, from one millimeter to another.

Basic points about lung sliding are considered in Chap. 18.

Lung rockets associated with lung sliding behave like pendulums, which amplifies their dynamic. This is one of the countless advantages of our microconvex probe, which gives a sectorial image.

With experience, 1 s is enough to recognize lung sliding, a crucial advantage.

Technical note: Lung sliding, or sliding lung, is easy to pronounce. Pleural sliding and pleural gliding are more difficult (even for native English speakers). The term "gliding sign" can be confused with pericardial, peritoneal, muscular, eyeball, and many other gliding structures.

Important technical note: Lung ultrasound easiness is explained by the pleural line being visible wherever the probe is applied. No time is lost in searching for a window. The pleural line and the normal signs arising from it (A-lines and lung sliding) are the same at any part of the thorax. The lung is a simple organ, unlike a heart, an abdomen (which contains more than 21 organs), or a fetus.

Very important technical note: An immoderate use of the M-mode can generate confusions requiring long explanations, which will be detailed in Chap. 18. Basically, the user must detect lung sliding on real-time, and then make a hardcopy using M-mode – not the reverse way.

Development of the Seventh Principle: Acute Disorders Have Superficial Location

The seventh principle explains all about critical lung ultrasound.

The superficial extension of most disorders to the pleural line, which is superficial, is providential. This explains the 98–100% feasibility of lung ultrasound in the critically ill. Pleural effusion and pneumothorax always reach the pleural line (no necessary study for proving it – read any CT). We will see in Chap. 16 that alveolar consolidations seen in acute situations touch the chest wall in nearly all cases, and in Chap. 17 that acute interstitial changes involve deep areas as well as superficial, subpleural ones. Figure 14.8 explains how these disorders are sharply detected. As opposed to bedside radiography, which creates a summation of pleural, alveolar, and interstitial changes, ultrasound distinguishes each of them. The next chapters will show that each acute disorder gives a particular signal: alveolar consolidation from pneumonia to atelectasis, interstitial disorders, abscess, and even pulmonary embolism.

A figure in Chap. 19 page 186 shows that only 10 signs are required for diagnosing normal lung surface, pleural effusion, alveolar consolidation, interstitial syndrome, and pneumothorax (Fig. 19.3).

Practical Progress of a Basic Normal Lung Examination

We apply the probe on the right upper BLUE point. We identify the bat sign (2 s). Then we identify lung sliding (2 s). Then we analyze the Merlin space. Only A-lines should be visible (2 s). A routine Carmen maneuver indicates that no B-line is visible (getting rid of the unlikely possibility of having inserted the probe precisely between some thickened subpleural interlobular septa). This takes 3 s. The lower BLUE-point is then analyzed (9 s more). The Stage 3 is performed (6 s for setting the patient) and the PLAPS point is analyzed, searching either air artifacts or PLAPS, i.e., taking 8 s. The left lung is then analyzed.

All in all, the procedure takes 1 min and informs on the existence or not of interstitial syndrome, pneumothorax, pleural effusion, and most of alveolar consolidations, i.e., the same information in an emergency that is obtained *from a CT*.

We could have added other points, but, in the words of Sybile Merceron: “too many points would kill the points.” We agree. Note that these sophistications did not come at the outset of our work [1].

Reference

1. Lichtenstein D (1997) Lung ultrasound: a method of the future in intensive care? (Editorial). Rev Pneumol Clin 53:63–68

Pleural Effusion

15

We begin with pleural effusion for two reasons: 1) to follow the air-to-fluid ratio of the lung ultrasound terminology, and 2) to begin slowly. Pleural effusion is a familiar application that has long summarized the interest of thoracic ultrasound. This possibility was imagined by Dénier in 1946 [1] and assessed by Joyner in 1967 [2]. Pleural effusions are common in critically ill patients: 62% in a medical ICU, 41% being present on admission [3].

This application could be, in itself, a sufficient reason to use ultrasound. Yet in some institutions, this basic diagnosis still remains, somehow, little exploited. We think that additional signs should be considered because this diagnosis can be of variable difficulty using traditional approaches.

Ultrasound evaluates the volume, the nature of an effusion, and indicates the appropriate area for a thoracentesis far better than radiography.

The fast detection of pleural effusion is part of the BLUE protocol.

For this application, our 5-MHz microconvex probe is perfect.

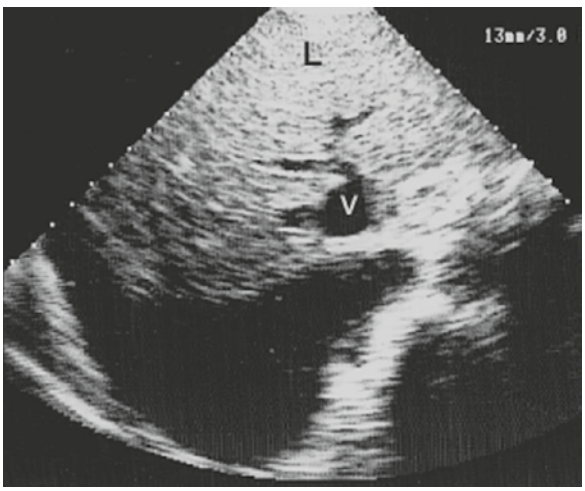

Fig. 15.1 Pleural effusion, traditional approach. It appears during a transabdominal approach, through the liver (*L*), in a transversal scan. This does not provide a definite diagnosis with certain lower lobe consolidations and also does not allow ultrasound-guided thoracentesis. Note that the effusion goes posterior to the inferior vena cava (*V*), a feature that distinguishes, if necessary, pleural from peritoneal effusion

Positive Diagnosis of Pleural Effusion

Our Technique

Traditionally, pleural effusions were detected during abdominal examinations, using abdominal probes and a subcostal approach (Fig. 15.1). This is a really limited approach. We find it safer to analyze the pleura directly through the intercostal spaces with a microconvex probe. Therefore, new signs adapted to this new approach have to be described.

Pleural effusion collects in dependent areas (principle number 2 – fluid is heavier than air). Any free pleural effusion is therefore in contact with the bed in a supine patient. Rotating the patient laterally is constraining and not satisfactory if the effusion moves to inaccessible dependent areas (see Fig. 14.4 page 120). We remind our solution, detailed in Chap. 14. We use a *short* microconvex probe. Such a probe can be easily inserted, as posterior as possible, at the posterior wall after having slightly rotated the patient, therefore scanning at the *PLAPS point* (described in page 121).

The principle of the PLAPS point is simple: if only one "shot" was allowed for determining whether there is, or is not, a pleural effusion, it should be this location. The

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PLAPS point indicates in a few seconds the huge majority of free pleural effusions, either abundant or minute. In addition, it indicates 90% of cases of acute alveolar consolidations, which preferably locate here [4].

The Signs

Traditionally, the diagnosis is based on an anechoic image. This is not a satisfactory criterion in the critically ill. Life-threatening effusions are echoic: hemothorax, pyothorax, etc. We begin characterizing the effusion through its position: abnormal dependent image located above the diaphragm (i.e., at the PLAPS point). We now add two criteria of our own.

1. *The quad sign.* This is the main static sign. A pleural effusion can be framed within a quad. It is limited by four *regular* borders forming the shape of a quad (Fig. 15.2). These borders are the pleural line, from where it arises; the upper and lower shadows of the ribs, regular as any artifact; and the deep border, which is always *roughly parallel to the pleural line* and *regular,* as it represents the lung surface. We imagine that apart from irregular pleural tumors (that we never yet see), the lung surface is always regular. This line was called the lung line, an ultrasound marker of the visceral pleura. The lung line is visible when the visceral pleura is separated from the parietal pleura by a structure that allows ultrasound transmission, like a fluid effusion. In a healthy subject, the lung line is virtual, making one with the visceral pleura and the parietal pleura.

As a part of the definition, the lung must arise from the lung line. This avoids possible confusion between effusion and alveolar syndrome (see Chap. 16). The lung can appear as normal, yielding horizontal artifacts. It can yield vertical artifacts, the sub-B-lines (Fig. 15.2). It can yield alveolar consolidation (see Fig. 15.6).

Additional note: The aerated lung floats over the effusion. When lung injury increases, the lung gets the same fluid density that the effusion and floats within it. The impressive vision of the inferior recessus of the lung freely dancing within the effusion is reminiscent of algae; this is referred to as "the jellyfish sign," although the term "sirena tail" was suggested by Anne-Charlotte (from Tahiti 2005). Agnes Gepner gave a label that we could not assume. The jellyfish sign is a variant of the sinusoid sign, see below (Fig. 15.4).

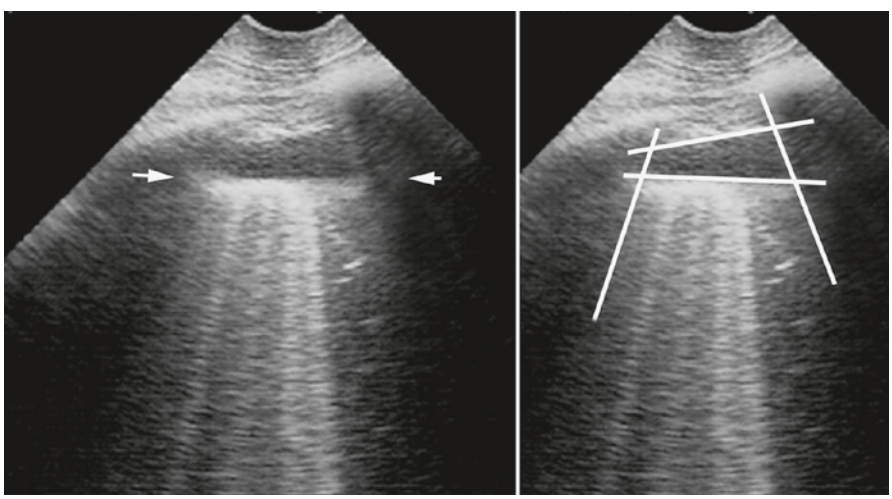

Fig. 15.2 Minimal pleural effusion. Longitudinal scan at the PLAPS point. This figure indicates several pieces of information. (1) It shows the quad sign: the dark image is an effusion because it is framed within four regular borders: the pleural line, the shadow of the ribs, and mostly the regular deep border (the lung line – *arrows*). The quad sign is drawn at the right image. (2) It shows the absence of local lung impairement, since the image beyond the lung line is artifactual. (3) It indicates the volume of the effusion. The interpleural expiratory distance is 7 mm. This corresponds to a 20- to 40-mL effusion. Such thickness found on Stage 1 would indicate major effusion. (4) This effusion seems too thin for safe thoracenthesis. (5) This figure shows the sub-B-lines (artifacts looking like B-lines, arising not from the pleural line but from the lung line, whose meaning is not strictly the same, since a healthy lung may be compressed by the fluid)

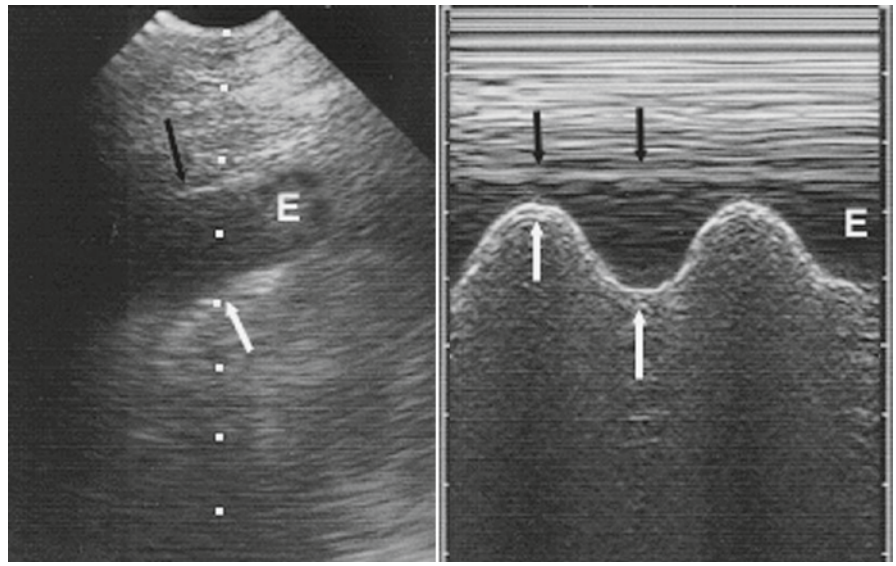

Fig. 15.3 The sinusoid sign. In a longitudinal scan of the base, this collection's thickness (*E*) varies in rhythm with the respiratory cycle. The deeper border (*white arrows*) moves toward the chest wall, shaping a sinusoid, whereas the superficial border (*black arrows*) is motionless (pleural line). The sinusoid sign is specific to pleural effusion

Technical note: to have a well-defined lung line at the PLAPS point, the probe must be as perpendicular as possible (a long probe length is a factor of difficulty).

2. *The sinusoid sign.* The main dynamic sign is the respiratory variation of the interpleural distance with inspiratory decrease, i.e., a dynamic of the lung line toward the pleural line (Fig. 15.3). This sign, called the sinusoid sign, indicates the inspiratory increase of size of the lung, hiding the fluid collection. As the lung moves toward a "core-surface" axis, the pattern on M-mode is a sinusoid.

The sinusoid sign is quite specific to pleural effusion. In addition, it indicates low viscosity, as we will see below. In very viscous effusion or septate effusion, the sinusoid sign is not present.

Note: In the logic of the BLUE protocol (see Chap. 20), i.e., for making fast diagnosis of acute respiratory failure, the distinction between pleural effusion and alveolar consolidation is not required. This allows a rapid training of the teams.

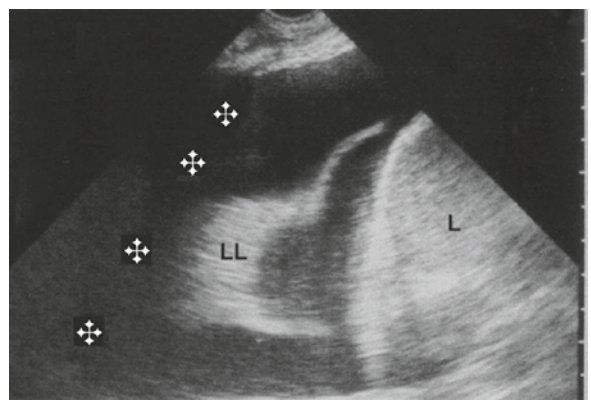

Fig. 15.4 Substantial pleural effusion. Intercostal route, longitudinal scan, PLAPS point. The anechoic pattern just evokes the transudate. The lower lobe (*LL*) swims within the effusion in real-time (yielding sinusoid sign). The phrenic course can be measured. The pleural effusion (real image) and the posterior shadow of the rib (*asterisks*) are both anechoic. The PLAPS index should be measured roughly at the lung line (i.e., here, 35 mm, indicating roughly 1,500–2,500 mL), and not below the lung, where it should be meaningless, going up in fact to the mediastinum (here more than 9 cm). *L* liver

Value of Ultrasound

The quad and sinusoid signs confirm the presence of pleural effusion with a specificity of 97% when the gold standard used is withdrawal of pleural fluid [5]. Sensitivity and specificity are both 93% with CT as the gold standard [6]. Note that extremely small effusions generating anyway a quad sign and sinusoid sign can be missed on CT, raising the problem of the pertinence of this gold standard.

Interest of Ultrasound

Ultrasound provides clear advantages compared with the physical examination (we rarely hear a pleuritic

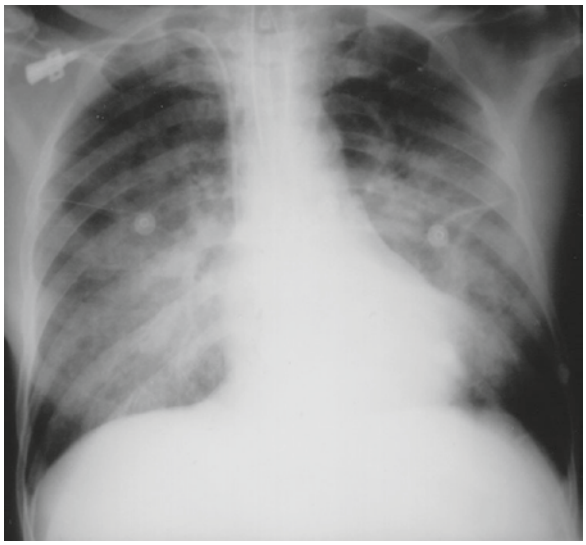

Fig. 15.5 Bedside radiography in patient ventilated for acute respiratory failure. Initial diagnosis: cardiogenic pulmonary edema. Both cul-de-sacs seem free. Using ultrasound, pleural effusion is safely tapped, withdrawing exudate. Definitive diagnosis: infectious pneumonia

murmur or pleural rubbing in critically ill patients), but above all compared with radiography (Fig. 15.5). Ultrasound usually detects the effusion occulted in radiography [6,7]. Up to 525 mL can be missed with bedside radiography [8,9]. Small effusions are regularly missed. Some alveolar consolidations perfectly mimic pleural effusions on radiography.

We will see that ultrasound can diagnose and safely tap pleural effusion that is radio-occult, even in ventilated patients. The poor value of bedside radiography was highlighted again by a study showing that one-third of ultrasound-visible effusions in ventilated patients, with enough volume for safe thoracentesis, remained occult to bedside radiography [5]. Conversely, when the radiograph is very pathological, ultrasound distinguishes the fluid and the solid components.

Ultrasound can perfectly detect effusions of 1-mm thickness (Fig. 15.2), provided the probe is applied at the correct spot. This can be difficult with respect to the constraints of gravity if the probe is too long. Our 8-cm long probe has an appropriate length for reaching the PLAPS point in supine patients.

Septated pleural effusions: Ultrasound is a major tool, long known in this application. These effusions do not always locate at the PLAPS point. Yet, finding a free PLAPS point associated with lung sliding should make septated pleural effusion unlikely, since this case supposes pleural adhesions, a condition resulting in abolishment of lung sliding. We await our first case.

Technical Notes

Abundant effusion allows analysis of deep structures (lung, mediastinum, descending aorta). One must take advantage of this effusion to explore them before evacuation: a ruptured descending aortic aneurism will be detected immediately.

A Minor Problem: How to Distinguish a Lung Line from an A-Line?

Sophisticated minds may ask such a question. Two points answer the question:

- The A-line is separated from the pleural line by the exact skin-pleural line distance.
- The A-line is standstill, without any sinusoid dynamic.

In addition, the space between the pleural line and the first A-line is usually echoic (with A′, A″ lines), whereas a noncomplicated pleural effusion is more often anechoic.

Assessing Pleural Effusion Quantity

We think that a rough estimation is sufficient, provided there is a policy behind it. Withdrawing fluid only when it is superior to (for instance) 1,500 mL is not fully satisfactory, since a highly diseased lung will not tolerate a restrictive syndrome as well as a more healthy lung. The approximation that we use seems more precise than the words “minor,” “moderate,” etc., and is sufficient for clinical practice, especially since our policy of thoracentesis in a critically ill patient is large (see Section on Interventional Ultrasound). We therefore accept a margin from the simple to the double. For instance, we can estimate that this effusion contains between 30 and 60 mL, the other one between 1,000 and 1,500 mL.

We evaluated several protocols for roughly indicating the volume of the effusion.

1. Our most recent approach: the "PLAPS index"

It favors simplicity. The PLAPS index requires inserting the microconvex probe at the PLAPS point, and simply measuring the distance between pleural line and lung line. Care must be taken to have a probe as tangential as possible to the chest wall. Each centimeter (of probe length, of body habitus) can be a hindrance, resulting in overestimating the dimensions by simple mathematic distorsion.

The PLAPS point indicates all volumes of free pleural effusion. A minimal effusion will have a millimetric thickness. It is detected without difficulty since it generates a small but frank quad sign and sinusoid sign (Figs. 15.2 & 15.3).

We measure in expiration (since in minor effusions, the lung line touches the pleural line on inspiration). Care must be taken to measure from the pleural to the lung line. A measurement from the pleural line to the mediastinum would not make sense, as seen when it is made too low (too podal) and does not reach the lung line but the mediastinum, since each effusion, small but able to detach the basis of the lung from the cupola, will have a standard depth of 10 ± 1 cm. Here is a simple rule for beginners: at the PLAPS point, the pleural thickness can range from 1 mm to 4 cm, rarely 5, exceptionally 6, never 7. A 10-cm value invites questions about one's technique. See comment in Fig. 15.4.

And now we can use the "PLAPS index." In the normal-sized adult, 0.3 cm correspond to 15–30 mL. One centimeter corresponds to 75–150 mL. Two centimeters correspond to 300–600 mL. Thirty-five millimeters correspond to 1.500–2.500 mL. Six centimeters seem a maximum, and measurements around 10 cm (in our defined conditions) cannot come from a pleural effusion. These numbers are extremely indicative.

Limitation of the PLAPS index: If the lung is massively aerated, it floats above the effusion, toward the sky. If the lung is massively consolidated, it will dive to the posterior wall, toward the earth, driving back the pleural effusion, which must skirt around this voluminous lung.

2. Experience

It was our previous way, but it cannot easily be transmitted; this is why we prefer to transmit the concept of the PLAPS index. Yet the gold standard that we used for validating the PLAPS index is our experience (based on scientific measurements done after thoracenthesis).

3. Approach by searching the anterior location of the effusion

A possible landmark is the location where the effusion begins to be visible with respect to the anterior axillar lines, in a strictly supine patient. A minimal but anterior effusion supposes abundant effusion (Fig. 15.2), yet this does not work in the case of massive lung consolidation (see above, Limitations of the PLAPS-index).

4. Other approaches

Several works can be consulted [10–13].

Diagnosis of the Nature of Pleural Effusion

In the ICU, the main causes of effusion are transudate, exudate, and purulent pleurisy. In a medical ICU, Mattison found a 62% prevalence of pleural effusion, 41% at admission [3]. The main causes were cardiac failure (35%), atelectasis (23%), parapneumonic effusion (11%), and empyema (1%). Analysis of the echogenicity provides a first orientation [14]: to sum up, transudates are anechoic, anechoic effusions can be either transudates or exudates, and all echoic effusions are exudates. This indicates that ultrasound is not reliable for indicating that a puncture is not necessary. We, therefore, have a rather active tap policy each time there is space for debate (complex patient). In addition, unfavorable conditions (challenging patients) create parasite echoes with difficulties to affirm the anechoic pattern of the effusion. We respect anechoic effusions when the context is clearly the one explaining transudate, with no argument for infection, etc.

Congestive Heart Failure and Situations of Hyperhydratation

These situations yield transsudates, yielding anechoic effusion.

Pulmonary Embolism

Cases of pulmonary embolism with acute respiratory failure yield small pleural effusions in half of the cases (for a synthesis, please refer to Chap. 29 page 284).

Infectious and Inflammatory Effusions (Exudates)

Exudate can be anechoic, regularly echoic, or contain various amounts of echoic particles (plankton sign) or septations.

Purulent Pleurisy

The pattern can be anechoic and homogeneous. Fine septations (Fig. 15.6), up to a honeycomb pattern (Fig. 15.7), can be clearly observed. A tissue-like pattern can be observed (Fig. 15.8). Novice operators can evoke alveolar consolidations. First, the lung line provides a solid discrimination. A sinusoid sign can be absent. The plankton sign is the name we suggested for the characteristic visualization within this tissue-like image of a slow whirling movement of numerous particles, as in weightlessness, punctuated with respiratory or cardiac movements. This pattern, even discrete, indicates the fluid nature of the image. Hyperechoic elements should correspond to infectious gas. As opposed to some teams (usually from pulmonology), we do not require Doppler for differentiating empyema from lung abscess – using the quad sign, sinusoid sign, tissue-like sign and shred sign.

In acute pachypleuritis due to pneumococcus, the effusion is separated from the wall by a tissue-like, heterogeneous thickening, with a lung line but without sinusoid interpleural variation (Fig. 15.9).

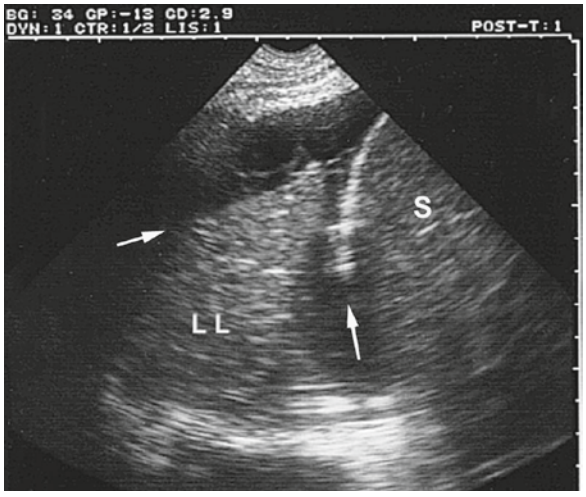

Fig. 15.6 Septated pleural effusion. Left PLAPS point. These septations indicate an infectious process. Deeper to the lung line (*horizontal arrow*), the lower lobe (*LL*) is entirely consolidated. The cupola is completely motionless (*vertical arrow*). The spleen is clearly detected (*S*), far enough from the puncture site. Example of PLAPS including pleural and alveolar disorders in one same view

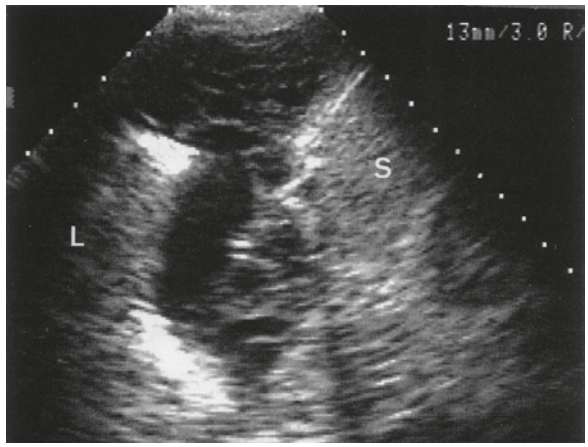

Fig. 15.7 Massive honeycomb pattern. Septic shock in 37-year-old man with pneumopathy due to *Clostridium perfringens*. White lung on chest radiograph. *L* lung, *S* spleen

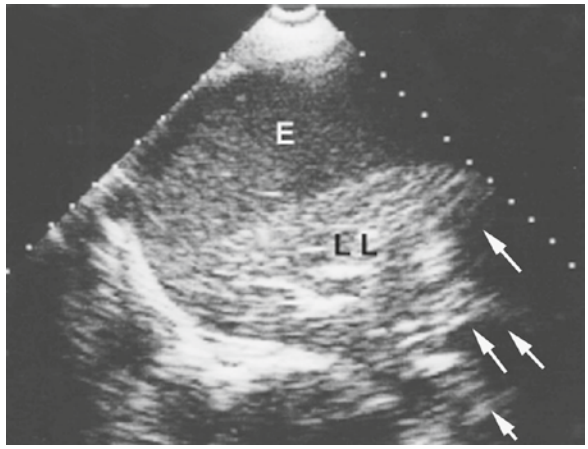

Fig. 15.8 Empyema. Lateral chest wall (exceptionally transverse view). Two areas (E and LL) have tissue-like echogenicity. The superficial area, E, is separated from the deep area LL by a regular line, making a lung line (which would yield a quad sign if longitudinal, with the rib shadows). The area E has a massive, slight movement: plankton sign, indicating not only fluid origin but also exudative pleural effusion. The area LL is limited by the regular lung line (between "E" and "LL") and a deep, shred sign (*arrows*), indicating its alveolar origin. It contains hyperechoic points generating dynamic air bronchogram (indicating non atelectatic origin). Abolished lung sliding, motionless cupola, and absence of sinusoid sign are typical from infectious process.

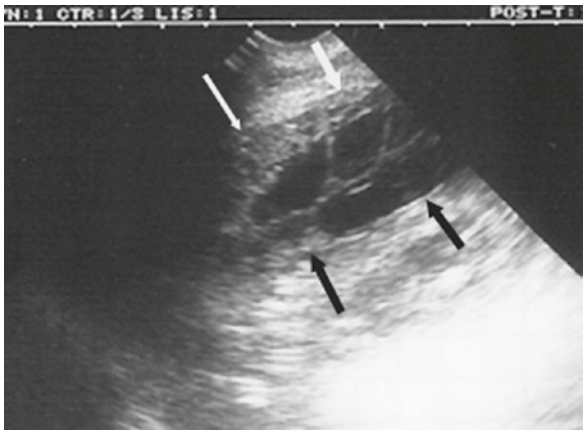

Fig. 15.9 Pachypleuritis. A 30-mm width pleural thickening around the lung (*arrows*) in pneumopathy due to pneumococcus. Note the echoic, tissular zones, and the anechoic zones (fluid septations). Lung sliding was completely abolished. Black *arrows* designate the lung line

In all these cases, the radiological pattern shows nonspecific pleural effusion (when it shows the effusion). Even CT misses the septations and various fibrinic structures [15].

Hemothorax

Hemothorax can yield echoic effusion giving the plankton sign (Fig. 15.10). Some protocols have been developed for fast detection of traumatic hemothorax. We are afraid they use abdominal probes (not suitable for posterior analysis) and even do not aim at posterior search. This leads to delay in the diagnosis of a hemothorax. We advise the use of a short microconvex probe and the use of the PLAPS point.

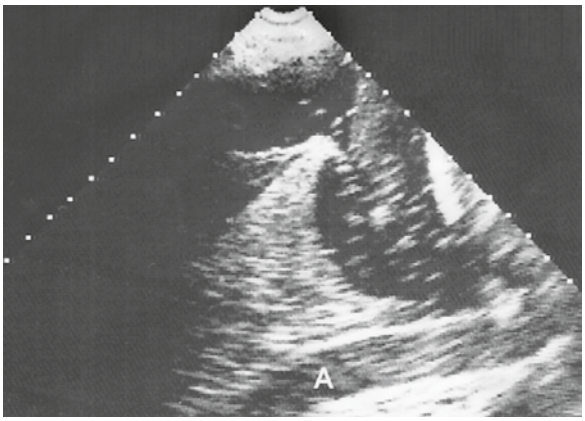

Fig. 15.10 Left hemothorax. This scan shows substantial effusion with multiple echoes, mobile and whirling in real-time (plankton sign). The lower lobe is consolidated. Note through this disorder a perfectly visible descending aorta with multiple ghost artifacts (*A*). The aorta is definitely far from a needle, which should be inserted at the top of the image

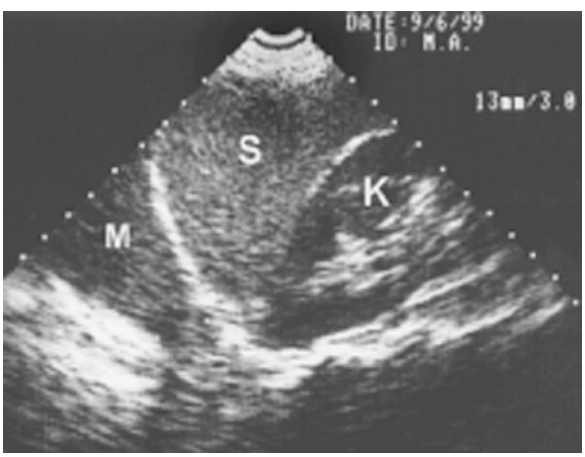

Fig. 15.11 Ghost. On this longitudinal subcostal scan, the left kidney (*K*), the spleen (*S*), the hemidiaphragm, then an area (*M*) evoking pleural effusion can be observed. This mass *M* has a structure a bit too close to the spleen. This can be a ghost generated by the spleen reflected by the diaphragm, a concave structure. Direct intercostal scans make these ghosts vanish

Apparent Pitfalls

An image appearing through the diaphragm during an abdominal approach can be due to pleural fluid, but also compact alveolar consolidation or subphrenic organs (spleen, liver). The sinusoid sign cannot be detected by the abdominal approach. Like all concave structures, the diaphragm has reflective properties and can reverberate underlying structures at an upper location (generating genuine ghosts) (Fig. 15.11). The best to avoid this kind of pitfall is to forget the abdominal approach.

An apparently fluid image without the sinusoid sign can be an alveolar consolidation, an encysted effusion at the periphery of a lung which has lost its compliance (parietal adhesions) or a very viscous effusion. The main pitfall must be recognized before any puncture: a hiatal hernia full of fluid gives a massive lateroposterior fluid image. The fluid, which as a rule is heterogeneous, evokes empyema. A swirl sign is sometimes visible, indicating the air–fluid level. Several points allow distinction with

pleural effusion. The main and sufficient one is the absence of lung line in the case of full stomach.

In rare cases, the image is completely hypoechoic, with no difference in structure between compact alveolar consolidation and pleural effusion. We call it the ultrasound dark lung. Discriminant signs such as the sinusoid sign, plankton sign, or dynamic air bronchogram can be absent and prevent any conclusion. Usually, the radiograph shows a white lung. This pattern is more often due to pleural effusion. In these rare cases, CT shows whether to carry out thoracentesis. In the absence of CT, if the image is compact (without air bronchograms), if the lung sliding is abolished, unpublished experience shows that the insertion of a needle does not create any pneumothorax. Positive withdrawal of fluid, if any (usual case), shows the fluid nature of the anomaly (the "syringe" sign, so to speak). See section "Interventional ultrasound" in Chap. 16 page 147.

A picturesque pitfall is the silicone that is found within some breasts. Its anechoic tone may confuse. A hundred tricks allow us to avoid this confusion; we will cite the first in the scale: no bat sign will be found above this collection, which is superficial to the lung.

Interventional Ultrasound: Thoracentesis in the Critically Ill

Ultrasound allows puncture of even minimal pleural effusions.

Technique

An ultrasound-guided procedure can be undertaken, but it is much simpler and effective to make an ultrasound landmark immediately before thoracentesis. The idea is to puncture where fluid is seen in a sufficient amount. We strongly suggest five criteria for safe thoracentesis [5]:

1. Presence of a quad and a sinusoid sign, confirming the pleural effusion (and especially distinguishing it from an ectopic full stomach).
2. The safety distance: an inspiratory interpleural distance of 15 mm, visible over three adjacent intercostal spaces, seems a reasonable minimum.
3. One must check for the absence of interposition (usually respiratory) of one of the five adjacent critical organs: lung (Fig. 15.2), aorta (Fig 15.10), heart, liver, or spleen (Fig. 15.7). Once they are known to be out of the field of puncture, a safe procedure can be initiated. Note than the lung may appear on the screen only at the end of inspiration. If no safe approach is recognized, one must rotate the patient laterally and proceed to a posterior tap.
4. Thoracentesis should be done immediately after ultrasound localization, with the patient remaining strictly in the same position. A clinical landmark made in the radiology department and followed by a tap once the patient is back in the ICU seems highly inadequate. In half of cases, the patient can remain supine, meaning a simple procedure.
5. Technical note: in elderly patients with skinfolds, the cutaneous area that was designed for puncture risks being shifted if care is not taken.

We use a 21-gauge (green) needle for diagnostic taps and a 16-gauge (gray) catheter for evacuation (see Fig. 26.2 page 265). The sinusoid sign indicates a low viscosity of the effusion, providing the possibility of using a fine needle. Typically, a few seconds (less than 10) are needed to obtain a fluid sample in most (88%) cases.

Safety of Thoracenthesis

Some doctors are reluctant to insert needles in the thorax of ventilated patients. Using our visual guidance, accidents are hard to conceive. In our published experience and others, ultrasound was of major help.

In Mayo's study, a 1.3% complication rate was noted [16]. In our experience, on 45 procedures in ventilated patients – one third being not apparent on radiograph – the complication rate was nil and the success rate was 97% [5]. We were able to leave the patient in the supine position in 49% of the cases, and a small-caliber needle was used each time with success: 21-gauge needles in 38 cases, and 16-gauge needles in six cases [5].

Interest of Thoracenthesis

Pleural effusion, frequent on admission of patients with acute respiratory failure, is rarely exploited; it is either

not detected on the usual radiographs or the intensivist aimed to not harm the patient (who received meanwhile probabilist antibiotherapy). By this approach, the physicians deprive themselves of a diagnostic tool, and from a therapeutic withdrawal. Ultrasound invalidates these hesitations. Even with no effusion visible on bedside radiography, in a ventilated patient on positive pressure (PEEP), the procedure is safe.

1. Diagnostic thoracentesis

Facing anechoic effusions, we believe it more prudent to perform ultrasound-assisted thoracentesis, if this might improve the prognosis. It provides a variety of diagnoses: purulent pleurisy, hemothorax, glucothorax. Distinction between exudate and transudate allows to distinguish hemodynamic pulmonary edema from ARDS (see also Chap. 20). The bacteriological value of a microorganism detected in a pleural effusion is definite [17]. A routine ultrasound examination at admission for all acute cases of pneumonia, when positive, should discredit the probability of antibiotic therapy. Personal observations of patients who had thoracentesis have found a rate of positive bacteriology of up to 16%, a high rate that dramatically increases if only untreated patients are included, on admission. Using ultrasound visual guidance, the high risk-to-benefit ratio speaks for a policy of easy puncture. This simple procedure makes long discussions of differential diagnoses irrelevant.

2. Evacuation thoracentesis

Fluid withdrawal improves the respiratory condition of the critically ill [10,11,18,19]. We estimate that a critically ill lung should not receive additional discomfort, and we routinely withdraw effusions that meet the safety criteria. How to scientifically quantify the relief of the patient may remain delicate. For weaning a patient, this application finds a first-line place. We avoid large tubes and use a system we have developed with our 16-gauge, 60-mm-long catheter (see Fig. 26.2 page 265). Ultrasound guides needle insertion. Using a 60-mL syringe, the fluid is withdrawn with an average flow of 1 mL/s, i.e., 20 min for a 1.2-L effusion. The catheter is withdrawn at the end; a simple small dressing is applied on the skin. This system has numerous advantages, including simplicity, no loss of time, no infectious risk generated by the dissection of the wall, no large wound, no need for making a bursa (pouch), no pain and limited costs.

Technical notes: Our multipurpose catheter has no lateral hole. The lung will come into frontal contact with the distal hole, suddenly blocking the aspiration in the syringe. The operator should withdraw the catheter millimeter by millimeter and go on aspiration, until the catheter comes out of the pleural cavity. The small dressing is interesting because a postprocedure ultrasound can be performed easily at the PLAPS point, unhindered by extensive dressings.

Unusual sites can be punctured – such as the right upper quadrant – where the liver usually is, when ultrasound had detected encysted pleural fluid instead.

Pleural effusion: seven main points:

1. Our 5-MHz microconvex probe is perfect in the adult (12 MHz in the newborn).
2. Forget the subcostal route.
3. Search for small effusions first at the PLAPS point.
4. The first main sign: deep limit is regular (the quad sign).
5. The second main sign: the lung line moves toward the pleural line on inspiration (sinusoid sign).
6. The echogenicity is *usually* dark (anechoic), but thanks to the quad sign and sinusoid sign, echoic effusions are straightforward detected.
7. Safe thoracentesis is possible in ventilated patients, even with radioccult effusions, following basic criteria.

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Lung: Alveolar Syndrome

16

Lung ultrasound was supposed to be of limited interest. We saw in the previous chapter that pleural effusion, although a familiar application, could benefit from enriched signs in order to yield a standardized approach. We now get deeper in the heart of the matter. In diseased lung, virtually any disorder gives a characteristic pattern (alveolar consolidation, atelectasis, interstitial syndrome, abscess, pneumothorax, even pulmonary embolism). We will introduce the lung smoothly by an application referring to a real image: alveolar consolidation.

In lung ultrasound, the images arise from the mingling of air and fluid (second principle). In alveolar consolidation, fluid is the major component. Nearly all disorders abut the pleura, therefore creating an acoustic window (seventh principle). With acute alveolar consolidation, these disorders abut the pleura in 98.5% of cases [1]. The way is opened for its ultrasound diagnosis.

This chapter will be mainly descriptive. The clinical relevance of this potential will be detailed in Chap. 20.

Our 5-MHz microconvex probe is perfect for investigation of the lung.

Some Introduction

Numerous terms are used in current practice: alveolar syndrome, condensation, density, infiltrate, parenchymatous opacity, pneumonia, bronchopneumonia, pulmonary edema. The word "atelectasis," in particular, is often misused facing any alveolar consolidation. This profusion of confusing words simply means that physicians do not often use these elements for taking major therapeutic decisions (and the words are therefore of lesser importance). "Hepatization" is a nice word in the ultrasound field, since the lung and the liver have a similar pattern. The term "alveolar filling" refers to a nonretractile cause. The term we use in daily practice, "alveolar consolidation," has the advantage of remaining neutral, not involving a particular etiology (infectious, mechanical, hydrostatic).

As early as 1946, Dénier, the father of ultrasound, described this possibility [2]. Ultrasound's potential was noted in the meantime [3–5]. However, CT correlations were rarely available, and we propose simple and standardizable signs for spreading out this application to the critically ill.

Alveolar Consolidation, Definition

Alveolar consolidation is a fluid disorder. Fluids are easily detected, explaining ultrasound potential. Here, the fluid (transudate, exudate, blood, water, saline solution, etc.) fills an alveola. One filled alveola should be too small for ultrasound detection but, usually, countless alveoli are contiguously filled. These fluid-filled alveoli, separated by interstitial tissues (interlobular septa), make a macroscopic pattern.

The ultrasound beam penetrates the consolidation, provided it reaches the chest wall (Fig. 16.1). The sound will be reflected by each interlobular septum, resulting in a diffuse tissue-like pattern. We hypothesize that each septum gives an image more echoic than the alveolar content. What is actually seen is alveolar-interstitial syndrome, since filled alveoli and interstitial tissue are simultaneously visible (see Fig. 14.8 page 124 and corresponding caption).

D. A. Lichtenstein, *Whole Body Ultrasonography in the Critically Ill,*
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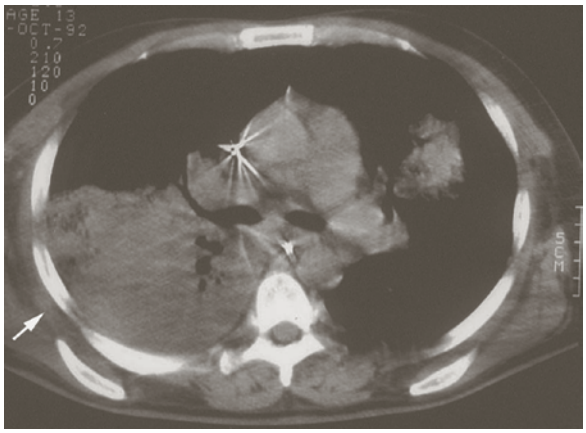

Fig. 16.1 This CT scan of an alveolar consolidation shows a large pleural contact at the posterior aspect of the lung, a condition usual but necessary to make it accessible to ultrasound. Such a consolidation cannot be missed, even if only the PLAPS point is investigated (*arrow*)

Ultrasound Technique

Where to apply the probe raises a slight issue. Whereas pleural effusion, pneumothorax, and interstitial edema benefit from extensive location, and therefore from standardized points of search (the BLUE points), alveolar consolidations can locate in various sites and have various size. However, applying the probe at the PLAPS point detects most cases (90%) and makes ultrasound superior to bedside radiography in terms of diagnostic accuracy.

Ultrasound Diagnosis of an Alveolar Consolidation

Acute alveolar consolidation yields two characteristic patterns.

1. **The Tissue-Like Sign** The consolidated lung has a tissue-like pattern, echoic, with regular trabeculations reminiscent of a liver. We should add: of an *ill* liver, containing gas like in mesenteric infarction, since small gas collections are possibly present (yet not required) (Fig. 16.2).

The label "tissue-like sign" assumes a tissular behavior of the mass, which keeps constant dimensions during breathing, consequently not generating any sinusoid sign (see Fig. 15.3 page 131).

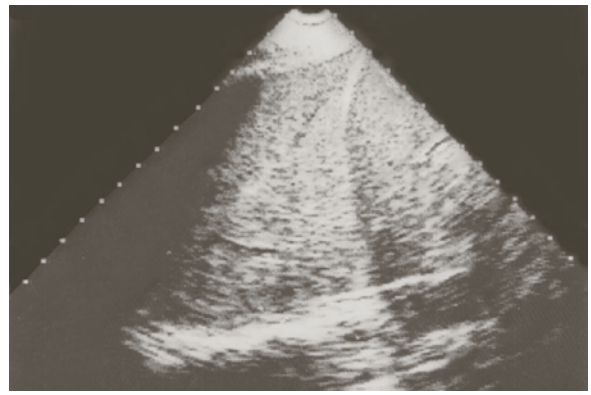

Fig. 16.2 Massive alveolar consolidation of the lower left lobe. The acoustic barrier normally expected is replaced by an anatomic image. For didactic reason, we first show a massive, translobar consolidation. The basic sign here is the tissue-like pattern, for a fluid lesion. The area here is 50 cm^2, i.e. an index of 50, showing, even in only one view, evidence of substantial consolidation. The homogeneous pattern indicates absence of necrotizing complication. Pleural effusion and air bronchogram are not visible. Longitudinal scan of the left base, lateral approach

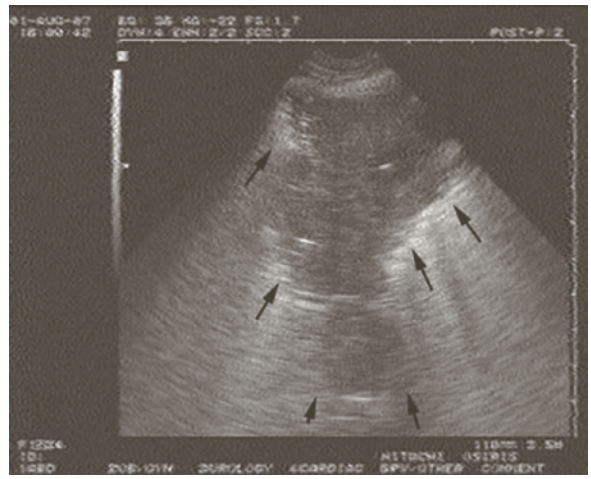

Fig. 16.3 The shred sign. Typical alveolar consolidation, with a frank tissular pattern arising from the pleural line, and here, a highly irregular, shredded border (*arrows*), since the consolidation is in contact with aerated lung: the shred sign. The shred line is completely different from the regular lung line. In spite of the ill-defined quality (see the letters, showing major loss of definition), the image is self-speaking

2. **The Shred Sign** In a longitudinal view, the upper, superficial border is the pleural line, or, in the case of associated pleural effusion, the lung line (see Fig. 15.6 page 130). The deep border is shredded, displaying the shred line (Fig. 16.3). The irregular shred line is totally different from the lung line, described in Chap. 15.

Major cases: in the case of massive, translobar consolidation, the deep border is the opposed visceral pleura and is regular, since it outlines the mediastinum (whole lung consolidation) or the heart (lingula consolidation). The distinction with a pleural effusion is immediately possible: this tissue-like mass is compact, without any visible lung line, and the distance between the pleural line and the mediastinal line (at the PLAPS point, probe perpendicular) is roughly 8–11 cm, i.e., the translobar size of the lung (see Fig. 16.1). A pleural effusion cannot reach this dimension (5 or 6 cm is an extreme limit). In other words, the deep border can be called the "mediastinal line"—or the "heart line," to clarify the concept.

In the neonate, the same rule can apply. The "mediastinal line" is roughly located four times the length of the pleural line (which is, in the adult longitudinally scanned, usually 2–2.5 cm).

Note: the detection of a lung line makes one more diagnostic criterion, if needed: a pathologic image deep to a pathologic image identified as a pleural effusion – in the critically ill – can be nothing but an alveolar consolidation – or what else? See Figs. 15.4, 15.6, and 15.8. The "logical sign".

3. The value of these signs

When the definition of the alveolar consolidation includes a tissue-like sign and shred sign, sensitivity of ultrasound is 90% and specificity 98% with CT as the "gold standard" [1]. The 90% sensitivity can be increased easily if the operator takes care to make comprehensive, time-consuming scanning. In the study where these data were extracted, the operator missed some small consolidations that were not on easy locations. The interest of detecting a small consolidation is a function of the context (see below).

Other Signs

The tissue-like sign and the shred sign are required. Other signs are of interest for the beginners.

The Air Bronchogram

A consolidation can include none, some or many hyperechoic opacities, obviously corresponding to the air bronchograms (Fig. 16.4). They can be punctiform or linear. The air bronchogram is certainly a specific sign (of consolidation), but it is visible within another specific sign (the tissue-like sign and/or the shred sign), and therefore is not mandatory for the diagnosis.

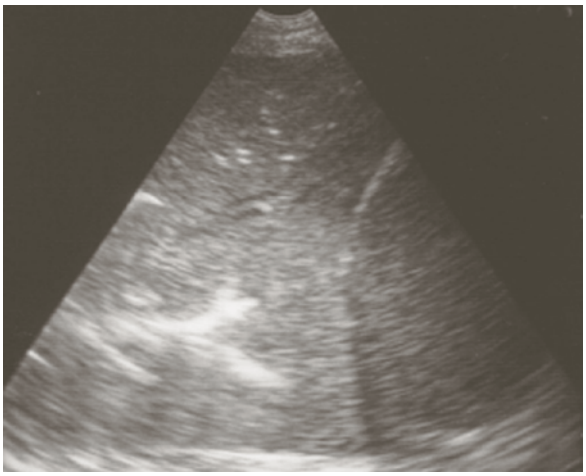

Fig. 16.4 The air bronchogram. Massive alveolar consolidation of the lower right lobe, longitudinal scan. Hyperechoic opacities are visible, punctiform at the *top*, linear at the *bottom*. They indicate air bronchograms

The Dynamic Air Bronchogram

Visualization of the dynamics within an air bronchogram (Fig. 16.5) has clinical relevance: the air present in the bronchi receives a centrifugal inspiratory pressure, making it move toward the periphery. An air bronchogram that shows these dynamics is thus in continuity with the gas inspired by the patient (either spontaneously or through mechanical ventilation). In other words, a dynamic air bronchogram indicates that the consolidation is not retractile: resorptive atelectasis can be ruled out. The dynamic air bronchogram was quite rarely (6%) observed in case of atelectasis, whereas it was observed in 60% of cases of alveolar consolidation of infectious origin [6, 7]

Two patterns can yield confusion. An air bronchogram that suddenly appears, or disappears, is probably not a dynamic air bronchogram, but an off-plane effect. These patterns seem to light up, whereas an air bronchogram moves. The bronchial axis must be in the probe axis. An operator making an M-mode at a dynamic air bronchogram can see a kind of sinusoid

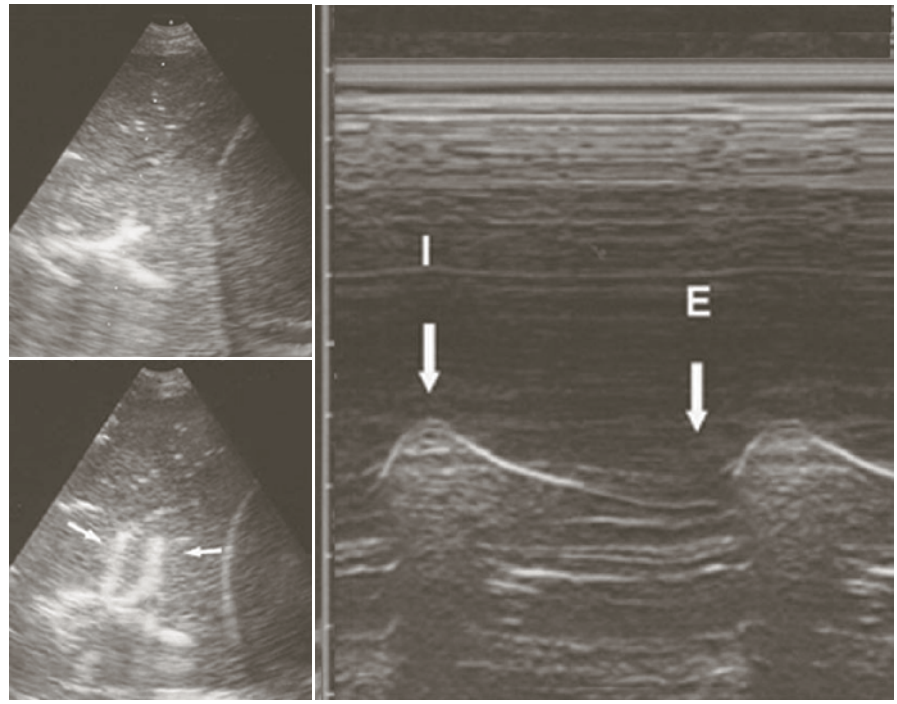

Fig. 16.5 Demonstration of dynamic air bronchogram. This is the sequel of Fig. 16.4, The air bronchograms happen to show an inspiratory centrifuge motion. The M-mode highlights this dynamic (*I* inspiration, *E* expiration). This demonstrates the nonretractile character of this alveolar consolidation. Take care not to confuse this dynamic with a sinusoid sign by first analyzing the real-time (*left*) image. The M-mode sign is performed to have a paper record of what is seen on real-time

(Fig 16.5). This M-mode must not confuse: an air bronchogram cannot be confused with a lung line.

The Static Air Bronchogram

When no dynamic is observed on air bronchograms, we speak of static bronchogram consolidation. This can mean air bubbles trapped and isolated from the general air circuit (before being dissolved), consistent with resorptive atelectasis.

Consolidation Without Visible Bronchogram

The consolidation can be compact, exclusively tissue-like (Fig. 16.2).

Lung Sliding

A consolidation is often associated with abolished lung sliding, possibly by a decrease in lung expansion or adherences.

Signs of Abscess or Necrosis

When the volume of the consolidation is substantial, it is possible to scan this area, checking for the homogeneous pattern (air bronchograms excepted). A necrotizing area or an abscess can then be detected. It appears as a hypoechoic, clearly defined, rather regular image (Fig. 16.6). A collection of gas gives a strong hyperechoic barrier. Abscess detection is an old application [8].

The air–fluid level is sometimes accessible to ultrasound at the PLAPS point or, if possible, more posteriorly, with the probe frankly pointing to the sky (Fig. 16.7). When the acoustic window is favorable (abscess within a large consolidation), the beam crosses first the fluid part, then the gas part, with massive acoustic shadow (see Fig. 6.20). Since the fluid is at atmospheric pressure, the air–fluid level freely swirls, especially if slight movements are created from outside. This gives a shimmering air–fluid border, which is difficult to describe but obvious to see: the swirl sign. This sign has already been used for diagnosing bowel occlusion (see Fig. 6.19) and will be exploited again for diagnosing hydropneumothorax (see Fig 18.13 page 174).

Ultrasound is of interest since bedside radiographs are usually inadequate – each time the air–fluid level is not aligned by the X-rays. Abscesses are most often

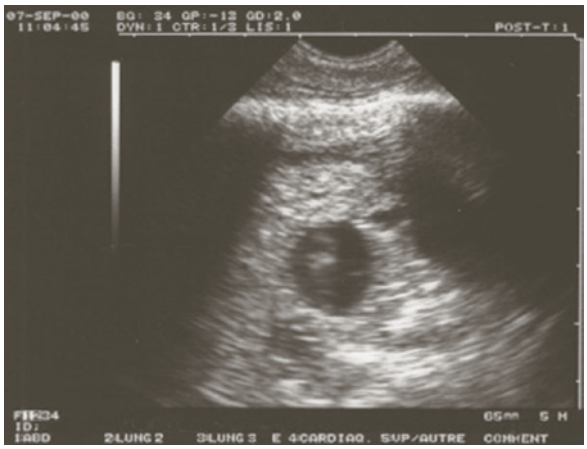

Fig. 16.6 Abscess. Within an alveolar consolidation, a hypoechoic rounded image is visible in this longitudinal supraphrenic image of the right base. Located 20 mm below the pleural line (and 30 mm beneath the skin), this abscess is ready for ultrasound-guided aspiration. No need for Doppler to distinguish it from an empyema. Lung sliding was abolished. Index at least 16

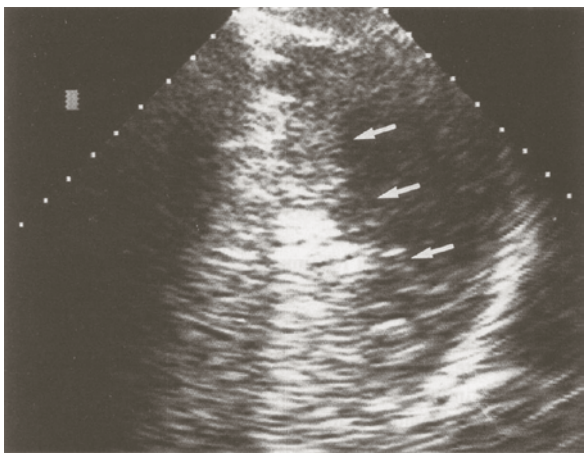

Fig. 16.7 Abscess, air–fluid level. Two zones are visible: one fluid at the *right*, one aerated at the *left*. A roughly vertical line (on the screen, but parallel to the horizon) is thus created (*arrows*). Real-time showed air–fluid swirls at this line level. In order to pick up this interface, the ultrasound beam must first enter the fluid zone then the air zone. Optimally, the probe should point to the sky, from an extended PLAPS point. CT showed a voluminous fluid–air collection in a consolidated lower lobe

peripheral and benefit from a parenchymatous acoustic window. Ultrasound works on occasion better than CT [9].

Note: In the logic of the BLUE protocol (see Chap. 20), for fast diagnosis of acute respiratory failure, pleural effusion and alveolar consolidation are considered one entity (PLAPS). This allows rapid training of the teams.

Some Characterizations of an Alveolar Consolidation

Location of a Consolidation

Ninety percent of cases are located at least at the PLAPS point [1]. The other cases are dispatched at the axillary, anterior, apical, juxta-rachis areas. The operator is condemned, either to make comprehensive, time-consuming, and chancy scanning, an unrealistic option in critical settings, or to accept the 90% sensitivity of ultrasound [1].

The energy for studying the location is a function of the clinical question. Dependent alveolar consolidations in ventilated patients after a few days are pathologic but not surprising. Finding an anterior consolidation in a patient with acute dyspnea has major relevance for knowing its origin (see Chap. 20), as is a small consolidation in a young pregnant patient seen for acute thoracic pain.

Complete consolidations (lung atelectasis, massive pneumonia) are visible everywhere (including the PLAPS point).

Rough correlations between the BLUE points and lobes were seen in Chap. 14.

Volume of a Consolidation

After having used several more or less practical approaches, we redefined the consolidation index, using two remarkable points. First, our microconvex probe has the major advantage of a sectorial view (also convex). Second, observation shows that most alveolar consolidations behave like compact masses. The three dimensions are roughly the same, i.e., considering two of them is sufficient for estimating the third. Consequently, the consolidation index simply considers the area in the most informative view. The index of the consolidation in Fig. 16.2 is roughly 50, indicating a substantial one. Ultrasound underevaluates the consolidation volume, because the area is limited by the Merlin space, with the upper and lower rib shadows (a minor problem that we do not try to solve by using oblique scans), and because

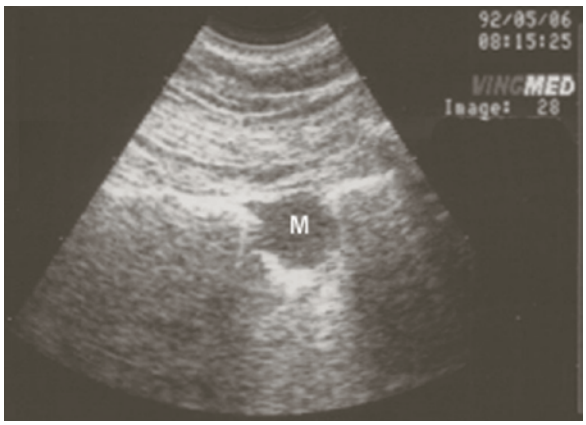

Fig. 16.8 C-line. The pleural line is interrupted by a centimeter-scale image, concave in depth (*M*). This is a C-line, a sign of very distal alveolar syndrome. Index between 2 and 3, giving a rapid indication of the small volume

massive deep gas collections (air bronchograms) may stop the beam. Conversely, overevaluation is hard to conceive (provided the probe is tangential). The mediastinal line is a sign of major volume.

One can also use a rapid, intuitive approach, estimating by scanning that a given consolidation occupies something like 1% (C-line), 5% (minimal), 20% (consequent), 50% (huge), etc., of the lung volume.

The C-line. An image touching the pleural line, with a centimetric size, or less, roughly curvilinear or cupola-shaped, with alveolar pattern, i.e., tissue-like, is a small alveolar consolidation (hence the C for centimetric curvilinear consolidation) (Fig. 16.8).

Anomalies Surrounding a Consolidation

Among the following items, some will maybe have clinical interest.

A pleural effusion may or may not be associated with consolidation. How to distinguish pneumonia from passive atelectasis due to the compression by the fluid? One part of the answer is in easily withdrawing the fluid and analyzing the visible volume of the consolidation after the procedure.

Interstitial patterns (see Chap. 17) can be present or not in the surrounding areas.

The diaphragm location and dynamic can be modified by certain kinds of alveolar consolidations.

Nearby organs can be shifted toward the consolidation (resorptive atelectasis).

Alveolar Consolidation and the Main Causes of Acute Respiratory Failure

Several causes of acute dyspnea yield alveolar or pleural changes: hemodynamic pulmonary edema, pneumonia and *permeability*-induced edema (ARDS), pulmonary embolism, even pneumothorax. Decompensated COPD or asthma are not supposed to yield alveolar, interstitial or pleural patterns [10]. Chapter 20 will demonstrate how posterior locations without anterior interstitial syndrome or anterior locations in dyspneic patients indicate pneumonia.

ARDS is mainly characterized by a substantial alveolar part. This is evoked in Chap. 29 page 286.

Pulmonary embolism was dealt with in Chap. 13 (venous part) and Chap. 15 (pleural part). The interstitial part will be dealt with in Chap. 17, an integration of the lung and venous analysis in Chap. 20, the cardiac part in Chap. 22, and a synthesis in Chap. 29 page 284. Here we only comment on the alveolar part of this disease. Our findings show that the alveolar syndrome is usually small in size. We find it most often against the diaphragm, associated with some pleural effusion. We rarely find C-lines at lateral and anterior areas in massive pulmonary embolism (roughly 4% of our cases). Mathis et al. [11] described these C-lines as indicating pulmonary infarction. Our explanation for the rarity of this sign is that pulmonary infarction is correlated with mild pulmonary embolism: the smaller the embolism, the more distal the disorder. In patients with massive pulmonary embolism, C-lines have no time to develop. C-lines present at the moment of the diagnosis of a massive embolism simply mean previously neglected small episodes, which are usually recognized in the history when they yield pleural pain. C-lines are usually observed in severe pneumonia with hematogenous extension in our experience.

Infectious lung injuries may have typical patterns. Studies are coming [12]. Pneumonia due to *Streptococcus pneumoniae* often yields massive consolidation with dynamic air bronchogram, abolished lung sliding, and absence of pleural effusion. The systematized character of the typical cases is maybe more obvious in usual radiographs. In aspiration pneumonia, the initial disorder is alveolar. An alveolar disorder not associated with surrounding interstitial pattern is therefore mildly suggestive of aspiration. Tuberculosis is usually, in our institutions, a "surprise" coming from

laboratory results. This means that the usual diagnosis is not obvious. We await the publication of a large series with statistical value. Our few cases did not show specific images. Miliary tuberculosis may yield diffuse anterolateroposterior lung rockets, usually B3-lines, without any pleural or alveolar pattern. Pneumocystosis also often yields exclusive interstitial patterns. When a pleural effusion is associated, we advocate liberal thoracenthesis, in order not to lose diagnostic time.

Resorptive Atelectasis

Dealing with atelectasis is a didactic challenge. First, there is a frequent confusion between the usual understanding and the physiopathologic meaning of this disorder. Many doctors label "atelectasis" as the areas of basal alveolar consolidation seen on radiography or CT. Second, there are different causes of atelectasis. Another difficulty is that atelectasis yields immediate signs, which are functional, and late signs, which are anatomic.

We deal here with real atelectasis (i.e., a tele ectasis, absence of peripheral expansion). We deal with resorptive atelectasis, i.e., secondary to bronchial obstacle.

It is easy to create an experimental complete, bilateral atelectasis. By just halting breathing, we create a highly unstable situation that allows pathologic phenomena to be observed. After 20 s, the oxygen saturation initiates descent, confirming the unstable state. After a few hours, a chest X-ray would show two white lungs with massive loss of volume. Far before reaching this rather *theoretical* stage, we can observe immediate signs. Since we are in the chapter of the alveolar syndrome, we should deal only with the alveolar look of an atelectasis. Dealing here with functional signs was an arbitrary choice.

An Immediate, Functional Sign: The Lung Pulse

In the normal subject, the respiration generates lung sliding. Lung sliding masks cardiac activity. When creating experimental complete atelectasis, lung sliding is immediately abolished. Single-lung intubation also creates complete atelectasis. Through abolished lung sliding, the cardiac activity becomes immediately visible: a kind of vibration arising from the pleural line in rhythm with heart beats, recordable in M-mode (Fig. 16.9). A lung pulse means that the heart transmits

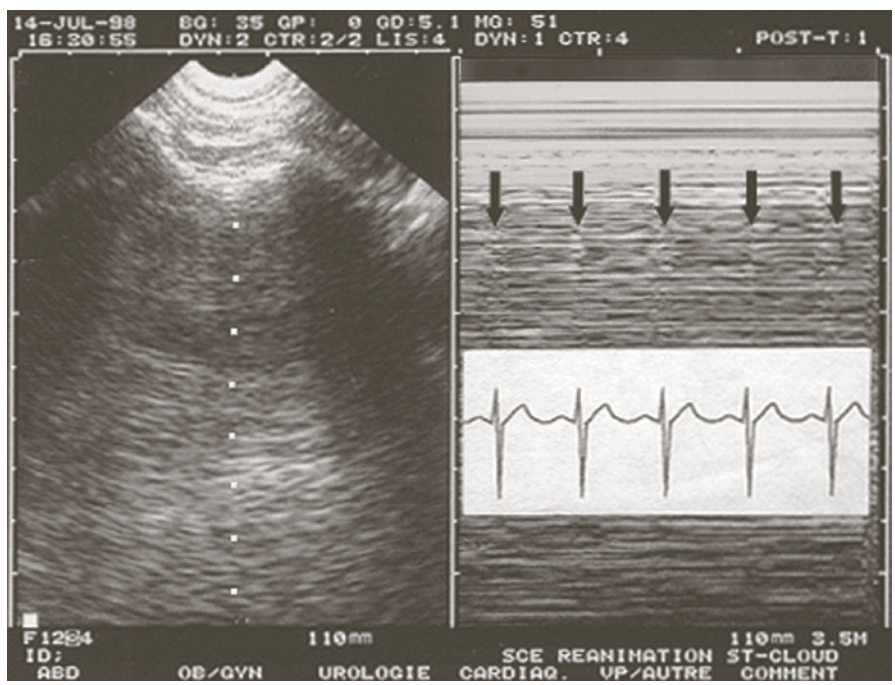

Fig. 16.9 The lung pulse. In this selectively intubated patient, left lung sliding is abolished. Vibrations in rhythm with the heart activity can be recorded at the lung surface, in the M-mode (*arrows*)

its vibrations through a motionless parenchymatous cushion.

The lung pulse can be observed within the first seconds of atelectasis, in 90% of cases (and lung sliding is abolished in all cases) [13]. A radiograph taken at this moment would show a still normally aerated lung. The hemidiaphragm descent is abolished.

The lung pulse rules out pneumothorax. It will therefore be recalled in Chap. 18.

Late Signs

The gas is resorbed little by little with passing time. At this late stage, atelectasis becomes visible on radiography. On ultrasound, the consolidated lung yields a tissue-like pattern (Fig. 16.10). Gas that is not fully resorbed is seen through air bronchograms. Characteristically, they have no intrinsic dynamic. This is referred to as the static air bronchogram sign, with 94% sensitivity for atelectasis [7] and low specificity, since pneumonia shows this pattern in 40% of cases.

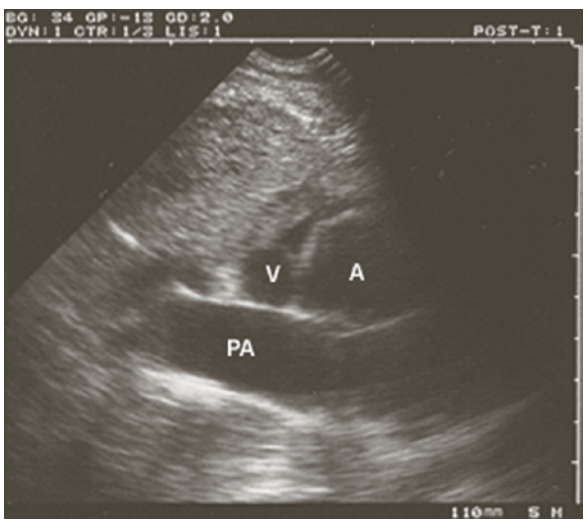

Fig. 16.10 Complete atelectasis of the right lung. Transversal scan of the right anterior lung for once (between upper and lower BLUE points). Complete consolidation of the upper right lobe. We can observe the ascending aorta (*A*), the superior vena cava (*V*) and the right pulmonary artery (*PA*), in brief the mediastinum, which is here frankly shifted to the right, making clear diagnosis of obstruction. Other pathological points were noted in this ventilated patient: static air bronchograms, phrenic elevation, abolished lung sliding, and lung pulse among others. Index 18

Characteristic signs are all the signs indicating a loss of lung volume. The intercostal spaces are narrowed. The cupolas and abdominal organs (liver, spleen) are found above the nipple line (usually at the PLAPS point). The heart can be seen at the right parasternal window (Fig. 16.10). It can also be seen all over the left anterior chest wall, a sign simply called the *heart sign*. The absence of any air bronchogram is a very indirect sign of atelectasis.

Fluid bronchograms yield small anechoic tubular structures. They would be observed in obstructive pneumonia only [14]. Some argue for Doppler for distinguishing fluid bronchograms from vessels, but we fail to find a practical interest for this up to now.

The mediastinum, usually difficult to access, becomes analyzable, as during transesophageal examinations. This serendipitous phenomenon allows a clear analysis of usually hidden structures: the vena cava superior at the right (see Fig. 13.13 page 107), the pulmonary artery and its left and right branches, the pulmonary veins can be analyzed. Before the treatment of an atelectasis, fast scanning of the mediastinum (even simply recording data), allows quiet searching for venous thromboses, mediastinal tumors, etc.

The Diaphragm: Phrenic Disorders

We chose to deal with the diaphragm in this chapter. The normal diaphragm has been described in Chap. 4 (see Fig. 4.9), Chap. 14 for the usual insertion, and Chap. 15 for its basic imaging (see Figs. 15.4, 15.6, and 15.11). We add here for Chap. 4 that the cupola is part of a circle of roughly 22-cm diameter, to help inexperienced users figure it out in standard adults.

The location of the diaphragm is a basic step in any lung ultrasound examination (if the BLUE points are not used). The cupola dynamic is accessible to ultrasound and ultrasound alone in the critically ill (the referral to fluoroscopy being a rather infrequent option).

It should be understood that we do not search for the diaphragm itself. Which interesting features should emerge from its vision? Tumors? Assessing its function does not require direct visualization. Observing lung items at the left of the image and abdominal items at the right ensures correct phrenic location. Lung sliding or liver movements answer the dynamic question.

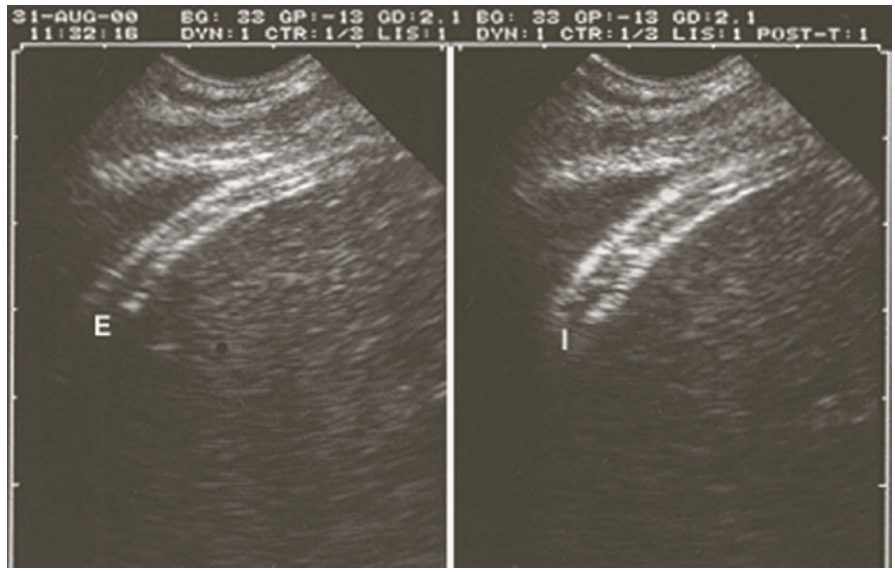

Fig. 16.11 Phrenic respiration. These views objectify the inspiratory thickening of the cupola, increasing from 4 to 6 mm. *E* expiration, *I* inspiration

The normal inspiratory amplitude can be analyzed in a longitudinal scan of the liver or the spleen. In spontaneous ventilation in a normal subject, or in conventional mechanical ventilation in a patient without respiratory disorder, it is located between 15 and 20 mm. A pleural effusion, even substantial, does not affect this amplitude, even in mechanical ventilation.

The amplitude of the phrenic course is normally the same when analyzed by a lateral (supine patient) or a posterior scanning (patient in Stage 3 or 4).

The thickening of the muscle (in spontaneous ventilation) is a subtle sign that we do not require in an emergency (Fig. 16.11).

A location above the defined landmarks (phrenic line) is pathological. An amplitude under 10 mm, for instance 5 mm, or null, or negative (paradoxical dynamic) is pathological. Pleural symphysis, atelectasis, low tidal volume, or abdominal hyperpressure explain a diminished or abolished phrenic amplitude. Phrenic palsy is a complication of cardiac or thoracic surgery and nerve blockade. It yields abolished lung sliding, elevated and motionless cupola (or paradoxical movement), absence of inspiratory thickening, for those who can assess this.

Pitfalls

The distinction between complex pleural effusion and alveolar consolidation is usually easy (see Chap. 15). The sinusoid sign, the shred sign, air bronchograms, especially when dynamic, make the difference. In very rare cases, it is impossible to distinguish the solid part from the fluid part (the ultrasound dark lung; see Chap. 15 page 135). Note that for the diagnosis of an acute respiratory failure, in the BLUE protocol, the PLAPS concept allows this distinction not to be required (See Chap. 20).

Abdominal fat may mimic alveolar consolidation, for those who did not use the BLUE hands for correctly locating the thorax from the abdomen.

The F-lines. Rarely, diffuse ghost images are visible in the Merlin space and may mimic air bronchograms (Fig. 16.12). Observation immediately shows that they are parasite images, but the beginner can be confused. The solution is simple: these "air bronchograms" are very static. In actual fact not only is there no dynamic air bronchogram but also the whole of these images are motionless, whereas lung sliding can be identified, demonstrating their parasite nature: real (even static) air bronchograms should have a dynamic following lung sliding. In addition, a shred sign is never seen. These diffuse lines have been called the F-lines (from Fabien Rolland who pointed out this image at a CEURF session).

Interventional Ultrasound

Pneumonia yields mortality, or at least delayed discharge from the ICU. Colleagues are afraid to insert a needle within the lung itself. We daily deal with extremely ill

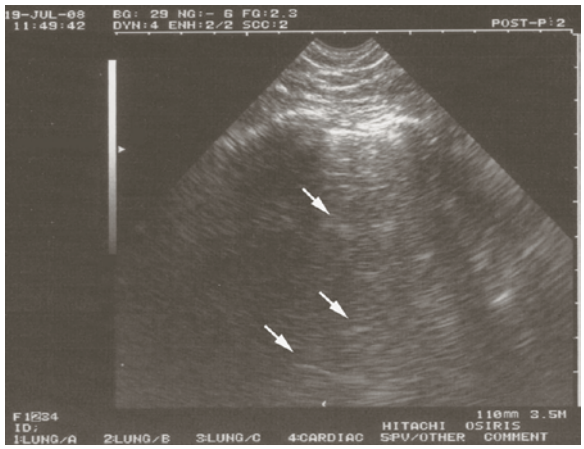

Fig. 16.12 F-lines (F for fantomas). Some ill-defined echoic spots are sometimes visible in Merlin's space, and novice users may see air bronchograms (some arrows were inserted in order not to burden the image). Experience works well for recognizing their artifactual nature, but two elements can be standardized. Mostly, they are standstill, whereas there is conserved lung sliding. And there is no shred sign

patients, many of whom will die. Our approach is to ask whether the prognosis can be improved by an early bacteriological documentation. We do not deal with aspiration of abscesses using ultrasound, a field slightly different from ours [8]. Ultrasound allows some considerations.

1. Accurate diagnosis of pneumonia, community-acquired but also ventilator-acquired, is a traditional challenge [15,16].
2. We should consider that the microbe is swarming within the lung tissue, i.e., just under the skin.
3. If the needle traverses a fully consolidated lung, the risk of pneumothorax appears more theoretical than real.
4. If the procedure is done in a patient with abolished lung sliding, which is a usual event, one can suppose that the patient has a pleural symphysis, another factor lowering the risk of pneumothorax.
5. Ironically, lung puncture has been already been advocated, but under a simple fluoroscopic control, i.e., a suboptimal, quite blind approach, responsible for a high rate of iatrogenic pneumothoraces [17].

Criteria for Performing a Lung Puncture

1. The physician must be convinced of the interest of having the bacteriological diagnosis in terms of benefit/risk balance – bearing in mind that if a pneumothorax should occur (a theoretical unlikely complication), it should be immediately recognized using postprocedure ultrasound checking.
2. A large consolidation (index value >16 for fixing a flexible barrier) must be visible at an accessible site.
3. Lung sliding must be abolished.
4. Air bronchograms should be absent or far from the puncture site; dynamic air bronchogram is a logical contraindication.
5. A fine 21-gauge needle should be used. A substantial vacuum is made in order to obtain a minute drop of brown material. We send the syringe to the laboratory, with the needle inserted, and without additional fluid (serum or other). This can probably be debated.
6. An immediate postprocedure control checks for the absence of pneumothorax.

Results

With these described criteria being present, pneumothorax never occurs as a consequence of the procedure. The tap is positive in 50% of our procedures. A pure culture of the responsible microbe in the specimen sent to the laboratory is usually obtained.

Interest

Ultrasound-assisted tap of lung consolidation represents a direct route, with no risk for contamination. It should be compared with the drawbacks of the usual methods (fibroscope, and, above all, plugged telescopic catheter, a blind technique): serious risk of pneumothorax, risk of contamination (i.e., false-positive results), risk of the blind procedure (i.e., also, false-negative cases), complexity, and costs.

Alveolar consolidation, seven main points:

1. Our 5-MHz microconvex probe is perfect in the adult (12 MHz in the newborn).
2. Most cases locate at the PLAPS point in the critically ill.
3. A tissue-like pattern, in actual fact like an ischemic liver with gas collections.
4. A shredded deep border, or the detection of the mediastinal line (10 cm distant in the adult).
5. Ultrasound can detect areas of necrosis better than CT.
6. The dynamic air bronchogram demonstrates nonretractile consolidation (usually pneumonia).
7. An alveolar consolidation can be found in patients with hemodynamic pulmonary edema, pneumonia, ARDS, pulmonary embolism, atelectasis, and even pneumothorax. Some considerations allow correct classification (anterior locations, posterior locations associated to anterior interstitial syndrome, volume, etc.).

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Lung and Interstitial Syndrome

17

"The lung is a major hindrance for the use of ultrasound at the thoracic level"
TR Harrison, Principles of Internal Medicine, 1992, p. 1043

"Ultrasound imaging is not useful for evaluation of the pulmonary parenchyma"
TR Harrison, Principles of Internal Medicine, 2001, p. 1454

"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

The previous chapters dealt with more or less usual fields. We now go deeper within this vital organ that has been slightly overlooked by the academics, demonstrating that the diagnosis of pleural effusion or alveolar disorders was just an appetizer. If lung ultrasound is a raison d'être of critical ultrasound, the potential of interstitial syndrome is the raison d'être of lung ultrasound. Based on artifact analysis, it changes the approach to the critically ill.

The lung was reputed to be inaccessible to ultrasound mainly because of the artifacts, which were qualified as indesirable [1, 2]. Therefore, the physician was not ready for making diagnoses based on artifacts. Similarly, when we began to define the field of critical ultrasound, we saw at the thoracic area various kinds of fog, snow, and parasites. We could have chosen to be resigned to this like the whole community but decided to persist. This was a vital organ after all. Little by little, we wondered whether these parasites, sometimes horizontal, sometimes vertical, could not be a *language?* Perhaps it was a simple language that we just did not understand. This initiated a work of observation, assessment, classification, and, above all, of endless submissions.

Let us begin by a double observation.

First, the diagnosis of interstitial syndrome is not accessible in acute situations using usual tools. The auscultation, nearly two centuries old [3], does not provide any sign of interstitial syndrome to our knowledge. Bedside radiography, more than one century old [4], rarely demonstrates interstitial changes in critical settings. It shows rough alveolar-interstitial patterns, but rarely the Kerley lines. Even in a good-quality radiograph taken in an ambulatory patient, this diagnosis is subjective, and a imaging specialist can make different interpretations from one day to another [5]. CT has been fully available since the 1980s [6]. It can possibly describe interstitial patterns, but referring patients to this heavy technique for this diagnosis alone would be questionable. Furthermore, experience has shown us that standard CT scans inconsistently show subtle interstitial changes.

Second, the intensivist would invest little for knowing whether this patient does or does not have interstitial syndrome: maybe for a lack of easy-to-access diagnosis, she or he never integrated this disorder in her or his medical thought process, and got accustomed to do without this piece of information. Meanwhile ultrasound has matured [7].

We saw in Chap. 14 the normal pattern, the A-lines. We evoked the numerous artifactual signals generated by the gas structures. They can be differentiated from each other and classified into A-, B-, up to Z-lines. A complete description will be provided in Chap. 19.

We will see what should be understood by "interstitial syndrome," then *how* to detect it using ultrasound, then *why* to detect it.

The diagnosis of interstitial syndrome was heralded since 1994 [8] and officialized in 1997 [9].

D. A. Lichtenstein, *Whole Body Ultrasonography in the Critically Ill,*
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Our 5-MHz microconvex probe is perfect for this part of lung investigation.

A Preliminary Definition: What Should Be Understood by "Interstitial Syndrome"?

Radiologists often question the notion of ultrasound diagnosis of interstitial syndrome because this term involves many conditions and they are accustomed to high-resolution CT. In the critically ill, the interstitial syndrome is limited to acute phenomena: nearly always pulmonary edema, either hemodynamic or permeability-induced. Hemodynamic pulmonary edema includes fluid overload and cardiogenic pulmonary edema. Permeability-induced edema includes ARDS and any inflammatory syndromes surrounding infectious processes (bacterial, viral, etc.). Rarely, patients with chronic interstitial syndrome (usually idiopathic fibrosis) are seen in acute settings.

The Ultrasound Signs of Interstitial Syndrome

Nine criteria allow ultrasound interstitial syndrome to be defined. The term "comet-tail artifact" is not sufficient. The eight other criteria are: arising from the pleural line, hyperechoic, laser-like, long, dominant, dynamic, multiple in one scan, and disseminated.

For didactic purpose, we first describe the B-line – the elementary sign.

Elementary Sign of Interstitial Syndrome, the B-Line

The B-line, so-named using alphabetic order, is a *fluid-air artifact*, which has seven characteristic features (Fig. 17.1).

1. This is a comet-tail artifact.
2. It arises from the pleural line.
3. It is well defined and laser-like.
4. It is hyperechoic.
5. It is long, spreading out without fading to the edge of the screen.
6. It erases, or obliterates, the A-lines.
7. It moves with lung sliding.

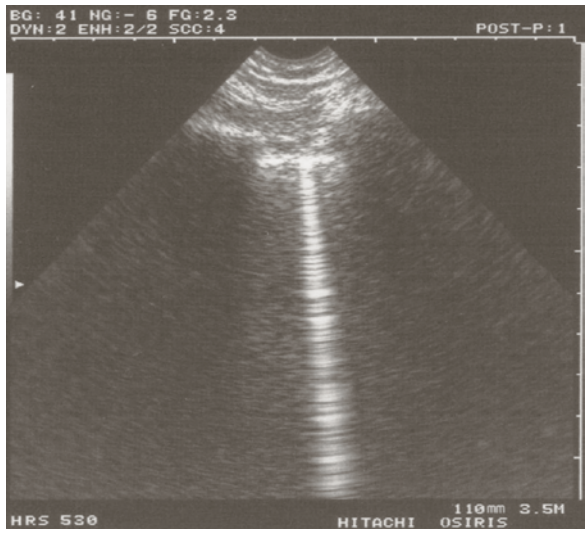

Fig. 17.1 Typical B-line. This simple, elementary image has seven features. This is a comet-tail artifact. It arises from the pleural line. It is well defined, laser-like. It is hyperechoic, like the pleural line. It spreads up to the edge of the screen without fading. It erases A-lines. In real-time, it would be seen moving with lung sliding. This description is the starting point of the use of lung ultrasound in the critically ill. Note that this B-line is isolated (labeled b-line), and has not the meaning of an interstitial syndrome

These seven features allow immediate distinction with any other artifact that can be seen in the human being (see below).

Some Developments

1. *The B-line is a comet-tail artifact.* But it is not *the* comet-tail artifact. The label "comet-tail artifact," suggested long ago for describing shotgun pellets within a liver was the one we adopted [10]. The point is that no study gave artifacts a precise meaning at the lung area. This generated some confusion in the literature (some still speak of comet-tails for designating the B-line). Some energy was necessary for correctly classifying this precious artifact.
2. *It arises from the pleural line.* The longitudinal scans have only advantages, including the one to permanently show the lung surface (using the bat sign). Disrespecting this rule will have the user confused by comet-tail artifacts arising above the pleural line.
3. *It is well-defined.* This makes the B-line immediately detected by beginners. B-lines are narrow (roughly, no more than one-tenth of the width of the pleural line).
4. *It is hyperechoic.* The B-line is as echoic as the pleural line.

5. *It is long.* The B-line does not fade. Using our system, which provides a 17-cm depth, the B-line spreads up to this limit. In some occasions, slight probe angulations can make it appear a little shorter than 17 cm, but usually more than 13 cm so B-lines are definitely long.
6. *It erases the A-lines.* This is of prime importance. The B-line dominates the A-line, so to speak.
7. *It moves with lung sliding,* provided there is a lung sliding. When lung sliding is abolished, the B-line appears at a standstill. Since our probe is sectorial, the bottom of the B-lines moves more than the top. This amplifies the demonstration of abolished lung sliding.

Developed Sign: The Lung Rockets

The definition of the ultrasound interstitial syndrome implies the visualization of *several* B-lines (Fig. 17.2). Three or more B-lines visible in a longitudinal view between two ribs were coined lung rockets (since the pattern is reminiscent of a rocket at lift-off). By definition, lung rockets are plural. Less than three B-lines are not consistent with interstitial syndrome.

Lung rockets can be isolated (i.e., visible at only one focal area). This defines focalized interstitial syndrome.

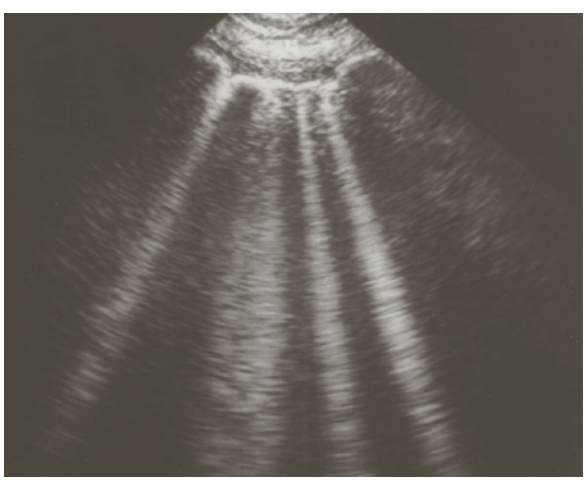

Fig. 17.2 Lung rockets (B7-lines). Five B-lines are identified in this longitudinal scan of the anterior chest wall. Reminiscent of a rocket at lift-off, they have been called lung rockets. They are separated from each other by an average distance of 7 mm. Ultrasound elementary sign of interstitial syndrome. Seen on the four anterior BLUE points, it provides the diagnosis of pulmonary edema in a few seconds. Patient with cardiogenic pulmonary edema

Lung rockets can be disseminated to a whole area, i.e., consistently visible on several points of the anterior or lateral chest wall, wherever the probe is applied. This defines diffuse interstitial syndrome.

Disseminated lung rockets on both lungs define bilateral interstitial syndrome.

Assessment of the Lung Rockets

Our principal study, assessing 121 cases of patients with diffuse alveolar-insterstitial syndrome on radiography, and comparing them with 129 patients without any alveolar or interstitial pattern, showed a sensitivity of 93% and a specificity of 93% for the disseminated lung rockets [9]. When CT was used as a reference, the concordance was *complete* with interstitial syndrome. No disorder to our knowledge can yield lung rockets, if not interstitial syndrome. We await our first case, since the 100% is said not to exist in medicine, but after nearly 20 years of observation, if something new happens, it will be an extreme rarity. Similarly, we never observed disseminated lung rockets in any of the countless healthy subjects that we scanned in workshops, etc.

Physiopathologic Meaning of the B7-Lines and the B3-Lines

The B-line is generated by a precise structure, which nine items clearly define.

1. The comet-tail artifact indicates an anatomical element with a major acoustic impedance gradient with its surroundings [10], as are air and water.
2. The detected element is small, inferior to the resolution power of ultrasound, which is roughly 1 mm and hence not directly visible.
3. This structure is visible at the lung surface.
4. It is visible all over the lung surface.
5. The element is separated from each other by roughly 7 mm (or less).
6. It is present at the last intercostal space in about one-quarter of normal subjects (see below).
7. It is correlated with pulmonary edema.
8. It vanishes with the treatment of the pulmonary edema (in a few hours when the edema has cardiogenic origin).
9. It is also present in any interstitial disease.

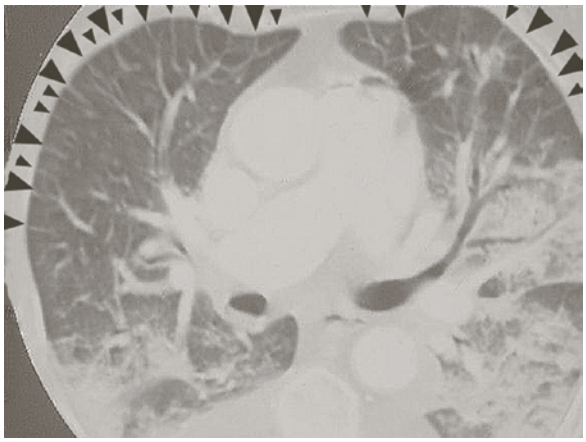

Fig. 17.3 CT scan of massive alveolar-interstitial syndrome. Thickened interlobular septa are visible touching the anterior surface (*arrows*). In a normal subject, no dense structure (apart from fissurae, see Fig. 17.6) is visible abuting the surface

All these criteria, in a way casting out the nines, precisely describe the subpleural thickened interlobular septa surrounded by air-filled subpleural alveoli. CT analysis showed that normal visible dense structures stop being visible a few centimeters before the lung surface, whereas thickened interlobular septa reach the visceral pleura (Fig. 17.3).

B7-Lines and Thickened Interlobular Septa

These B-lines are roughly 6 or 7 mm apart. This is the anatomic distance between two subpleural interlobular septa (Fig. 17.2). This label was reserved for adults initially. The distance decreases with the size (neonates). These ultrasound B7-lines appear as an ultrasound equivalent of the familiar Kerley's B-lines [11].

B3-Lines and Ground-Glass Areas

When interstitial syndrome reaches one more degree of severity, it generates ground-glass areas on CT. These disorders are correlated with B-lines that are twice as numerous as B7-lines, i.e., separated by 3 mm from each other, and called B3-lines (Figs. 17.4 and 17.5)

The potential of ultrasound to detect fluids explains this application. Here, fluid is present in a minute amount, submillimetric in thickness. However, this fluid is surrounded by air. This mingling seems to be the condition required to generate the ultrasound B-lines.

B7-lines and/or B3-lines are called B+ lines.

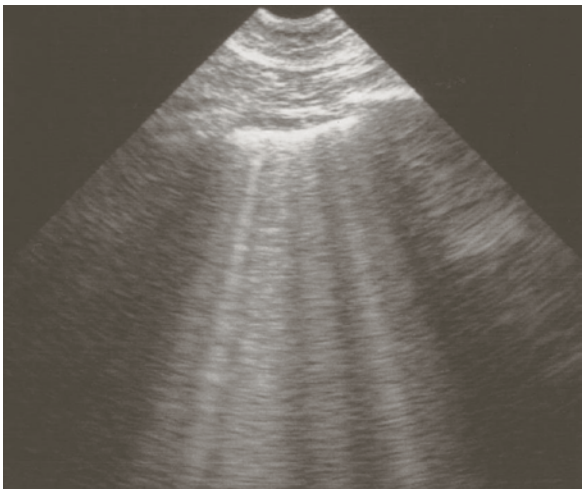

Fig. 17.4 Lung rockets (B3-lines). Here, six or seven comet-tail artifacts can be counted and the distance between each comet-tail is approximately 3 mm. These B3-lines, detected again in a few seconds, are specific to ground-glass areas, indicating a severe stage of interstitial edema

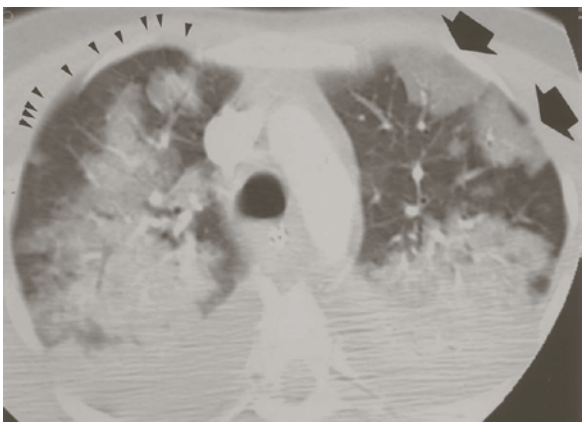

Fig. 17.5 CT. The large *arrows*, at the left lung, point on typical ground-glass areas, that indicate severe interstitial edema. Note the subpleural interlobular septal thickening at the right lung (*arrowheads*), discrete, but generating typical lung rockets

Variants of the B-Lines

The b-line (lower case): It is defined by a single B-line between two ribs. It cannot be assimilated to interstitial syndrome nor any disease. It can be the sign of a minor fissura (Fig. 17.6). Disseminated b-lines are an uncommon finding, so we do not have enough cases to draw any conclusions.

The bb-lines: Two B-lines between two ribs are not enough to be assimilated to interstitial syndrome. This unfrequent finding has still no pathologic correlation.

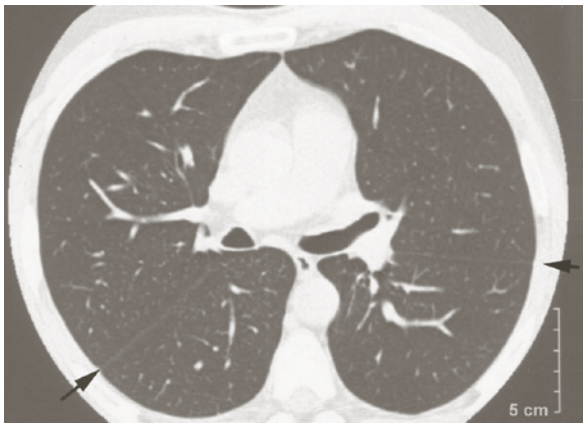

Fig. 17.6 Normal CT. This CT scan shows some fissures (*arrows*), generating fine structures abuting the pleural surface. Such structures are assumed to generate b-lines.

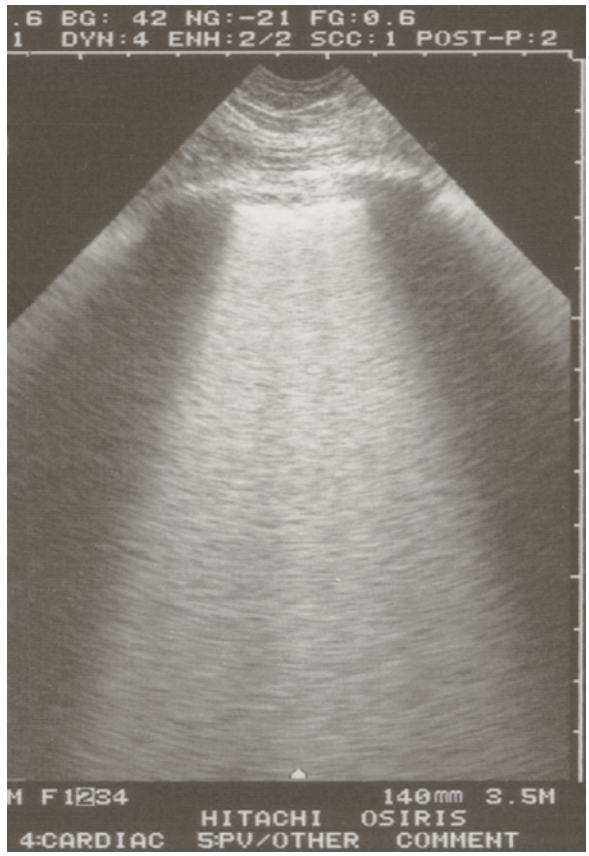

Fig. 17.7 Extreme case of pulmonary edema. The B-lines are so contiguous that they shape a homogeneous hyperechoic Merlin space (Birolleau variant). The underlying pattern is ground-glass disorder. The pleural line can be used as a reference tone. As opposed to the O-lines of Fig. 14.9 page 125, the Merlin space is as echoic as the pleural line (Storti's distinction). This demonstrates that in this zebra, the native, natural tone is dark

The X-line: Characteristically, A- and B-lines cannot be visible at the same location. B-lines are dominant and erase A-lines. Lung artifacts are *either* A- *or* B-lines. This provides standardization for the test. In rare instances, A-lines and B-lines are visible in the same image (see Fig. 19.5 page 188). This pattern was termed X-lines (indicating the crossing of diametrically opposed lines). We still investigate this pattern, assuming that it may possibly indicate a mild degree of septal thickening.

The Blinder variant: B-lines that are visible on a real-time acquisition can vanish during the respiratory cycle. They are not permanently seen. This simply indicates an off-plane effect. The meaning is the same (from Gilles Blinder, an attendee of a CEURF session).

The Birolleau variant: B-lines are sometimes so contiguous that no anechoic space is managed between two, and the Merlin space appears homogeneous and hyperechoic (Fig. 17.7). We suppose it corresponds to extremely severe edema. This variant cannot be confused with an O-line (see Fig. 14.9 page 125), which also yields a homogeneous Merlin space: O-lines make a dark space, the Birolleau variant makes a white space (Storti's distinction).

The vanishing B-line: Operators will sometimes see a patient with clear B-lines, which are not found again a few moments after, or conversely. We explain this comprehensively in Chap. 23, which is devoted to hemodynamics. Since there is no intermediary artifact between the A-line and the B-line, the B-line should appear suddenly. Once a critical amount of fluid opens the way to ultrasound, the B-lines are generated, like a nuclear chain reaction. This surely happens when the pulmonary artery occlusion pressure turns around the value of 18 mmHg.

The pseudo-absent B-line: Exceptionally, the probe is applied precisely between several B-lines, wrongly indicating absence of B-lines. A slight Carmen maneuver, routine when one detects A-lines, will immediately show the concurrent lung rockets.

The squirrel variant: Some B-lines are large (without precise meaning), up to one third of the distance of the pleural line (at the pleural line distance), but never more (look the B-lines of Fig. 18.10 page 171).

The b, bb, B+, B7, B3-lines, and the Birolleau variant simply indicate the number of B-lines per view between two ribs. The label "b" specifies that only one B-line is visible. The label "bb" is for two B-lines. The

label "B+ lines" is for three or more. The label "B7" specifies that B-lines are 7-mm apart, i.e., space for three or four B-lines. The label "B3" is for B-lines that are 3 mm apart, i.e., space for six to eight B-lines. The Birolleau variant indicates side-by-side B-lines (making them impossible to count).The label B-lines does not infer a special number of B-lines. The meanings are as follows:

- B- and bb-lines: no meaning (minor fissura?), just meaning absence of pneumothorax
- B+ lines: interstitial syndrome
- B7-lines: interstitial syndrome (thickened interlobular septa), possibly mild stage
- B3-lines: interstitial syndrome (ground-glass areas), possibly severe stage
- Birolleau variant: to our knowledge, ground-glass areas

Some Artifacts That May Mimic the B-Lines

Other comet-tail artifacts can on occasion be encountered. The reader can skip this section, provided the seven signs of the B-line are mastered.

The Z-line: A frequent artifact should in no case be confused with a B-line. This is a comet-tail artifact, and it arises from the pleural line. The last five criteria are diametrically opposed to the B-line, making immediate distinction. It is ill-defined. It is not hyperechoic. It is short, rapidly vanishing after 3–4 cm, usually. It does not erase the A-lines. Last, it stands still and is not synchronized with lung sliding (Fig. 17.8). This artifact has been called the Z-line, the last letter of the alphabet symbolizing the place it should take, since it seems for once to be a genuine parasite. Note that some Z-lines can be long, and we called them perfid Z-lines. This label was witnessed by Gabriela in Milano (family name not included in the absence of contact for authorization).

The E-line: This artifact, again a comet-tail, is well defined and spreads up to the edge of the screen without fading. However, it does not arise from the pleural line but from superficial layers, and results in erasing the pleural line. The bat sign is no longer visible. This artifact has been called the E-line, *E* for emphysema (see Fig. 18.14 page 176). We will see that parietal emphysema (or rarely parietal shotgun pellets) can generate this artifact, which should never mislead the novice operator.

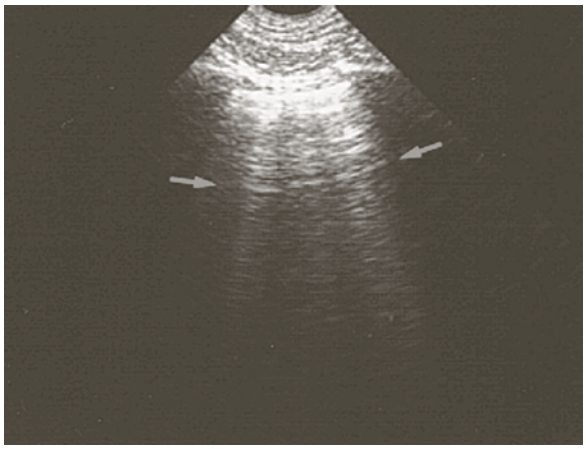

Fig. 17.8 Z-lines. This figure has major relevance, since some colleagues confuse B-lines with parasite images. Three vertical, ill-defined artifacts arising from the pleural line and fading after a few centimeters are visible, without erasing the A-line (*arrows*). These are Z-lines, a typical parasite artifact with no known meaning that should never be confounded with B-lines

The A-line: Stating that B-lines are vertical and A-lines horizontal is schematic but not sufficient. We showed multiple B-lines to a student, asking whether they were vertical or horizontal. She candidly answered "horizontal," and she was right. The point is that a B-line, in fact, superposes multiple *horizontal* lines, that are roughly 2–3 mm wide at the begin, and roughly 1.5 mm separated from each other, shaping a large vertical line. An eye looking at the image at a very low speed would see each of these lines, shot like from a machine-gun, and spreading to the edge of the screen at a real speed of 1,540 m/s. As a tribute to this student (Julie), each of these minute lines was called J-line. For standardizing lung ultrasound and playing the same music, it is critical that each physician has the same vision of the signs. The J-lines allow misconceptions to be avoided (Fig. 17.9).

The π-line (Pi-line): This is a group of A-lines that are narrow and may mimic from a distance a giant vertical comet-tail (Fig. 17.9). For scientific minds who would appreciate clues to avoid confusion, the A-lines have usually the width of the pleural line, the B-lines roughly one-tenth of this width.

The I-, K-, N-, R-, S-lines: (see Fig. 19.5 page 188) I-lines are like B-lines but they are short and have no known meaning. They seem to be often generated by linear high-frequency probes. K-lines (*K*lingon) are parasites invading the whole screen, sometimes visible in our walls (electrical interferences?). N-lines are

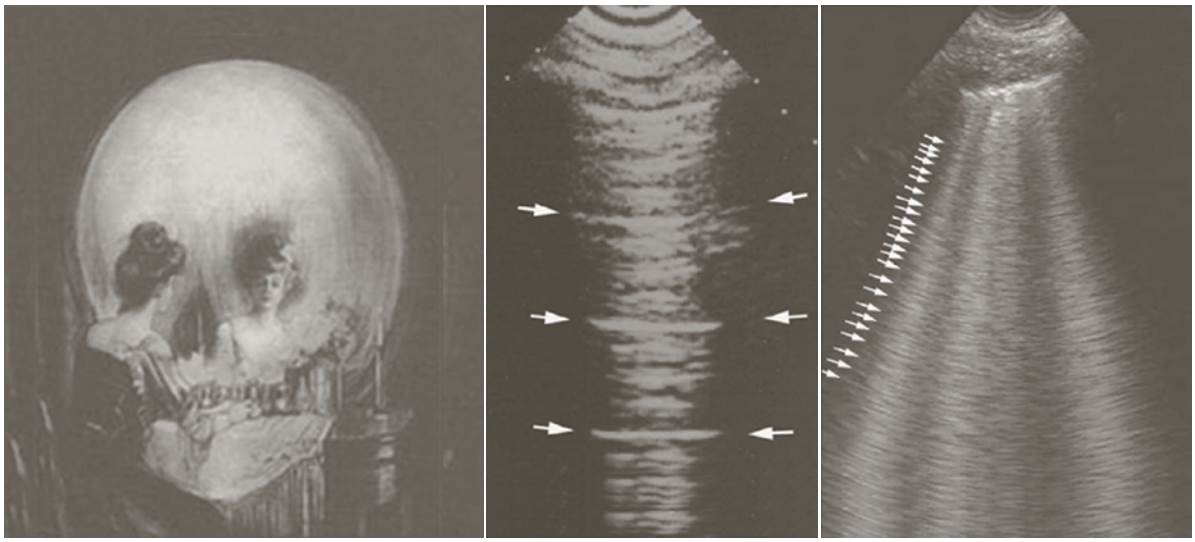

Fig. 17.9 Lung ultrasound will have a future if we speak the same language and see the same things. The *left image* may appear worrisome at first view, but is rather peaceful if looking twice (or using a lens). To the *middle*, tortuous or novice eyes may imagine a structure which is all in all vertical. We called this variant the π-lines. Three A-lines are frankly visible (*arrows*), surrounded by A′ and A″ lines. By the way, this patient precisely had a pneumothorax. To the right, typical B-lines. The *arrows* indicate some of these numerous J-lines (idle readers can count, they will find 70 of them shaping this B-line). Each J-line is horizontal it is true, but all J-lines create an overall vertical artifact: the B-line

vertical artifacts that are black – i.e., far from hyperechoic. They were coined N-lines (*N* for noir, i.e., black in french, and also for Neri, who witnessed this labeling). N-lines are maybe normal subpleural interlobular septa. The R-lines, suggested by Roberta Capp, from Boston, have most patterns of the B-lines, but they arise from the pericardium – lung interface – often visible during TEE. S-lines are sinuous vertical artifacts generated by large metallic structures (pacemakers).

Sub-B-lines: These artifacts have the most patterns of the B-lines, but they arise from the lung line, i.e., below a pleural effusion (see Fig. 15.2 page 130).

The standardization of the B-line allows distinction from all these lines, mainly from the Z-line. B-lines usually have seven features. Features 1 and 2 are constant. Features 3–7 can be debated, like everything in medicine. Perfid Z-lines are long. Some B-lines are less well defined than others, or not as echoic as the pleural line. With maximal range (17 cm with our probe), some B-lines stop at 13 cm. Abolished lung sliding prevents appreciation of the dynamic criterion. Exceptionally B-lines and A-lines cross each other, shaping the X-line (see Fig. 19.5 page 188). We show here how to understand this description. A comet-tail artifact that arises from the pleural line can be a B-line or many others. When a third feature is present, the probability increases to 99%. Using four features, the probability is 99.9%. Using five features, it is 99.99%, etc. A patient with actual pneumonia, who should have the variety of B-lines that are not fully hyperechoic, large, stopping at 13 and not 17 cm, crossing A-lines, with abolished lung sliding, with a confusing clinical presentation, would be so unlucky (we refer to the Grotowski law) that we expect him to have in addition, even with a correct diagnosis, all possible complications (allergy to antibiotics, errors in doses, etc.). We have no picture of such a tricky artifact. Briefly, the comprehensive definition of the B-line prevents any serious risk of confusion.

Where and How to Detect the B-Lines

A standard interstitial syndrome in the critically ill displays lung rockets at both the upper and lower BLUE point (enhanced if needed by the Carmen maneuver).

Multiple other locations can be defined.

Focalized interstitial syndrome can be the sign of a focal pneumonia. Focal interstitial scars, after breast

radiotherapy, can generate focal lung rockets. Anterior isolated B-lines (b-lines) possibly indicate a minor fissura.

B-lines localized at the two last intercostal spaces above the diaphragm are found in 28% of normal subjects [9]. Normal interstitial syndrome is a well-known pattern. Kerley's B-lines were observed at the bases of 18% of thoracic radiographs of healthy subjects, i.e., a roughly similar rate [12]. The slight difference probably indicates a superiority of ultrasound to detect these very fine elements. In these normal subjects, the B3-line variant is never found.

Lateral lung rockets including more than two intercostal spaces above the diaphragm are not normal. The label used is "extensive lateral rockets." This is usually a redundant finding since anterior scanning usually shows anterior lung rockets, and posterior scanning usually shows alveolar and/or pleural syndrome (PLAPS). Extensive lateral lung rockets without anterior lung rockets is rare, and usually due to pneumoniae in our experience. This may be also the sign of mild hemodynamic pulmonary edema, to be confirmed.

Posterior lung rockets in supine patients possibly indicate that the lung water accumulates in the dependent areas. Analysis of CTs without lung disorders often shows these dependent changes. On the other hand, the absence of posterior lung rockets in a chronically supine patient may mean, if validated using a correct gold standard, substantial hypovolemia.

The Clinical Relevance of the Lung Rockets in the Critically Ill

We have learned how to recognize the B-lines, what is their physiopathological basis. Now, the reader may say: So what? Interstitial syndrome is not routine in our art; we have now to explain how it highlights multiple pathologic processes. To avoid making the book heavier than necessary, the main part of the physiopathologic basis will be discussed in Chap. 20.

Ultrasound Diagnosis of an Acute Respiratory Failure

Chapter 20 is devoted to the role of the B-lines in diagnosing pulmonary edema, exacerbation of COPD, acute asthma, pulmonary embolism, pneumonia, according to the presence or absence of B-lines, a diffuse or unilateral distribution [13].

Ultrasound Diagnosis of Hemodynamic Pulmonary Edema

This is the main practical use of the lung rockets, long heralded [14].

Chapter 20 explains how lung rockets disseminated at the anterolateral chest wall are nearly constantly present. We just here show the interest of ultrasound when compared with radiography. We simplify our last edition, gathering in the same paragraph situations where the radiographic diagnosis is difficult (ill-defined), not immediately available (extreme emergency), or not available at all (extra-hospital settings mainly).

The imaging tests would not be so useful if the clinical examination answered the question perfectly. Rales can be absent at the early stage [15], or replaced by wheezing, yielding the cardiac asthma. Fine auscultation is illusory in ventilated patients or in point-of-care medicine, airplane, crowded ER, etc. The radiograph can be subnormal, possibly because it was made too early, but also in genuine severe cases of pulmonary edema [16,17]. We assume that the radiologic signs show up only in advanced stages. A radiograph taken in optimal conditions can be difficult to interpret [5]. Taken in an emergency, at the bedside, it cannot be better. Signs like vascular redistribution do not work in supine patients. X-ray sensitivity in detecting interstitial edema can range between 18% and 45% [18,19]. Kerley B-lines can be observed in exacerbation of COPD [20].

Lung ultrasound for diagnosing interstitial syndrome has been increasingly used since very recently [21–24].

Differential Diagnosis Between Hemodynamic and Permeability-Induced Pulmonary Edema

Chapter 20 explains why asymmetric lung rockets and the absence of anterior lung rockets favor the diagnosis of permeability-induced pulmonary edema in patients with radiologic white lungs – among other signs.

Ultrasound Diagnosis of Exacerbation of Chronic Obstructive Pulmonary Disease (and Differential Diagnosis from Pulmonary Edema)

Among patients seen by the intensivist (i.e., severe cases), diffuse lung rockets are observed in 8% of cases of patients with exacerbation of COPD, versus 100% of patients with acute hemodynamic pulmonary edema [14].

In this situation, lung ultrasound offers a highly dichotomic test, with little place, if any, for intermediate situations (mild cases may rise different problems).

Ultrasound Diagnosis of Asthma (and Differential Diagnosis from Cardiac Asthma)

Asthma involves bronchial disease. The bronchial tree is not accessible to critical ultrasound, and the main sign is indirect: absence of lung rockets in a dyspneic patient. Disseminated lung rockets are observed in no case of bronchial asthma, and is the main pattern in cardiac asthma.

Ultrasound Diagnosis of Pneumothorax

The recognition of B-lines immediately rules out complete pneumothorax [25]. This item is particularly relevant when lung sliding is absent, a common finding in ARDS. One b-line is sufficient. Absence of anterior lung rockets in a patient with a white lung on radiography can just suggest pneumothorax.

Diagnosis of Pulmonary Embolism

The physiopathology of pulmonary embolism is recalled in Chap. 20, explaining that interstitial signs are not expected. We do not deal here with venous, pleural, alveolar, or cardiac signs, but exclusively with the artifacts analysis. The visualization of anterolateral lung rockets is uncommon. Diffuse A-lines (associated with lung sliding) are found in 92% of cases when pulmonary embolism is defined as severe [26], and 95% when it is defined as yielding acute respiratory failure [13]. This pattern is immediately suggestive in a sudden dyspnea occuring in a patient without chronic lung disease (asthma, COPD).

The normality of the ultrasound lung examination is the equivalent of the normal chest X-ray. Note this finding (under submission): our rare cases of lung rockets included B7 patterns. We are still waiting for our first case of massive pulmonary embolism (not complicating a chronic interstitial syndrome, not complicating an ARDS) with a bilateral B-3 pattern. In other words, the B3-profile (i.e., bilateral B3-lines with lung sliding) has a 100% negative predictive value for pulmonary embolism. How to solve the challenge of pulmonary embolism in patients with ARDS is dealt with in Chap. 29 page 285.

Controlling Fluid Therapy by Qualitative Estimation of Pulmonary Artery Occlusion Pressure

We invite the reader to Chap. 23, where the application is detailed extensively. We invite the reader to consider the B-line as the *direct* marker for fluid assessment in the critically ill. The absence of lung rockets indicates low PAOP [27]. This gives, in a few seconds, clearance for initiating fluid therapy. Conversely, the apparition of lung rockets may be recognized as an endpoint for fluid therapy.

Evaluation of Lung Expansion

The movement of the B-lines can be analyzed and measured. This can give an accurate index of the lung expansion, with clinical implications. The normal lung excursion is 20 mm at the bases in ventilated patients. It can be completely abolished in case of lung stiffness. Thanks to our microconvex probe, the lower part of the B-lines moves more than the upper part at the pleural line. This amplifies the movement, allowing sharp measurement (using mathematic formula). This application allows indirect assessment of the diaphragmatic dynamic.

Managing ARDS

This is dealt with in Chap. 29 page 286.

Diagnosis of Nonaerated Lung

The detection of lung rockets in a posterior approach of a supine patient is equivalent to ruling out alveolar consolidation, since 90% of cases of alveolar consolidation reach the posterior pleura [28]. In these cases, the posterior aspect of the lung is interstitial, but not alveolar. We previously suggested that posterior lung rockets are quasi-physiological in chronically supine patients. Following this logic, if alveolar consolidation is detected in a dependent area, pleural effusion can be ruled out as well. This paragraph introduces major simplicity for the use of the BLUE protocol.

Managing Hyponatremia

The diagnosis of hyponatremia makes the distinction between the lucky doctors who master its physiopathologic mechanism, and the others. For them (the others), we use the first principle of lung ultrasound: simplicity. Depletion hyponatremia should yield low volemia and ultrasound A-lines. Dilution hyponatremia should increase the fluid volume, and induce, even before clinical respiratory signs, lung rockets.

Airway Management

It is easy to demonstrate abolished lung sliding when B-lines are motionless (see above, lung expansion), making immediate diagnosis of correct intubation or the possibility of one lung intubation.

Weaning Ventilated Patients

Lung rockets are probably not a good indicator of easy weaning. This means interstitial changes are still present.

Miscellaneous

One can see the lung rockets rapidly disappear under therapy of pulmonary edema [29].

One Word for the Attention of the Manufacturers

Manufacturers (taking one step backward) currently spend energy trying to suppress the artifacts. We please ask them to read (or have translated in commercial terms) Chaps. 18, 20, 23, 29, and give a new life to artifacts.

To Conclude, a Small Update About Lung Rockets

This 4th edition updates points of our principal work [9].

The title of the work published in the American Journal of Respiratory and Critical Care Medicine was "*The comet-tail artifact, an ultrasound sign of alveolar-interstitial syndrome.*"

The first part of the title is incorrect. Many comet-tail artifacts are not B-lines, particularly the Z-lines. This distinction was specified through all our subsequent papers.

The second part of the title is incorrect. The B-lines are not a sign of *alveolar-interstitial* syndrome. They are correlated maybe with radiological alveolar-interstitial syndrome, but they clearly indicate the interstitial component, which is completely distinct from alveolar consolidation (as specified in the body of the article).

The section "Results of the Abstract" is incorrect. The sensitivity and specificity of the B-line is not really 93% and 93%, but rather, if CT correlations are taken into account, 100% and 100%. This basic information was available, but no reviewer required us to specify this in the Abstract section. We ask the readers to kindly warn us 24/7/365, if they meet diffuse lung rockets in patients with a proven absence of interstitial syndrome, or their absence in patients with documented interstitial disease.

At that time, the manuscript had already been rejected four times. We had the aim of at last publishing these findings – in order to be able to submit the subsequent ones. It was difficult to go against the requirements of the reviewers [30].

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Pneumothorax

18

A few seconds are sufficient to rule out pneumothorax and less than one minute is needed to rule it in at the bedside. This chapter is long because some details have to be known in order to master this daily life-saving application.

Our previous editions placed the pneumothorax before the lung, since it can be considered as an ultrasound of the "non-lung." Yet the signs generated by the lung, especially the B-lines, had to be described first. In addition, refering to the air-to-fluid ratio, pneumothorax is pure air. For this reason also, the normal lung should logically be described between interstitial syndrome and pneumothorax (see Fig. 14.1 page 118).

Pneumothorax occurs in 6% of cases in an ICU [1]. It requires immediate diagnosis, especially in ventilated patients. High-risk patients call for exceptional care, since the risk of a missed pneumothorax is major [2]. Up to 30% of cases are occulted by the initial radiograph [3–6], many of them evolving to tension pneumothorax [3]. Some tension cases remain even unclear in the bedside radiograph [7]. Some authors consider that any pneumothorax, even occult, should benefit from a chest tube before initiating mechanical ventilation [8]. In dramatic situations, time lacks for radiological confirmation [9]. CT, the "gold standard" [10], is a suboptimal option in a critically ill patient. On the other hand, excessive search for pneumothorax results in irradiation, delay, costs and lost energy.

The question of how to avoid losing a patient for undiagnosed pneumothorax, without referring *all* unstable patients to CT, can be elegantly answered by ultrasound. We explore the anterior area, fortuitously the most accessible one in the critically ill. The most difficult cases on radiography are the easiest to detect using ultrasound (anterior locations). The most severely injured lungs, which are the most at risk for pneumothorax, are the very ones in which ultrasound signs will be the most striking. Ultrasound is the answer for this problem.

Our 5-MHz microconvex probe is perfect for this investigation.

Advanced Features of Lung Sliding

Lung sliding is the main dynamic feature. Its description was initiated in Chap. 14. We now go into more detail.

Lung sliding is a kind of dynamic (sparkling, twinkling, glittering, shimmering) visible at the pleural line (see Fig. 14.10 page 126). This is a relative movement of the lung toward the chest wall: the parietal tissues are motionless, whereas the pleural line twinkles. This sparkling is homogeneously transmitted through the Merlin space (the whole of the Merlin space seems to shimmer). The notion of relativity is important since a diffuse movement of the whole image actually is unavoidable. The patient as well as the doctor are still alive, and both generate minute movements. Yet this background noise is diffuse, whereas lung sliding is relative, beginning at the very pleural line. The operator must be as standstill as possible (read caption of Fig. 18.15 page 176). Use of the M-mode, which seems insensitive to the background noise, perfectly highlights this relativity of movement of the lung toward the wall, generating the characteristic seashore sign.

Lung sliding, or seashore sign, indicates that the lung touches the chest wall.

It is of prime importance to see lung sliding in real time, then only to record it in M-mode if proof is required for the file. Doing the opposite can lead to trouble. The M-mode can raise questions that otherwise would not have been raised. This is paradoxically a

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very sensitive mode, which can highlight phenomena that might not be not visible when looking only at the real-time image. A lot of energy is necessary to explain how phenomena that appear in M-mode can confuse or mislead instead of helping. The best thing to do is to make moderate use of M-mode (think *M* for *moderate*). In exceptional cases, the M-mode will be the only way to demonstrate a very discrete lung sliding in a severely dyspneic patient. Read below about the mangrove variant and other phenomena.

Some Characteristics of Lung Sliding

Its amplitude is null at the apex, a sort of starting block, and maximal at the base. It is decreased in many critical processes: ARDS, low tidal volume, abdominal hyperpressure. Therefore, one must consider two degrees: (1) Present or absent lung sliding, in which a very weak dynamic means present lung sliding when searching for pneumothorax. (2) Normal or low amplitude, up to absolute standstill, in relationship with lung mechanic. The amplitude can be measured, see page 287 in Chap. 29. A very slight lung sliding creates a diffuse twinkling of the Merlin space. At the advanced level, the user must identify "ample lung sliding," "weak lung sliding," and "absent lung sliding" – as easy as distinguishing an awake person from a sleeping person from a corpse.

The pleural line is hidden by the acoustic shadow of the ribs, but not by the cartilages near the sternum (young bat sign, see page 123).

Lung sliding is present in spontaneous as well as conventional mechanical ventilation.

Lung sliding is visible at any age, from the neonate to the elderly.

Lung sliding is visible in thin and plethoric patients.

Lung sliding is present in bronchial emphysema. Giant emphysema bullae do not abolish lung sliding in our observations. This has a basic consequence when a radiograph is not able to differentiate bullae from pneumothorax.

Does dyspnea modify lung sliding? Some causes abolish lung sliding: pneumothorax, massive pneumoniae and atelectasis, mainly. Severe asthma decreases lung sliding, but the slightest dynamic enables one to rule out a pneumothorax (which may be evoked in such patients). For the other causes, mainly COPD, hemodynamic pulmonary edema, or pulmonary embolism, lung sliding is normal. Dyspnea with accessory muscle recruitment is evoked below as a source of potential difficulty (the Ifrac phenomenon).

Coupling Real-Time and M-Mode Image: A Critical Point

The usual machines devoted to the heart display the 2D image at the top and the M-mode image at the bottom. Such machines are not suitable for optimal lung ultrasound because the operator must *guess,* on the bottom image, where the pleural line is located (see Fig. 2.5 page 16). In a critical setting, under stress, there is no time for guesswork.

Another misconception can have dramatic consequences. In most laptop machines, which were not designed for the lung, the real-time image is displayed on the left of the M-mode, *but* not perfectly at the same level (with no setting for correcting it). It gives to the user the illusion that the right image corresponds to the left image. Phenomena arising above the pleural line may appear to arise from the pleural line. This is nonsense on lung ultrasound (Fig. 18.1). In stressful conditions, inexperienced users can be fooled by this gap, i.e., taking muscular sliding for lung sliding in a dyspneic patient who has precise pneumothorax. Faithfully locating the pleural line (bat sign) is the basis of lung ultrasound. This notion will be repeated in the textbook (in Chap. 30).

Smart systems like ours have displayed since 1992 (maybe before) both images at the same level, with no space for confusion, making muscular sliding immediately recognizable, like correctly writing musical notes on a score (see Fig. 14.10 page 126).

There are some variants of lung sliding.

The mangrove variant – Respiration is a permanent phenomenon, but with a short end-inspiratory and end-expiratory pause in normal respiration or in mechanical ventilation. The pause generates a brief interruption of the vital phenomenon of breathing (a bit like a crawler reaching the edge of the pool). On ultrasound 2D acquisition, the lung sliding quietly stops. In M-mode, the sandy pattern of the lung sliding is transiently replaced by a regular horizontal pattern evoking a stratosphere sign (Fig. 18.2). This pattern, called

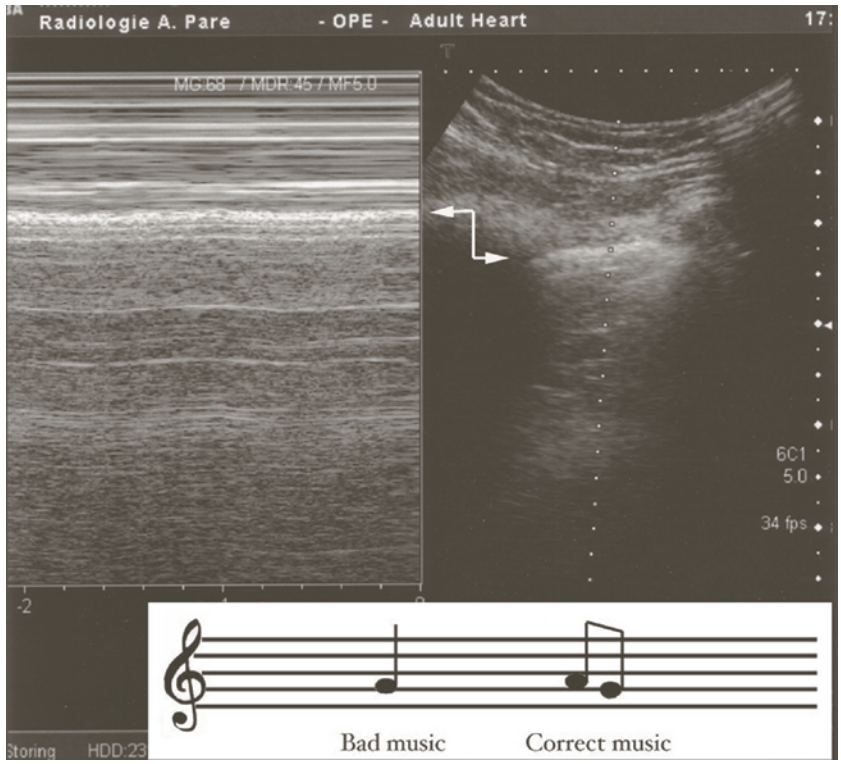

Fig. 18.1 A wrong note. The real time and the M-mode are not perfectly at the same level (compare with Figure 14.10 page 126). This is worse than the image provided in Figure 2-5 page 16, since young operators can be fooled. At the bottom, the left note is ill-defined, and no musician, even skilled, can understand the composer's intentions. The notes to the right are perfectly defined. The ultrasound diagnosis of pneumothorax, as lung ultrasound and critical ultrasound, is - and must remain - simple

Note: This is a wrong note since muscular recruitment in very dyspneic patients can generate noise coming from an aponevrosis superficial to the pleural line

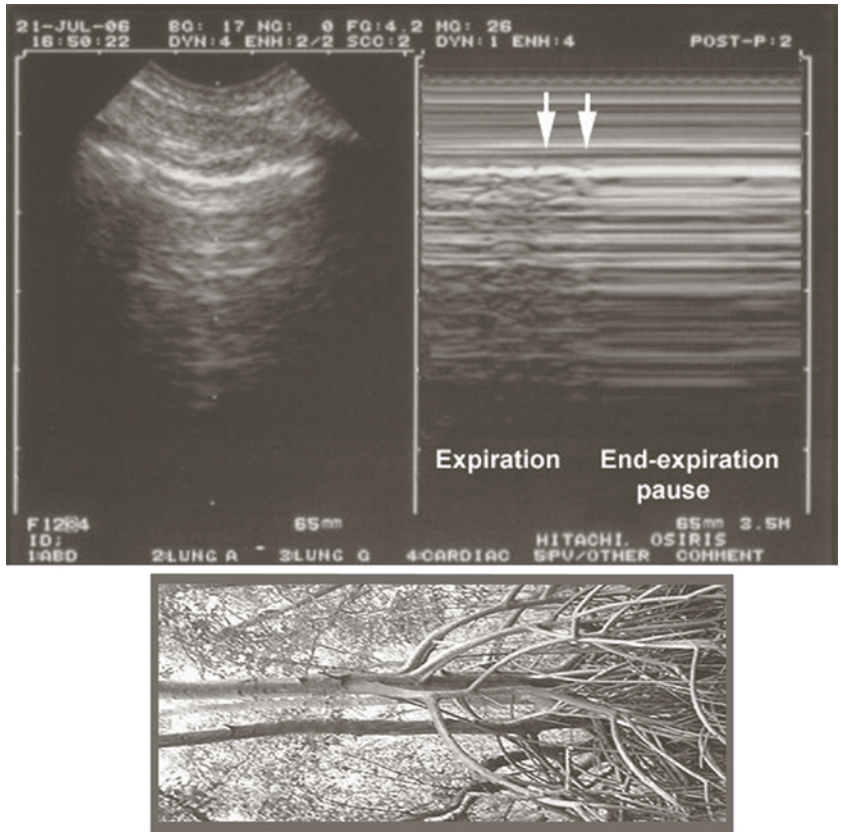

Fig. 18.2 The mangrove variant. Left, Real time, showing a pleural line with A-lines (example here of ill-defined A-lines). Right, M-mode showing an interruption of the sand yielding a regularly horizontal pattern. This interruption is progressive: the two arrows indicate the begin (left arrow) and the end (right arrow) of the mangrove phenomenon (see Fig. 18.12 for comparison). One may imagine aerial roots of mangrove trees (the mangrove variant was conceived in a training program in Neo-Caledonia). The message is: do not press the M button if not necessary

Note: The mangrove variant is seen when there are end-respiratory pauses, i.e., ventilated patients, but unlikely dyspneic patients

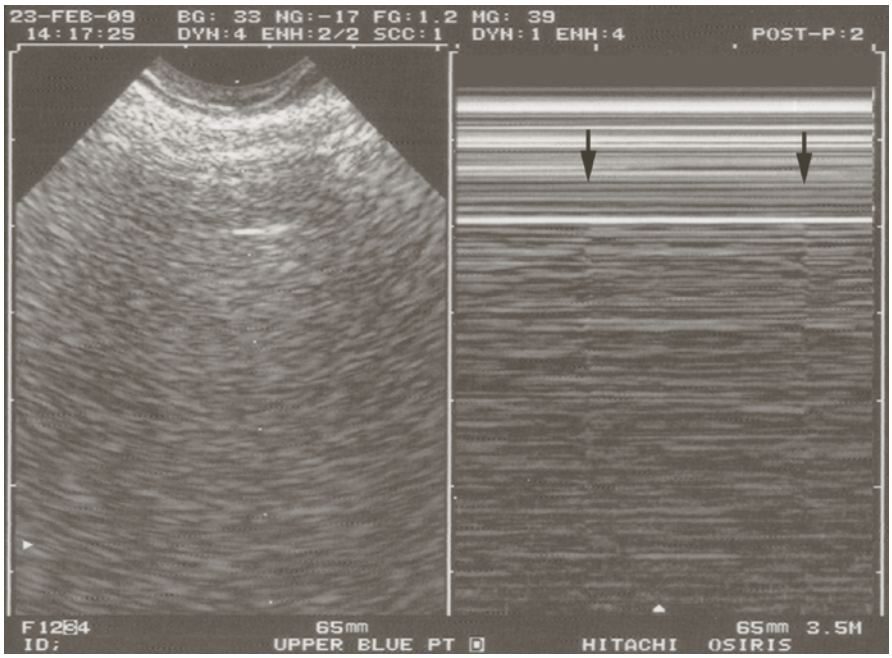

Fig. 18.3 T-line. Example of an extremely discrete lung pulse. This fine line (*arrows*) stops exactly at the level of the pleural line, shaping a kind of "T." The left image is ill-defined since the patient had substantial *subcutaneous emphysema*. In spite of these two extreme conditions, the rules of critical ultrasound are present: there is no pneumothorax. The left image can be labeled the "bat in the fog"

the mangrove variant, may be confused with a lung point by novice users (see below). This is one perverse effect of an immoderate use of the M-mode. We must devote some text for analyzing this problem.

1. The mangrove variant is a progressive phenomenon, whereas the word for describing the lung point is "sudden." A real lung point suddenly appears on the screen.
2. The lung point should be sought only if pneumothorax is suspected, in the case of anterior absence of lung sliding associated with absence of B-line. The mangrove variant occurs at the entire lung surface, including the anterior parasternal areas. In other words, the only confusion should be, if any, with an extremely limited parasternal pneumothorax, at first view by a young operator. The visualization, more laterally, of the strictly identical pattern would reassure this operator.
3. Mostly, the M-mode should not be used for confirming a lung sliding that has already been detected in real time. Using the M-mode is an efficient way of complicating a simple situation. The mangrove variant is a problem only when the M-mode is used.
4. Note that a polypneic patient has usually no end-respiration pause, making the problem of even smaller importance (a sedated patient has a quiet respiration, and the mangrove is more frequent).

The grain of sand variant – When lung sliding is extremely discrete, the seashore sign can be restricted to the visualization of some sand. In these cases, detecting even a few grains of sand, provided they stop exactly at the pleural line, is enough for considering that the lung is at the chest wall. One extreme variant makes a chimney pattern, or a termitarium pattern, again shaping a T and labeled the T-line (Fig. 18.3).

The lung pulse – Detailed in Chap. 16, it is defined by abolished lung sliding with subtle cardiac pulsations, allowing one to rule out pneumothorax [11]. It indicates impaired lung expansion, such as in one-lung intubation (see Fig. 16.9 page 145), and is frequent in ARDS.

The Peyrouset phenomenon – A noise mimicking a seashore sign can be created, simply by increasing, for no reason, the gain button. The far field is polluted by a background noise. This is not a serious pitfall for several reasons:

- The operator should not begin: making for no reason a high gain is a wrong note.
- The sand of the Peyrouset phenomenon is extremely fine, whereas the seashore sign gives a kind of coarse pattern.
- The sand of the Peyrouset phenomenon progressively fades, whereas the sandy pattern of the seashore sign stops at the very location of the pleural line.

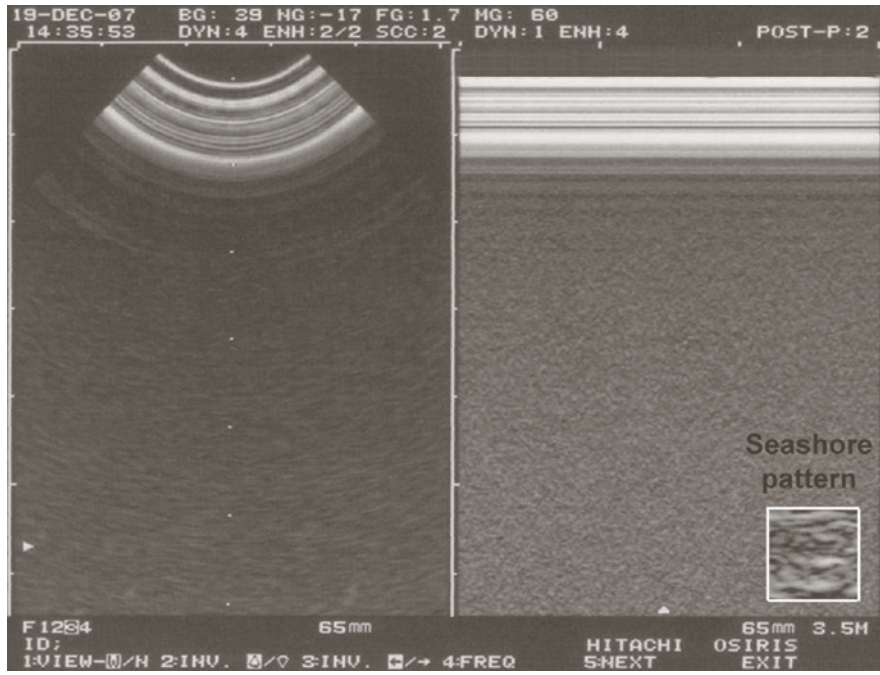

Fig. 18.4 Peyrouset phenomenon. The *left* image indicates the air of the ICU room – the probe is still on its stand. What is visible here is an air acoustic barrier. These roughly horizontal artifacts, reminiscent of the A-lines, were called (somehow artificially) H-lines, since this letter has a geometric shape reminiscent (from afar) of a stand of probe, with a horizontal line. To the *right*, on M-mode, the gain was increased too much, and a noise appears. We can see three major differences with the seashore sign: the "sand" is microscopic (compare with seashore sign, in the white frame), the sand density increases at the bottom of the screen, and there is no millimetric limit. Do not press the M button if not necessary

- The M-mode should not have a diagnostic interest, except in rare situations. It should be used only for keeping a document showing *what was actually seen in real time*. Lung sliding is detected using real time. In no case will the Peyrouset phenomenon give the illusion of lung sliding in a patient with a pneumothorax if the operator cares to focus on the real-time image.

Figure 18.4 summarizes clues that allow easy distinction from a genuine seashore sign.

The Ifrac Phenomenon

A severe dyspnea with use of accessory respiratory muscles creates muscular sliding instead of lung sliding. This can give the illusion of a seashore sign with a machine not devoted to the lung, displaying the real-time image not exactly at the level of the M-mode image. This prevents locating the pleural line without ambiguity. Called the "Ifrac phenomenon" (from a modified patient's name), this is a typical wrong note if we compare lung ultrasound with music (Fig. 18.5). Any sandy phenomenon that arises above the pleural line is not a seashore sign. We would like to be heard by some familiar critical ultrasound manufacturers (Figs. 18.1 and 2.5 page 16).

The Nogué-Armandariz Phenomenon

This rare occurence is seen when there is a perfect synchrony between the lung sliding and the muscular sliding. In M-mode, there is a kind of permanent sand arising at the muscular line, generated in parallel with the sand of the lung. Recognizing lung sliding can be possible, however, in real time. It just needs more expertise than for a normal subject. This is one more case where moderate use of M-mode is indicated.

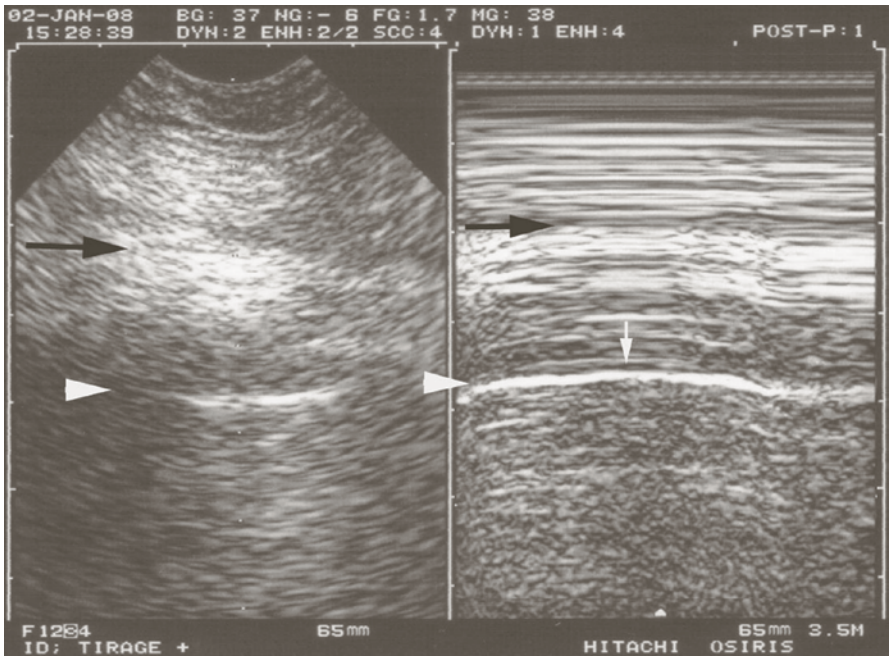

Fig. 18.5 The Ifrac phenomenon. *Left*: Real time. The upper arrow shows an aponevrosis between pectoral and intercostal muscles. The *lower arrow* shows the pleural line (in this frozen image, the bat sign is ill-defined). *Right*: M-mode. This image may appear to be like a stormy sea. The muscular contraction (indicating major dyspnea) has generated a sandy pattern stopping at the area of the *upper arrow*, i.e., superficial to the pleural line. Is this severe dyspnea due to a pneumothorax? The *vertical small arrow* clearly displays an area of typical seashore sign. This is sufficient. The diagnosis of pneumothorax can be excluded. This patient suffered from a severe asthma. The superposition of the 2D and M-mode images at the strictly same horizontal level makes easy the distinction between pleural line and muscle line. In extreme emergencies (stress helping), this configuration is appreciated. Here, the M-mode is relevant

List of Situations Abolishing Lung Sliding

For some who believe that abolished lung sliding means pneumothorax, here is a list of situations for which lung sliding can be abolished or hard to detect.

1. Visceral pleura present but motionless (Fig. 18.6)

A history of pleurisy, with pleural adhesions [12]
Acute pleural symphysis, maybe a frequent complication of ARDS and massive pneumonia. See physiopathologic notes page 192 in Chap. 20.

Complete atelectasis
Massive fibrosis
Abdominal compartment syndrome, possibly
Severe acute asthma
Apnea
Cardio-respiratory arrest

Esophageal intubation in a patient with cardiac arrest (bilateral abolition)

One-lung intubation (usually left-sided)
Jet ventilation

2. Visceral pleura absent

Pneumothorax
Pneumonectomy

3. Physical impediments

Parietal emphysema. It prevents clear analysis of the pleural line (but see below).

4. Technical insufficiencies

Inappropriate technique (the operator's hand is not still, for instance, or a transversal scan passing by a rib and generating M-lines)

Unsuitable ultrasound machines. The digital technology, especially using plasma screens, was disappointing. The first laptop machines devoted for the ER created a real regression (for no gain of space); they are now little by little improving slightly.

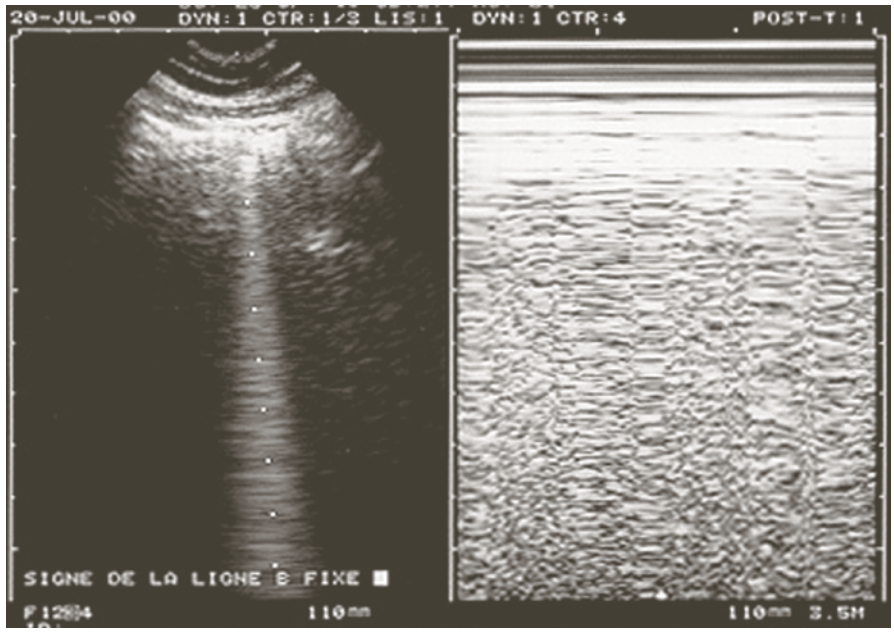

Fig. 18.6 Standstill B-line. The b-line of the *left image* is motionless. A M-mode view passing through it demonstrates the disorder: homogeneous clear pattern. A mobile B-line would escape at regular intervals outside the cursor line like a pendulum, and would yield a succession of clear and dark bands, and not this homogeneous clear pattern (*right image*). This indicates abolition of the lung expansion, of relevance in the BLUE protocol

Unsuitable probe. Low-frequency (2.5-MHz) probes, especially phased-array cardiac probes, are usually not adequate to study lung sliding. The several institutions already working with echocardiography-Doppler equipment with such probes were possibly discouraged from practicing lung ultrasound.

Filters. Filters yield softened, smooth images using temporal averaging. Like cosmetics, they create flattering images that mask the true content, but we want to see the wrinkles precisely. Filters yielding any time gap are improper for lung ultrasound. Harmonics seems to be the most destructive filter. The operator must work on a natural image.

Ultrasound Diagnosis of Pneumothorax: Technique of Detection

Since air is the only item investigated, pneumothorax signs may appear abstract. The user will need one, two or three signs (abolished lung sliding, the A-line sign, and the lung point). Numerous other signs are usually not required.

Pneumothorax is a nondependent disorder. In supine patients, a free pneumothorax collects at the less dependent area, near the sky [13]. The pneumothorax should be sought at the anterior and inferior aspect of the thorax, with a probe pointing toward the earth along the earth–sky axis. Any free pneumothorax collects at least at the lower half of the anterior chest wall in a supine patient [14]. All life-threatening cases involve this area – or more.

Where should the probe be applied in an extreme emergency? For giving standardized keys, the lower BLUE point in a supine patient, the upper BLUE point in a semirecumbent patient.

First Sign: Abolition of Lung Sliding

Description

The first sign of pneumothorax is a complete abolition of lung sliding. No movement in a vital organ is abnormal. This pattern is striking for accustomed users.

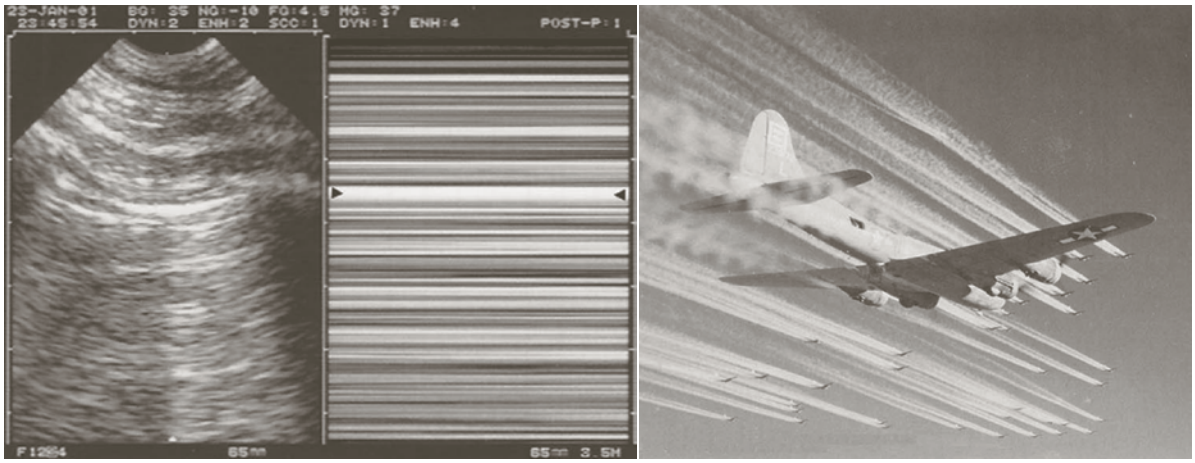

Fig. 18.7 The ultrasound diagnosis of pneumothorax. The *left image* shows an (ill-defined) A-line, and above all a complete abolition of lung sliding, perfectly demonstrated on the middle image, using the M-mode. This pattern made of exclusively horizontal lines was called the "stratosfere sign", in allusion to threatening stratospheric phenomena (*right figure)*

The M-mode demonstrates this abolition in a single picture (again, the eye of the operator must first see that the pleural line is motionless). The M-mode superposition of horizontal lines is characteristic of an absence of motion. A reminder of stratospheric condensation phenomena of B-17 flying fortresses squadrons at high altitude, this sign was called the stratosphere sign [15] (Fig. 18.7).

Assessment of the Sign

A study conducted in a medical ICU analyzed abolition of lung sliding in Stage 1 with CT as reference. Ultrasound sensitivity was 95% in this first paper [16]. Due to a mistake that escaped the authors as well as the reviewers, the exact sensitivity should be 100%. In actual fact, patients with parietal emphysema were wrongly considered as "false-negatives," in the spirit that lung sliding could not be analyzed. This was a misconception (maybe providential, because data priding on 100%, in a discipline not supposed to exist, are not easily accepted): false negative assumes lung sliding to be present. Either we exclude these patients for unfeasibility, or we describe what is seen, i.e., characteristically, no visible lung sliding. In other words, all cases of pneumothorax yield abolition of lung sliding. The negative predictive value is 100%. *Normal lung sliding confidently rules out pneumothorax.*

We had the pleasure to see, long after our observations, that abolished lung sliding had been described as a sign of pneumothorax in the veterinarian domain [17]. We have also seen some other studies supporting this notion [18,19]. We kept on submitting in this field since it appeared that rough analysis of lung sliding was far from summarizing the diagnosis. In our first study using mostly controls without lung disease, ultrasound positive predictive value was only 87% [16]. This rate decreased to 56% when the increasing control population included ARDS patients [20], and fell to 27% when only patients in acute respiratory failure were considered [21]. During the course of ARDS or severe extensive pneumonia, lung sliding is abolished in more than one-third of cases. We repeat that abolished lung sliding is not specific to pneumothorax (see the list above).

The poor specificity of the abolished lung sliding is not a problem. We should just consider other signs.

We also want to clarify a minor note of terminology about the barcode sign. Old barcodes looked like our stratosphere sign. Using this term would be of poor descriptive value (evoking nice images of shopping) but above all extremely confusing when considering the new barcodes, which actually display a seashore sign (Fig. 18.8). Is barcode quicker? The locution "barcode sign" takes 1.40 s versus 1.73 s for "stratosphere sign," but the time saved using ultrasound (instead of radiography or CT) is in the range of dozens of minutes not to say hours. For 0.33 s, we can use the original label.

Fig. 18.8 Barcode sign? This smiling barcode shows that some expression can be confusing. Even if referring strictly to traditional barcodes, the image sounds like making nice shopping with the family in a supermarket on a sunny Saturday. The term "stratosphere" suggests the threat of imminent bombing – like pneumothorax, a potentially deadly event

Second Sign: The A-line Sign

The artifacts analysis will be of critical help, especially when lung sliding is abolished. The constant sign is the complete absence of B-line, a sign referred to as the A-line sign (Fig. 18.9).

We saw in Chap. 17 that lung rockets indicate interstitial syndrome [22]. To see a diseased lung also means to see the actual lung – without air interposition between pleural line and lung. Our data indicate that the parietal pleural alone is unable to generate any B-line [23].

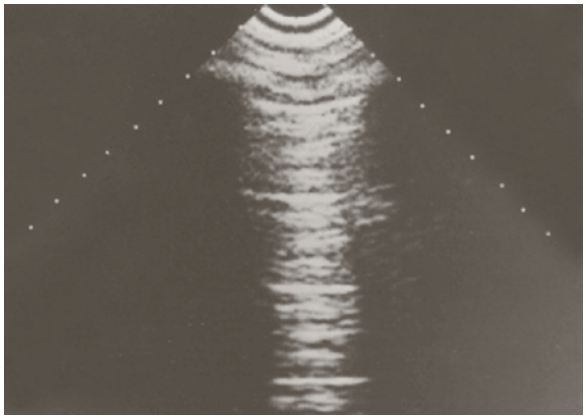

Fig. 18.9 Pneumothorax. Ultrasound static presentation. Absence of lung sliding is not visible here. Three A-lines can be described (intermediate horizontal lines, called A′ and A″ lines are also visible – without meaning). Extensive scanning shows the complete absence of B-line, a pattern called the A-line sign. We show on purpose an image taken in 1989 with the ADR-4000 (1982 technology) – with maybe a historical meaning (we have left it free of any marking). This image was evoked in Chap. 17 for demonstrating the Π-line variant, which should not mimic a B-line

An analysis of cases of complete pneumothorax confirmed that lung rockets were present in 60% of controls (defined using CT), and in no case of pneumothorax (Fig.18.7). Absence of lung rockets, in other words the A-line sign, had a sensitivity of 100% and a specificity of 60% for the diagnosis of pneumothorax [23]. The negative predictive value was 100%: B-lines allow pneumothorax to be ruled out (Fig. 18.10).

Lung artifacts come at the right time, since one benefits from a perfect combination: the patients who are the most at risk for pneumothorax and the most at risk for severe consequences are usually those who display lung rockets from extensive pneumonia, ARDS (see Chap. 17).

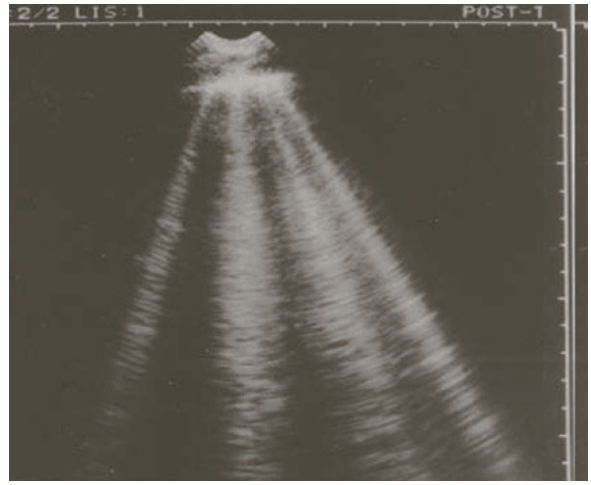

Fig. 18.10 Typical lung rockets. This allows immediate ruling-out of pneumothorax. Note that the two central B-lines are fusiform, reminiscent of a squirrel tail (squirrel variant, without meaning)

Lung sliding or lung rockets identify a majority of patients who do not have pneumothorax. Specificity of abolished lung sliding plus the A-line sign is 96% for the diagnosis of complete pneumothorax [23].

Third Sign: The Lung Point, a Specific Sign

Using lung sliding or B-lines, we can easily rule out pneumothorax. The role of ultrasound does not stop here.

Principle

Abolished lung sliding plus A-lines can be seen in any lung that has no freedom of movement (see the numerous causes above) and has no interstitial edema. A 100% specificity is here required since the consequence of diagnosing pneumothorax is to insert a needle in a critically ill patient (or ultrasound should not be performed).

One must imagine that any lung inflates on inspiration: spontaneous as well as mechanical ventilation, normal as well as collapsed lungs. If the collapsed lung has a contact with the chest wall, a slight increase of contact will occur on inspiration, at a certain location: the boundary between the living air of the lung and the dead air of pneumothorax (Fig. 18.11). This generates a characteristic sign.

The Sign

When (and only when) the operator has detected in Stage 1 an image suspect of pneumothorax, i.e., lung sliding abolished with the A-line sign, the probe is shifted laterally or more, until the lung point is found: a sudden and fleeting pattern at a precise location of the chest wall and along a definite line, at a precise moment of the respiratory cycle, usually inspiration, with the probe strictly motionless. This can be either lung sliding or lung rockets (Fig. 18.12). The location is constant provided the size of the pneumothorax does not vary during the examination.

Assessment of the Lung Point

Again in the ICU, when comparing pneumothorax and controls studied on CT, the lung point had a sensitivity of 66% and a specificity of 100% for the diagnosis of pneumothorax [20]. We have never observed a lung point in the countless patients we have visited who had no pneumothorax. When the focus is done on radio-occult cases of pneumothorax, sensitivity increases to 79% [15].

Comments

The lung point highlights the high sensitivity of ultrasound to display air patterns. It highlights the all-or-nothing rule of lung sliding. It proves that minimal, millimeter-scale pneumothorax was accurately detected. It confirms that the technique of search for lung sliding and the machine used (filters, probe, etc.) were correctly designed.

Major pneumothorax with complete lung retraction will never touch the wall, explaining the low sensitivity of ultrasound for these cases. Radio-occult cases are often anterior, explaining the high sensitivity of ultrasound.

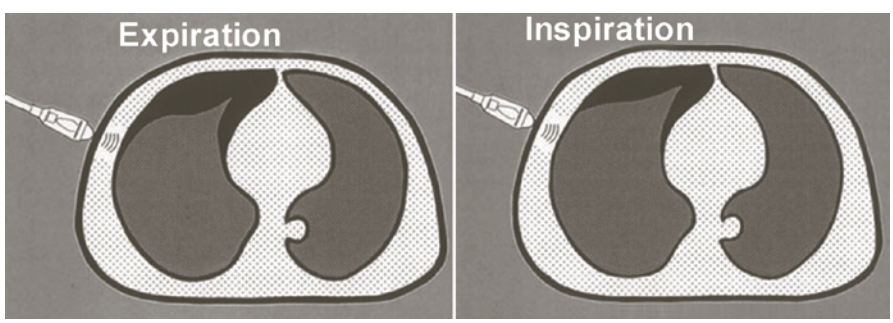

Fig. 18.11 The lung point, physiopathology. At the *left*, the probe is facing the pneumothorax, in expiration. At the *right*, after inspiration, the lung has slightly increased its volume, and now the lung itself is facing the probe, which remained motionless

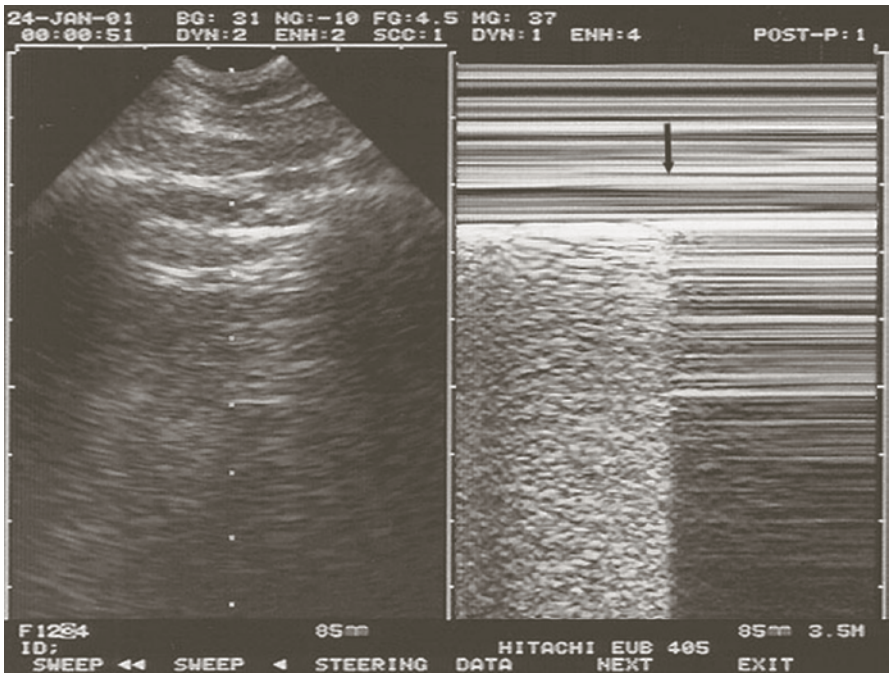

Fig. 18.12 The lung point. In real-time (*left*), not featuring, a transient inspiratory movement was perceived at the pleural line along the middle axillary line, in a young patient with pneumothorax of average volume. M-mode (*right*) shows that the appearance (or here disappearance) of lung signs is immediate, according to an all-or-nothing rule (*arrow*). If the probe is correctly applied on the thorax, no other disorder can generate a typical lung point, making this sign specific to pneumothorax

Abolished lung sliding with A-lines in one area, with lung sliding present or B-lines in another area of the same lung, separated by ribs, for instance, but without lung point can on occasion be seen. Lobar atelectasis or focal adherences may explain this pattern.

In a hasty examination, the liver or the spleen respiratory dynamic can roughly simulate a lung point. We call it the "liver point." To avoid any confusion, basic principle number 3 of lung ultrasound should be followed, i.e., having the probe at standardized lung areas for avoiding abdominal organs (the BLUE points). In case of doubt, the liver point alternates living lung (lung rockets, lung sliding) with a plain, anatomic tissular organ. The lung point alternates living lung with dead air (inert image).

Variants of the Lung Point

The half lung point – The lung usually touches the wall in a frontal approach, making a sudden change of pattern of the whole pleural line. It sometimes touches the wall from one side to another side of the pleural line, in a side approach, creating a smoother sign that we call the half lung point. In this variant, there is a visible lung sliding at one half of the pleural line, and an abolished lung sliding at the remaining half.

The heart point: In some cases, at the parasternal area, systolic visualization of the heart makes an equivalent of a lung point.

Additional Signs of Pneumothorax

Other signs can sometimes be extremely useful. The swirl sign, which has an equivalent at the abdominal level for the diagnosis of occlusion (see Fig. 6.19 page 51), indicates hydropneumothorax. The fluid collection is freely swirling in a depressurized pleural cavity. Consequently, when the probe is applied at bed level and when movements are gently transmitted to the patient, the fluid pleural effusion laps in a characteristic manner (Fig.18.13).

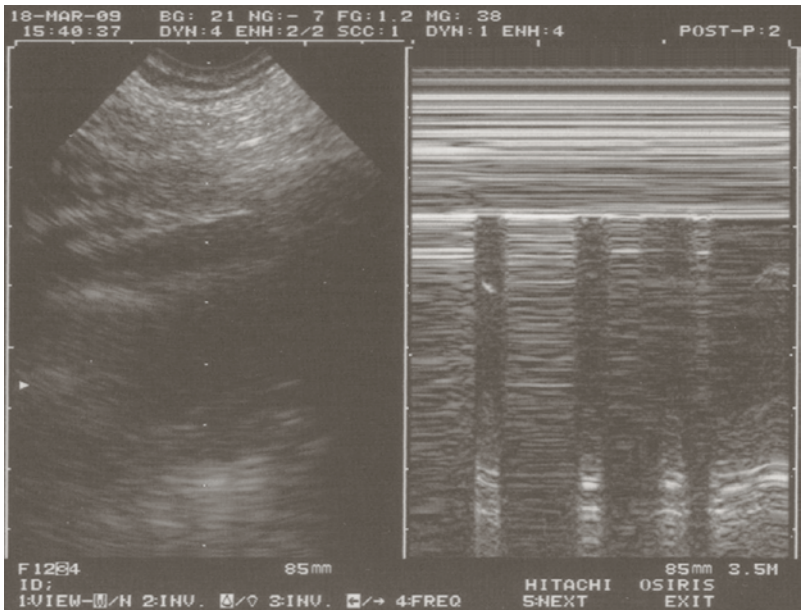

Fig. 18.13 The swirl sign. The *left image* shows a pleural effusion. *Right image*: a rapid succession of air artifacts, coming from the pleural line, alternating with transmitted sounds, are clearly visible. The rhythm is attributable neither to respiration nor to the heart, but to the swirl of the fluid in a depressurized cavity. A case of hydropneumothorax

Evaluation and Evolution of the Size of Pneumothorax

Evaluation raises two problems.

1. If we compare ultrasound with radiography, poor results will be expected, because radiography is not an acceptable gold standard [3–7].
2. If we order a CT when a radiography has already shown the pneumothorax (even with wrong appraisal of the volume), we raise an ethical issue of unnecessary irradiation.

Bearing these heavy limitations in mind, we only made a correlation for radio-occult cases, i.e., cases where CT was the only definite proof [15]. This correlation showed that one third of patients with radioccult pneumothorax needed a chest tube. Subsequent studies with greater use of CT confirmed the principal results [24].

In our study, the lung point location was correlated with the need for inserting a chest tube by independent team managers. The chest tube was indicated in 8% of cases when the lung point was anterior, versus 90% of cases when it was lateral [15]. The more lateral the lung point, the more substantial the pneumothorax. Major pneumothorax yields a very posterior – or even absent – lung point.

We must define what is a "minute" pneumothorax. A sheet of A4 paper has a minute thickness (<1 mm), but also an extensive surface (21 × 29.7 cm). This explains why even minute cases are easily detected using the standardized BLUE points.

Anterior lung point is correlated with minimal and generally radio-occult pneumothorax [15].

Evolution raises a slight problem.

One feature must always be kept in mind: a pneumothorax behaves as an unstable condition. Its volume can change suddenly, maybe because of fistulae behaving like valves, possibly moving with the patient's position – especially when the patient can move freely (personal theory). The pneumothorax volume can also spontaneously shrink and vanish, *even* in mechanical ventilation. We have evidence of this, using bedside monitored ultrasound as a gold standard, in critically ill patients. Soft ventilatory strategies are probably a good factor for absence of worsening of pneumothorax, but clearly, all cases do not shrink in intubated patients.

Pragmatically, when a pneumothorax is detected and the tolerance correct, we check for the lung point location at regular intervals. The lung point is stable at the initial diagnosis, i.e., following a few respiratory cycles. It can of course evolve, from worsening to shrinking.

This section is inserted in order to make the reader aware that for planifying standardized studies, comparing radiography and CT or ultrasound with one of these techniques, any delay can create distorsions.

A Place for Stage 4 Examinations?

Stage 4 is a comprehensive lung scanning that includes the posterior parts (needing a patient laterally positioned or sitting) and the apex. For diagnosing small cases of pneumothorax in noncritically ill patients who are often sitting, the apex analysis should be developed. It can appear difficult, since landmarks are less available compared with standard intercostal views. However, discrete lung sliding may be clearly visible (a paradoxical feature since the apex is rather a starting block) and B-lines may be frankly visible. In these two cases, a very small pneumothorax can be confidently ruled out. Note that only a microconvex probe has suitable ergonomy and resolution.

Practical Detection of Pneumothorax and Ultrasound-Enhanced Management

When a pneumothorax is suspected, the first step is to apply the probe at the anterior BLUE points. Detecting lung sliding or lung rockets rules out pneumothorax in a few seconds. If lung sliding is absent and no B-line is visible in this area, finding a lung point confirms the diagnosis and indicates the volume of the pneumothorax. In the absence of lung point, two ways are possible. Time permitting, one can use traditional tools such as X-ray or even CT. Time not permitting, in a patient with acute respiratory failure, the philosophy of the BLUE protocol can be used (Chap. 20): knowing that abolished lung sliding plus the A-line sign has a 96% specificity [23], integrating this ultrasound profile with the clinical context (sudden pain, tympanism after subclavian catheterization) should obviously prompt for urgent drainage.

Diagnostic potentials include the following:

1. Spontaneous cases seen in the emergency department have usually already undergone a chest radiograph. Let us temporarily accept this. On the other hand, we put our energy toward eradicating useless profile incidences and dangerous expiratory radiographs. The patient is monitored using ultrasound only. Pregnant women and children should benefit from this minimally invasive approach.
2. For pneumothorax occurring under mechanical ventilation, a young intensivist not fully familiar with ultrasound should ask for a radiograph, prepare the material for inserting the tube, and be ready, proceeding as soon as the radiography comes back: no time is lost. If the patient has poor tolerance and initiates bradycardia, it may be wise to get confident on the ultrasound findings.
3. The traumatized patient will increasingly benefit from on-site ultrasound, instead of these blind tube insertions that were once our only choice and were life-saving only when rightly indicated.
4. Routine after thoracentesis or subclavian catheterization: an ultrasound view (seashore sign) should replace the radiography in the file.

Therapeutic potential:

The insertion of the chest tube is planned depending on ultrasound data. We use neither traditional clinical landmarks (we forgot them), nor the radiologic document (those who want to use it should remember that the patient can be erect for the radiography, and supine for the chest tube insertion, altering the location of the pneumothorax). The tube is inserted far from the lung point. The nurse initiates the aspiration, while the probe is on the chest wall.

Ultrasound is a unique tool to see that the return of the lung to the chest wall can be very brief: sometimes 2 min. Knowing this, we prefer to make sequential aspirations in order to avoid such sudden changes.

One M-mode ultrasound view is taken, in order to keep a visual proof (with the mention of "upper BLUE point/Stage 1-prime," for example). No matter where the tube is, if a seashore sign has replaced a stratosphere sign, the tube works. When the chest tube is clamped, persistence of lung sliding indicates that the leakage is sealed. Recurrence of stratosphere sign likely indicates that the pneumothorax reoccurred after clamping. The tube is eventually withdrawn after the clamping has been judged effective according to the dynamic ultrasound maneuvers. A last ultrasound view is taken after withdrawal of the tube.

With such management, one should find in the patient's records only the radiograph performed at admission (in the absence of pregnancy). With irradiation, it may seem pathetic to invest in lung ultrasonography to avoid some chest radiographs if a CT is scheduled for documenting idiopathic pneumothorax, it is the radiation equivalent of 100–200 chest radiographs. The main information, i.e., search for contralateral abnormalities, is of little relevance since 89% of patients have such abnormalities, and CT does not contribute to predicting a new pneumothorax [25].

Pitfalls and Limitations

There is no real pitfall, only some limitations.

Parietal Emphysema

It stops ultrasounds, preventing recognition of underlying structures. This is an issue for beginners, but extreme cases can be a hindrance for experienced operators.

Parietal emphysema can generate multiple comet-tail artifacts, B-like lines. When the air collections are multiple and small (air bubbles), the generated comet-tail artifacts are randomly organized, shaping a kind of "W" letter: the W-lines (see Fig. 25.4 page 254). When the air collection makes a large, regular stripe between two muscles, the comet-tails can be aligned, arising from a horizontal line (Fig. 18.14). These lines, called E-lines, mimic B-lines arising from a pleural line at very first view: a deadly pitfall for the beginner.

A music score without a key cannot be used. Likewise, the user will first check for the bat sign. Parietal emphysema prevents recognition of the bat sign. This indicates a diagnosis of extra-thoracic air (in addition to the characteristic clinical crepitation). The visible horizontal hyperechoic line is not the pleural line. Without the bat sign (accessible on longitudinal scans only), this is not lung ultrasound. At this point, we advise beginners to switch-off the machine, and do with traditional tools, as done before, time permitting. We can even advise to not switch-on the machine when clinical parietal emphysema exists.

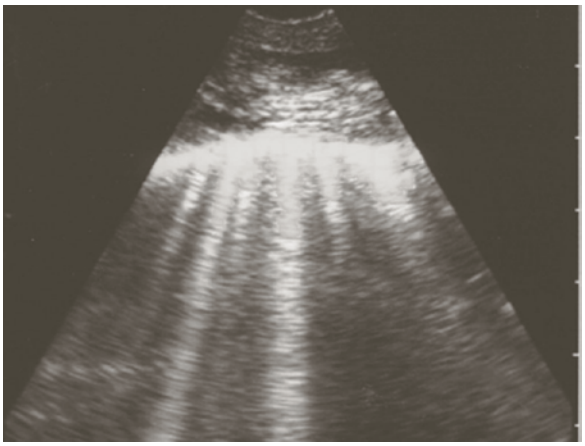

Fig. 18.14 E-lines. In this longitudinal scan of the chest wall in a traumatized patient, well-defined comet-tail artifacts are visible, some spreading up to the edge of the screen. They may give the illusion of lung rockets. However, no rib is identified: no bat sign. We are no longer in lung ultrasound. The discontinued hyperechoic line from which the comet-tails arise is not the pleural line. There is a layer of parietal emphysema in a patient with massive pneumothorax. These lines were called E-lines (*E* for *emphysema*)

Now for nonbeginners, the clue in these cases is to perform the *compression lung ultrasound examination*. Using our short-footprint probe, we can exert pressure (provided it does not harm, so look out for rib fractures). The air collections are little by little drawn away between the probe and the rigid ribs using a gentle Carmen maneuver. At one moment, large acoustic shadows are detected springing up from the haze: the rib shadows. The pleural line can be located at this moment. The permanent Carmen maneuver makes this location easier. Although more or less defaced, the image often allows one to answer the question of whether lung

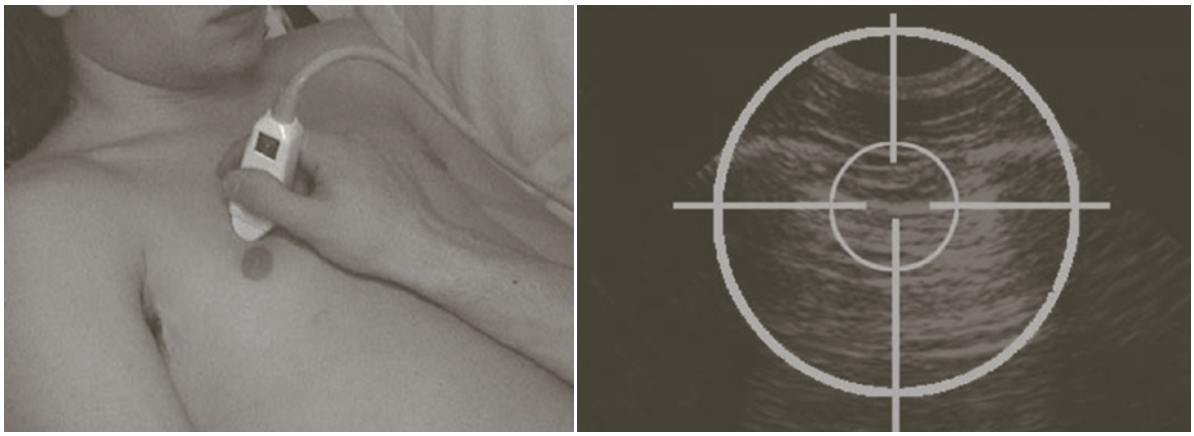

Fig. 18.15 As far as possible (setting permitting), the hand of the operator must be completely motionless, and be able to wait for hours, without moving, without fatigue, like a *sniper*. An unsteady hand is a key factor for failure. Only the patient is expected to move

sliding is present (avoiding referral to CT) or absent associated with A-lines (making pneumothorax likely). Even a lung point can sometimes be detected.

Note that E-lines and W-lines are motionless.

Posterior Pneumothorax

Such locations are rare. Posterior locations with clinical relevance are definitely rare (we await our first case). Yet a paradoxical but theoretical sign is expected: abolished lung sliding in Stage 1. It is expected because a posterior pneumothorax can develop only if there is massive pleural symphysis. Similarly, anterior lung sliding should rule out posterior pneumothorax. Another logical sign should be the absence of posterior lung rockets, a surprising finding after prolonged supine position (see next section). The clavicula makes the search for apical septated cases difficult (another rare location).

Septated and Complex Pneumothorax

This is a possible limitation, because it occurs within pleural symphysis, with areas of motionless A-lines alternating with areas of motionless B-lines or A-lines (if there is no diffuse interstitial injury). This diagnosis is definitely subtle. Obviously, such septated cases cannot generate a regular lung point (one also understands why the lung point is required for confident diagnosis). This is possibly time for requiring a traditional CT.

White X-ray without anterior lung rockets only suggests pneumothorax, since the anterior chest wall can be free of interstitial change, a possible pattern in ARDS. Pleural symphysis is also frequent in ARDS. Sudden changes in a routine daily ultrasound examination may be more suggestive (disappearance of previously present lung rockets from ARDS – those which are long to vanish).

Dyspnea

Major dyspnea requires experience, since lung sliding should be distinguished from the muscular sliding generated by accessory respiratory muscles (especially in the Nogué-Armandariz variant). Note that this concern does not affect spontaneous pneumothorax without dyspnea nor pneumothorax occurring in sedated patients. Agitation will render any examination delicate.

Dressings

Most dressings are voluminous (especially around chest tubes) and prevent ultrasound analysis. Our solution is to "think ultrasound" and avoid uselessly covering dressings.

Is the Tube Intraparenchymateous?

All the conditions are present for making this a challenge: the dressing is at the worst location, subcutaneous emphysema is often present, and a lung that is not fully consolidated will never give a satisfactory acoustic window for such a subtle diagnosis. It is worth trying, like always with ultrasound, anyway.

Subcutaneous Metallic Materials (Bullets, Shrapnel)

They generate comet-tails that are not B-lines since they arise above the pleural line in soft tissues. This is fortunately rare in our setting but can be encountered in unstable areas around the world.

Technical Errors

Using a technique other than the longitudinal technique, focusing on dependent zones, using unsuitable filters, an unsteady hand, confusion between B-, E- and Z-lines, not being aware of the mangrove variant, using an inappropriate machine or inappropriate probe are all errors that correct teaching promptly erases.

The Future of Ultrasound

Asking for confirmatory tools (X-rays, CT) can be valuable in the learning curve of ultrasound, but asking for them consistently would make ultrasound a loss of time.

It offers so many advantages that a minor investment effort is valuable. And the user will benefit from:

- Immediate diagnosis, quicker than the quickest radiograph (and obviously quicker than the quickest CT).
- Immediate ruling out, each time the question is raised (ventilated patients, invasive procedure, respiratory failure).
- Sensitivity superior to bedside radiography: a few millimeters of air thickness are sufficient. Since the birth of radiography, physicians have feared the delayed pneumothoraces, occuring hours after venous line insertions with normal check radiography. "Delayed" pneumothoraces have probably never existed. This notion probably highlights a deep insufficiency of the check radiography, done at an early stage, for detecting incipient pneumothorax.
- Opening to pre-hospital diagnosis.
- Major decrease in irradiation, of special interest to the child and young women.
- Major cost-savings, a godsend for most humans on earth.

Lung ultrasound for diagnosing pneumothorax is increasingly used [24,26–28].

Ten main points characterize pneumothorax:

1. A free pneumothorax locates at anterior areas in supine patients.
2. The first step is the recognition of the bat sign, which locates the pleural line.
3. The BLUE points make the search effective in a few seconds.
4. Ultrasound is superior to bedside chest radiographs for the detection of pneumothorax.
5. A cardiac probe is usually inadequate, a linear probe is limited for whole-body use, an abdominal probe is too large.
6. Lung sliding rules out pneumothorax.
7. Lung sliding is abolished by atelectasis, acute pleural symphysis, all causes of impairement of lung expansion, and rough technical errors: abuse of filters, erroneous gain setting, mainly.
8. B-lines rule out pneumothorax at the area where they are observed.
9. The lung point is a sign specific to pneumothorax (and indicates its size).
10. Make moderate use of the M-mode.

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Basic Applications of Lung Ultrasound in the Critically Ill: 1 – A Bedside Alternative to CT and Other Irradiating Techniques

19

The most severely ill patients are the ones who benefit least from CT or MRI. Bedside ultrasound neatly solves this paradox.

Now that we are familiar with lung ultrasound, we will see four main clinical potentials: (1) how to be able to decrease medical irradiation (the present chapter); (2) how to manage an acute respiratory failure (Chap. 20); (3) how to make the critically ill neonate benefit from this approach (Chap. 21); (4) how to simplify cardiac sonography (Chap. 22), by using lung ultrasound for hemodynamic assessment (Chap. 23).

Some academicians have found that lung ultrasound was futile in the light of the technological advances of the modern medicine. This was extremely wrong in 1989; on the contrary, it was the time for an absolute revolution. Now, in the era of multislice, ultrarapid CTs, this remains wrong, in light of the other drawbacks of CT. We will see why ultrasound can avoid most referrals to this traditional giant of imaging.

Lung Ultrasound Versus the Traditional Imaging Standards in the Intensive Care Unit

The five previous chapters showed how ultrasound performs better than chest bedside radiography for most indications in the critically ill. We must keep this centenary technique [1,2] for particular indications (need for overview, exact location of central lines, etc.). It may seem bold to now compare ultrasound with CT. Yet this is what we do daily. CT provides an image, ultrasound provides immediate information. In this view, ultrasound can replace a majority of CT referrals.

For years, thoracic ultrasound appeared limited to the sole diagnosis of fluid pleural effusion [3–5], or this simple application was virtually forgotten [6]. Consequently, for many doctors, the alternative for emergency lung assessment was bedside radiography or CT [7]. Ultrasound solves this quandary.

Lung Ultrasound and Bedside Radiography

An increasing number of intensivists know the inadequacies of the bedside chest radiograph [8–15]. Many basic diagnoses are occulted: pneumothorax (even tension cases), pleural effusions (up to 500 mL), alveolar consolidation (mostly of the lower lobes), and interstitial syndrome (at such a degree that this diagnosis is even not required from a bedside radiograph). The summation of the images makes the disorders difficult to interpret. Some excellent radiologists know how to read some bedside radiographs, but they are not available 24/7/365 in small, non-university-affiliated hospitals. We have evidence that the study of the ten ultrasound signs is much easier to reproduce. Either the radiography is normal or highly abnormal (white lung), ultrasound immediately discriminates the part of alveolar, interstitial, and pleural diseases, not to include subphrenic ectopic disorders.

Radiography is available only within hospitals. For all other settings (from desherited children in Indian villages to astronautes isolated in a remote spaceship), radiography is not an option. Also, the irradiating potential of radiography is a concern in each pregnant woman, child, or, by extension, any person.

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Tables 19.1 and 19.2 show why ultrasound usually shows what radiography cannot.

Lung Ultrasound and Thoracic Tomodensitometry

CT is a giant in imaging. It has the major advantage of providing an easy-to-interpret overview of the chest. We respect this precious tool, which has saved many lives. To consider the option of ultrasound in the face of this standard, we should remind ourselves of seven of the CT's drawbacks:

1. **Cost (Machine, Maintenance, etc.).** For us, this is a minor problem. For more than two-thirds of the people on the earth, who will never see a CT, this is a critical, life-threatening issue.

2. **Irradiation.** The institutions which have the privilege of affording CT must now face its high degree of irradiation: 200-times the value of chest radiography. Deleterious side effects of CT are now acknowledged [16–19]. Investigation of lung disorders in pregnant women raises concerns [20]. Diagnostic X-rays are the largest source of artificial radiation exposure, the source of 0.6–3.2% of the cumulative risk of cancer [18,19]. When a CT is performed at chest level on a 30-year-old or less woman, the risk of breast cancer is increased by 35% [21]. Exposure before the age of 1 year accounts for 3%, exposure in childhood (1–14 years) for 19% of radiation-induced cancers [18]. For a long time, authors have pointed out the drawbacks of chest CT, but without full knowledge of a real alternative [22]. Ultrasound provides an elegant solution.

3. **Delay.** Some anonymous experts found lung ultrasound a minor idea, since CT provides all answers in 10 s. Not only this vision has resulted in countless rejections, delaying publication processes, but above all it is not true. While lung ultrasound was fully implementable, i.e., since 1982 (or less), CT machines were in their infancy. The acquisition was long (a deadly issue for some patients). Now, the CTs are called "rapid". Yet the real overall time, i.e., from the moment the managing team comes to the point that a CT is necessary in a given ventilated patient, argues with the radiologist, prepares the patient, moves the patient to the CT department, then on the CT table, waits the 10-s acquisition, understands the CT results, takes the patient back to the ICU and is able to manage the disorder according to the CT result is more than 10 s. Those who can do the same incompressible sequence in less than 1 h can contact us.

4. **Need for transportation.** This is a major drawback in the critically ill. In the intensivist's brain, requiring CT scan is a *decision*.
   - An unstable patient is at permanent risk. Multiple life-support devices (catheters, tubes) can be harmed.
   - Transportation of unstable patients is a strain for the whole medical and paramedical team.
   - The intensivist is condemned to doing nothing during the entire procedure and cannot deal with other emergencies. It should be recalled here that during the night only one intensivist is present for the hospital's extreme emergencies.
   - Emergency CT scan is not the time for guaranting perfect asepsis – the critically ill patient with multiple multiresistant germs behaves as a "bacteriologic bomb" for the whole hospital.

5. **Iodine generates vascular overload**, risk of anaphylactic shock, renal injury.

6. **Comfort and safety for the patient**. The CT room is cold. The necessary supine positioning can be an issue. These two elements can generate redistribution of fluids subsequent to vaso-active stimulation and gravity, maybe not insignificant.

7. **Diagnostic inadequacies**.
   - Hindrances for a quality examination:

The signal is impaired by numerous artifacts: intracavitary devices (catheters), arms of the patient when they cannot be shifted, dynamic of respiration, or heart beatings.

- Low resolution power of CT:

The focal resolution power of CT is inferior to that of ultrasound. Septations within a pleural effusion are not visible. The superior resolution power of ultrasound has been proven for necrotizing pneumonia [23]. Colleagues can see again Fig. 8.13 page 66 or 19.1, and the most skeptical ones can do an in-vitro demonstration (Fig. 19.2). The distinction between

Table 19.1 Disorders which can be missed or confused with other disorders by bedside radiograph (*in parentheses:* erroneous diagnoses)

	Pleural effusion	Alveolar consolidation	Interstitial syndrome	Free pneumothorax	Normal subject
False- negatives	– Retro diaphragmatic location *(normal)* – Extensive but spread posterior location *(normal, or alveolar syndrome)*	– Too small lesion *(normal)* – Consolidation totally hidden by the cupola *(normal)* – Consolidation partially hidden by the cupola with blunting of culdesac *(pleural effusion)* – Summation of consolidation without air bronchogram with pleural effusion (*pleural effusion*)	– Too small images *(normal)* – Too dense patterns *(alveolar syndrome)* – Summation with posterior pleural and alveolar images *(alveolar or pleural)*	– Pleural line not tangential to the X-rays *(normality)*	– Not applicable
False- positives	– Basal alveolar consolidation blunting the cul-de-sac	– Pleural effusion with diffuse posterior location – Some interscissural pleural effusions – Summation of pleural images with dense interstitial syndrome	– None	– None	– Interstitial syndrome (if poor inspiration) – Pneumothorax (skinfolds)

Table 19.2 Disorders which can be missed or confused with other disorders by ultrasound (*in parentheses:* erroneous diagnoses)

	Free pleural effusion	Alveolar consolidation	Interstitial syndrome	Pneumothorax	Normal subject
False- negatives	(1)	– Deep lesion (*normal*) – Not scanned location (*normal*)	(1)	– Absence of lung point (2)	(1)
False- positives	(1)	– Thymus – Some loculated echoic pleural collection	(1)	(1)	(1)

(1) No condition yet considered

(2) In the case of absent lung point, in these patients with abolished lung sliding and absence of B-lines, it is preferable for ultrasound not to conclude, since abolished ampliation of noninterstitial lung can explain such a pattern

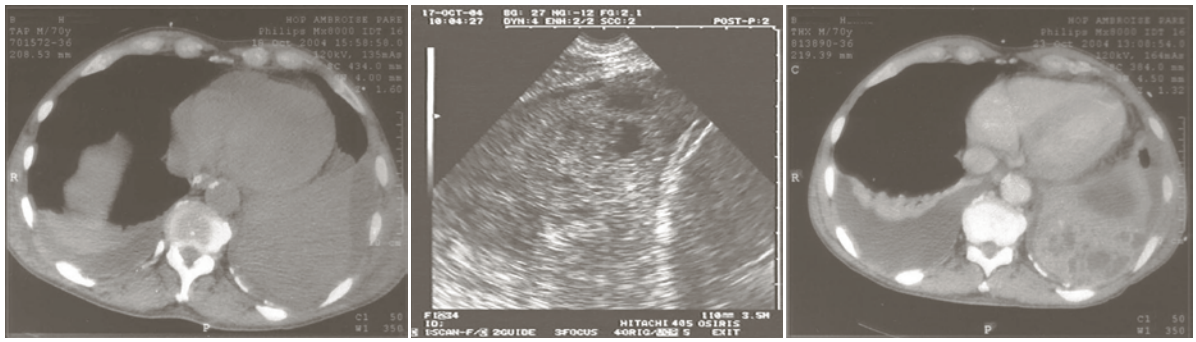

Fig. 19.1 Lung ultrasound superior to CT. The left figure (CT scan on first day) indicates an obvious massive pneumonia of the left lung. The middle figure (ultrasound) shows heterogeneous pattern, typical from necrotizing pneumonia. The right figure: CT scan performed on fifth day proves the necrotizing features of this pneumonia. This elementary case report has shown three features of clinical interest which were not provided by computerized tomography. (1) The necrotizing areas (which result in choosing the appropriate antibiotic therapy). (2) A complete abolition of lung sliding, a feature which indicates that lung ampliation is abolished, i.e., this alveolar consolidation is not a transudative process (such as hemodynamic pulmonary edema). 3) A clear visualization of the diaphragmatic cupola – its thickness can be measured – if needed. Note also the complete absence of pleural effusion – although highly suggested by the radiograph. Inserting a needle just for withdrawing pleural fluid was not indicated here. As regards the lung itself, the main conditions described in page 148 are gathered here

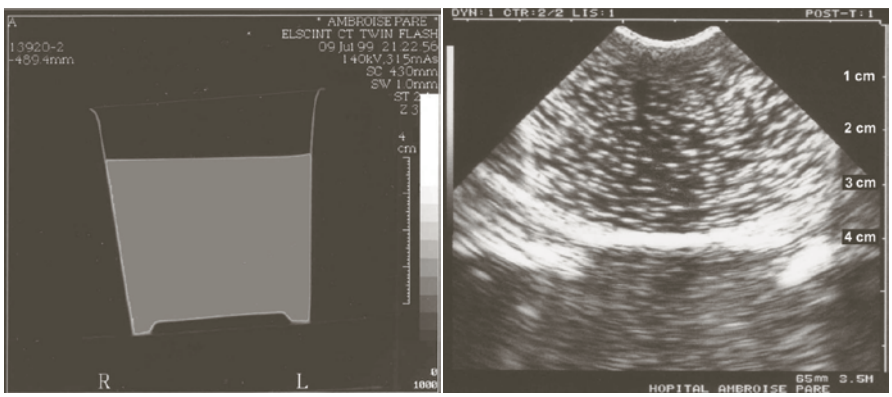

Fig. 19.2 Lung ultrasound superior to CT. This simple manipulation uses a glass of our Ecolight. The glass was shaken before CT and ultrasound acquisitions. The fluid within the glass seems to be inert (from the operator's eye). Depth of the glass is roughly 4 cm. *Left* (CT): the reader has a nice overview of the glass, but the content is homogeneous, just indicating fluid. *Right* (ultrasound): there is no overview. The shape of the glass has distortion (the white stripe concave to the top), but instead of the uninformative image of fluid given by CT, real time shows countless randomly whirling particles. This pattern is often seen in patients with empyema or hemothorax. Neither the eye nor the CT were able to see these particles nor this dynamic whirling. The reader can then chose between a nice overview and a deep vision of the real matter. This manipulation has shown that ultrasound has a better resolution quality than CT, similarly to what was proven on Figs. 8.13 and 19.1. If one mingles together the slight inferiority of ultrasound and its slight superiority (one point among others being demonstrated in this figure), this results in a rough equality, i.e., the possibility of considering ultrasound as a reasonable bedside gold standard in critically ill patients. We thank Marina Perennec who opened the CT room for this demonstration

Table 19.3 Published performance of ultrasound compared with CT

	Sensitivity (%)	Specificity (%)
Pleural effusion [1]	94	97
Alveolar consolidation [2]	90	98
Interstitial syndrome [3]	93	93
Complete pneumothorax [4]	100	96
Occult pneumothorax [5]	79	100

1. Intensive Care Med 25:955–958
2. Intensive Care Med 30:276–281
3. Am J Respir Crit Care Med 156:1640–1646
4. Intensive Care Med 25:383–388
5. Crit Care Med 33:1231–1238

alveolar consolidation and pleural effusion usually needs iodine injection. A millimetric effusion can be missed on CT, making in passing one "false-positive" for ultrasound. Interstitial syndrome can be hard to detect in ventilated patients. The dynamic features are not detected. Dynamic air bronchograms, abolition of lung expansion, diaphragmatic dynamic can in no way be documented by CT. Minimal pneumothorax is minimized since images are acquired at inspiration. The transverse scans have little relevance for phrenic damage.

All these issues are precisely strong points of ultrasound. The lung is a dynamic organ. This is the setting for a real-time method.

Table 19.3 shows that the performance of ultrasound, when compared with high-resolution CT in ARDS patients, is not far from 100%. Slightly inferior to CT in some respects, clearly superior in others, overall we think that ultrasound provides a reasonable bedside "gold standard" for the critically ill.

Lung Ultrasound: A Simple Discipline

Here (or elsewhere) is the opportunity to repeat that the majority of lung semiotics, allowing the diagnosis of the main acute disorders, as well as CT, is based on no more than *ten signs* (Fig. 19.3).

Suggestion for Classifying Air Artifacts

The artifacts useful or not for emergency diagnoses are numerous, and an overview may be useful. We took the initiative of suggesting alphabetic order (and a bit of logic for helping the memory). Figure 19.4 gathers the most relevant ones.

A-lines (*A* for the first letter)

Lung

Horizontal artifacts arising from the pleural line at regular intervals whch are equal to the skin-pleural line distance – indicating physiologic air (but also free air)

B-lines (*B* for the second letter, and also because this label unconsciously evokes interstitial syndrome for most physicians. We specify in fact "ultrasound B-lines")

Lung

Artifacts correlated with interstitial syndrome. They are defined according to seven criteria: (1) comet-tail artifacts, (2) arising from the pleural line, (3) hyperechoic, (4) laser beam-like, (5) long, without fading, (6) erasing A-lines, (7) moving with lung sliding

b line: one B-line visible between two ribs. The term b-line is always singular.

bb lines: two B-lines

B+ lines: three or more B-lines, representative of interstitial syndrome

B7-lines: B+ lines separated by 7 mm, i.e., the distance between two interlobular septa (interlobular septal thickening)

B3-lines: B+ lines separated by 3 mm, i.e., twice as many B-lines, due to one fluid element abutting the pleura between two septa: possibly intra-alveolar fluid (ground-glass areas).

Sub-B-lines (see Fig. 15.2 page 130): Artifacts having all the features of the B-lines but one: they arise from the lung line (i.e., from a pleural effusion), or from the shred line (i.e., from an alveolar consolidation).

C-lines (like *c*entimetric, *c*urvilinear, *c*onsolidation)

Lung

Curvilinear centimetric piece of alveolar consolidation abuting the pleural line.

D-lines

Available space

E-lines (like *e*mphysema)

Subcutaneous tissues

Multiple comet-tail artifacts, laser-like, hyperechoic, spreading to the edge of the screen, but arising

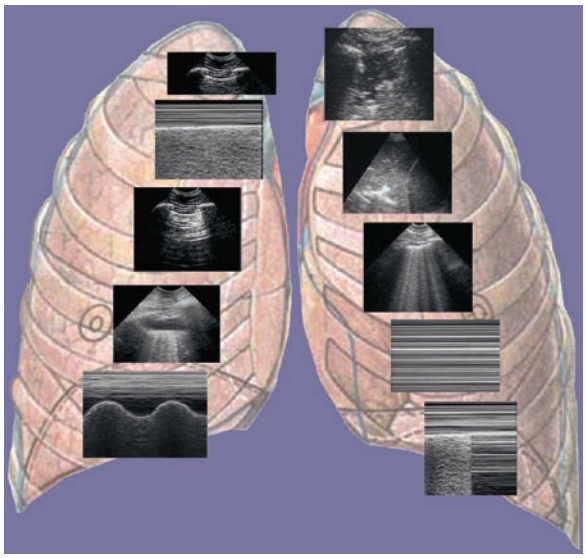

Fig. 19.3 The ten signs which originate lung ultrasound in the critically ill. The first, from the left and the top, is the basis (the bat sign). The second and third are signs of normality (A-lines and lung sliding). The rest are pleural effusion (quad sign, sinusoid sign), alveolar consolidation (tissue-like sign, shred sign), interstitial syndrome (lung rockets) and pneumothorax (stratosphere sign and lung point – A-line sign already featuring). The only color is the one of the background, for esthetic purpose. No space for Doppler

not from the pleural line, but from an hyperechoic line horizontal on the screen, which is a stripe of subcutaneous emphysema. No bat sign is visible: we are not in lung ultrasonography.

F-lines (from *F*abien Rolland)

F like *F*antôme also. Designates all these ghost punctiform or oblique lines sometimes found at the Merlin's space, and mimicking, for novice eyes, air bronchograms. They are identified as parasites since they stand still, whereas there is an active lung sliding.

G-lines (like *g*uts)

Extra-lung

G-A, G-B and G-Z lines

They look like A-lines, B-lines, and Z-lines, but arise from abdominal structures

H-lines (for the shape of the letter *H*)

Roughly horizontal lines (in fact, bent lines using microconvex probes) arising from a probe which is on its stand (or not yet in contact with the skin), demonstrating air of the room.

I-lines (like the letter *I*)

Lung. Rare pattern. Have the features of the B-lines but are short (2–3 cm). Unknown meaning.

J-lines (for *J*ulie)

Lung.

Small horizontal lines (1–3 mm width) superposed each 1–2 mm, and generating the B-line

K-lines (for *K*lingons)

Any location

Designates parasites due to external electric interferences (Figs. 19.5 and 11.11 page 86)

L-lines

Available space

M-lines (for Fernand *M*acone)

Horizontal hyperechoic artifacts sometimes generated below the rib surface. Can have a didactic relevance (Fig. 19.5).

N-lines (like *N*oir, and also like *N*eri)

Lung

Artifacts with roughly the same patterns as B-lines, but they are hypoechoic. Probably devoid of pathologic meaning. Wink to Luca Neri, who noticed them once (Fig. 19.5).

O-lines (like non-A, non-B)

Lung

Absence of any visible artifact – nor anatomic image of pleural or alveolar change

P-lines or Pi-lines or π-lines (look like the Greek letter π)

Lung

In some thin patients, the A-lines can be numerous and mimic a roughly vertical structure – reminiscent of the letter π. Yet they are in the foreseen distance (skin pleural line), and their length is roughly the one of the pleural line (B-lines are roughly one-tenth of the pleural line distance)

Q-lines

Available space

R-lines (from *R*oberta Capp)

Artifacts having nearly all features of the B-lines, but arising from the pericardium at the interface with the lung in short-axis ventricle views (Fig. 19.5).

S-lines (look like *S*-shaped lines)

Chest wall

Characteristic sinuous propagation. Generated by pacemakers.

T-lines (they look like the letter *T*)

Lung

M-mode. Fine vertical lines that strictly arise from the pleural line. They are a very narrow equivalent of the lung pulse and mean absence of pneumothorax.

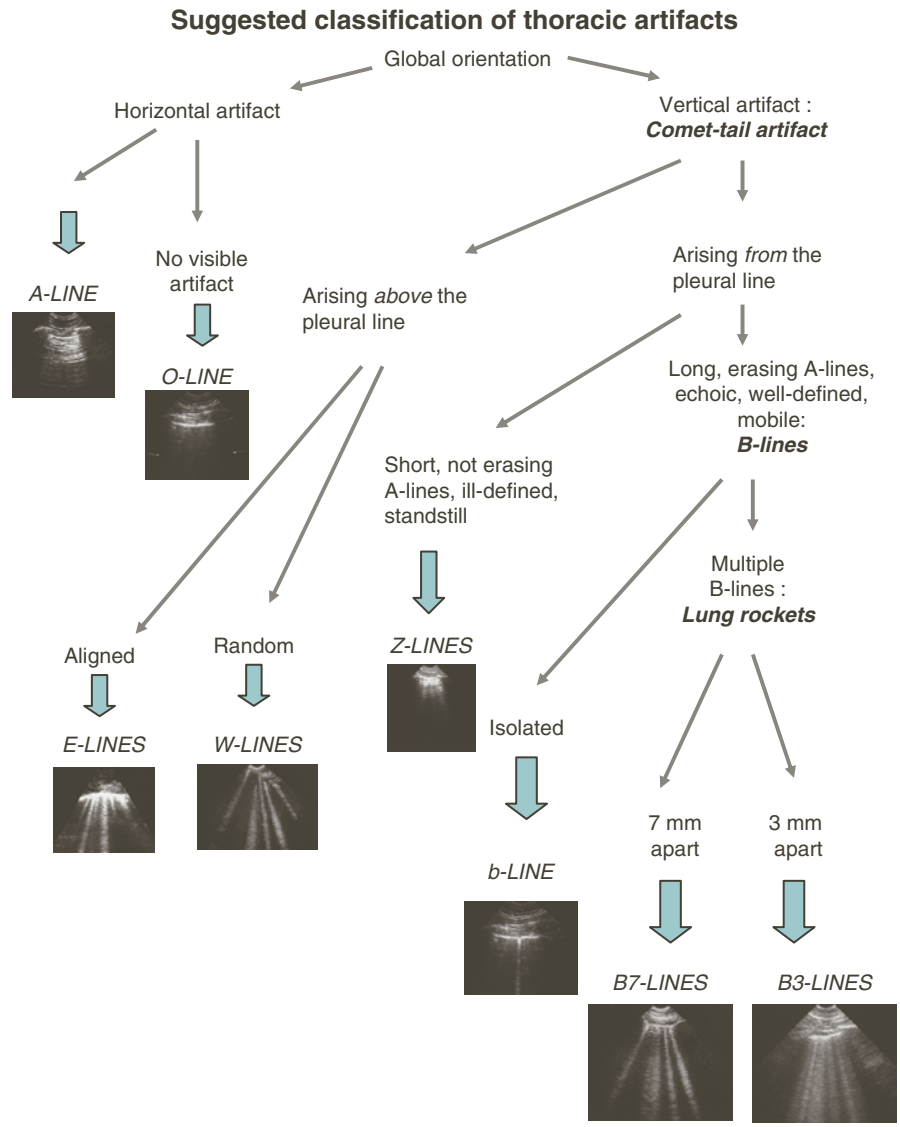

Fig. 19.4 The main thoracic artifacts. This figure shows the scientific filiation between the comet-tail artifact, the B-line, and the lung rockets

U-lines

Abdomen

Arciform artifact generated by bowel loops, shaping a reversed U.

V-lines

Available space

W-lines (shape of the letter *W*)

Subcutaneous tissues

A variety of artifacts looking like E-lines, but not aligned. They are the consequence of multiple air collections within the soft tissues (parietal emphysema).

X-lines (like the shape of an *X*)

Lung

Exceptionally, B-lines and A-lines are simultaneously visible, resulting in a cross-image (Fig. 19.5).

Y-lines

Available space

Z-lines (like the last letter)

Lung

Artifacts having two common points with the B-lines (comet-tail artifacts, arising from the pleural line) and five opposed points: not hyperechoic (rather

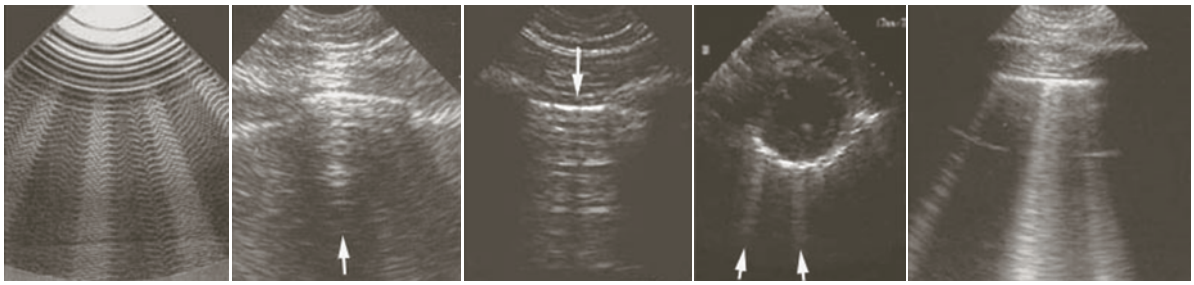

Fig. 19.5 Some artifacts not to be confused with B-lines. *Leftmost*: K-lines, coming from rough parasites from the sector (need filter between the ultrasound machine and the socket). See another example in Fig. 11.11 page 86. *Mid-left*: M-lines, small horizontal artifacts often seen arising from the rib, within its acoustic shadow (*arrow*). *Middle*: N-line (*arrow*). *Mid-right*: The R-lines, those comet-tail artifacts arising from the pericardium at the lung interface. *Rightmost*: X-lines, an exceptional variant where some typical B-lines are, however, erased by A-lines

gray), not well-defined, not long, not erasing A-lines, and not moving with lung sliding.

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Basic Applications of Lung Ultrasound in the Critically Ill: 2 – The Ultrasound Approach of an Acute Respiratory Failure: The BLUE Protocol

20

Severe dyspnea is one of the most distressing situations for a patient. Aiming at a therapy based on immediate diagnosis is a reasonable target.

The acute incapacity to breathe normally is one of the most distressing situations one can live with [1]. The BLUE protocol unites 18 years of efforts (mainly repeated submissions) aimed at relieving these suffocating patients.

The idea of performing an ultrasound examination on such patients was not routine in 1989. Our approach possibly intrigued some doctors and nurses in the emergency rooms of our institutions. During management of these critical situations, there was not time for quiet explanations, and the tired emergency doctors, after duty, rushed for a deserved nap, therefore turning their backs on this potential.

What these colleagues did not fully see was that, after a few minutes, we were able to give the nurses therapeutic options while organizing the transfer to the ICU. And what they did not see at all (occupied by a thousand other tasks) was that these options were in accordance with the final diagnosis.

The publication of the BLUE protocol was one of the three main reasons, along with Chaps. 21 and 23, that justified this 2010 edition.

The tools that are usually used in the emergency setting, i.e., the physical examination [2] and radiography [3], are not very precise. The crowded emergency room is not the ideal place for a serene and efficient diagnosis – an acknowledged issue [4–8]. One-quarter of the patients of the BLUE protocol in the first 2 h of management receive erroneous or uncertain initial diagnoses, and many more receive inappropriate therapy. The on-line document of Chest 134:117–125 details these 26% of wrong diagnoses. CT seems to be a solution, but Chap. 19 has already demonstrated its heavy drawbacks. One day, the community may find this tool to be too irradiating [9].

We initiated this long work using an ADR-4000 (from 1982) and its sectorial 3.0-MHz probe since 1989 and shifted to our Hitachi-405 with the 5-MHz microconvex probe in 1994.

The Design of the BLUE Protocol

The BLUE protocol was conceived in an observational study in university-affiliated teaching hospital ICUs. We performed ultrasonography on admission, in the climax of dyspnea, on serial patients with acute respiratory failure. Acute respiratory failure was defined based on clinical and biological criteria requiring admission to the ICU. The final diagnosis considered as a reference the hospitalization report, made by a medical ICU team who did not take into account the lung ultrasound data. Uncertain diagnoses, multiple diagnoses and rare causes (frequency <2%) were excluded (see below).

After the years necessary for the publication of the preliminary background (mostly lung terminology), we were able to propose the analysis of *three* items at the lung area – with a dichotomous answer, collected in standardized points (upper and lower BLUE points, PLAPS point).

1. Lung sliding abolition (present or not).
2. Lung rockets at the anterior wall (present or absent).
3. Posterior and/or lateral alveolar and/or pleural syndrome (present or absent). This association was termed "PLAPS" (see Fig. 15.6 and below).
4. We added an adapted venous analysis (indicated in 54% of cases, carefully see below).

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Introduction to the BLUE Profiles

A profiling system based on careful analysis of predata allowed us to suggest a nomenclature based on *seven profiles*.

The *A-profile* designates anterior predominant bilateral A-lines associated with lung sliding.

The *A′-profile* designates an A-profile with abolished lung sliding.

The *B-profile* designates anterior predominant bilateral B-lines associated with lung sliding.

The *B′-profile* designates a B-profile with abolished lung sliding.

The *A/B-profile* designates anterior predominant B+ lines on one side, predominant A-lines on the other (see Fig. 23.2 page 229).

The *C-profile* designates anterior alveolar consolidation(s).

The *normal profile,* or *nude profile*, associates A-profile with absence of PLAPS (regardless of posterior A-lines or B-lines).

We associated

- The *B-profile* with pulmonary edema
- The *B′-profile* with pneumonia
- The *A/B-profile* with pneumonia
- The *C-profile* with pneumonia
- The *A-profile plus PLAPS* with pneumonia
- The *A-profile plus venous thrombosis* with pulmonary embolism
- The *nude profile* with COPD or asthma (putting these diseases together)
- The *pneumothorax profile* (to make short, A′-profile and lung point) with pneumothorax

The Results

At the submission of the paper, 260 dyspneic patients with one definite diagnosis were enrolled. The main causes of acute respiratory failure seen in our cohort were pneumonia (31%), pulmonary edema (24%), decompensated COPD without cause (18%), severe asthma (12%), pulmonary embolism (8%), and pneumothorax (3%) details our results.

In this population, the BLUE protocol alone provided the correct diagnosis in 90.5% of cases. Each of the BLUE profiles warranted a specificity for the considered disease greater than 90%.

Table 20.2 details the accuracy of ultrasound for each diagnosis. These results are fully explained by physiopathologic basis (see below). All these major causes of acute respiratory failure in the adult have characteristic patterns.

Acute hemodynamic pulmonary edema: nearly all cases, i.e., 62 of 64, yielded bilateral disseminated anterior lung rockets, a pattern always associated to lung sliding. PLAPS were present in 56 cases.

Pulmonary embolism: patients had nearly always (20 of 21) an anterior normal surface. None had anterior B-lines (in the B, A/B or B′ variant). Half had PLAPS. Eighty-one percent had visible deep venous thrombosis.

Exacerbation of COPD, severe asthma: patients had usually a normal pattern. Of 49 cases of COPD, seven had pathologic patterns. These profiles will be deeply commented below ("missed" cases of the BLUE protocol).

Pneumothorax: all had abolition of anterior lung sliding with A-line sign. Eight of nine had a lung point.

Pneumonia: of 83 cases, 74 had one of four characteristic profiles. The A-profile plus PLAPS was seen in 35 cases, the A/B profile in 12, the C-profile in 18, the B′-profile in nine. Each of these four profiles was infrequent, but the whole made a 89% sensitivity, and these patterns were 94% specific to pneumonia.

Physiopathologic Basis of the BLUE Protocol

A knowledge of the physiopathology enables an understanding of the results of the BLUE protocol.

Hemodynamic Pulmonary Edema

This condition creates pressurized transudate. It invades all interlobular septa up to the anterior wall, against gravity. Constant edema of the interlobular septa is a known feature [10,11]. Similarly, lung rockets are consistently present, usually disseminated, making an immediate diagnosis wherever the probe is

applied at the anterolateral chest wall in patients with acute respiratory failure. Like hair when one has gooseflesh, like soldiers standing at attention, all interlobular septa of a wide given area (lateral, anterior) are involved. This explains the symmetric, diffuse interstitial patterns.

Transudate is a kind of lubricant that is not supposed to impair lung dynamic, which explains the conserved lung sliding (see below).

There is a double level of dichotomy at the basis of the B-profile. First the lung surface generates A- *or* B-lines, with no space to our knowledge for intermediate artifacts. This demonstrates that the transformation from A-lines to B-lines occurs all of a sudden, following an all-or-nothing rule, when a critical amount of fluid has thickened the interlobular septum. This subpleural septum speaks for the deeper compartment (not accessible to ultrasound), since CT observations show that interstitial edema is superficial as well as deep – there is also no room in CT for incomplete stages [12]. The second level of dichotomy is a B-line (i.e., a thickened interlobular septum) when compared with the neighboring septa. Observation shows that wide areas of subpleural interlobular septa are simultaneously thickened, making lung rockets the usual pattern seen. Why one septum is thickened by edema but not its immediate neighbors cannot be explained scientifically, apart from possible focal emphysema bullae. Intermediate stages between A-profile and B-profile (i.e., disseminated b-lines or bb-lines, or again focal lung rockets), are possible, but rarely enough for not having created a special section in our protocol.

We now will distinguish anterior, lateral and posterior ultrasound interstitial syndrome. Anterior lung rockets correspond to anterior Kerley lines, which are almost never visible on a front radiograph but are the most clinically relevant. Lateral interstitial syndrome was not considered in our algorithm for simplicity (see below). Posterior interstitial syndrome was not sought, since gravitational interstitial changes can be physiologic [13].

Note that the search of PLAPS was not required since it did not affect our decision tree. PLAPS were present in 88% of cases.

Anterior areas of consolidations were not observed in hemodynamic pulmonary edema. This finding means complete alveolar filling from the posterior to the anterior areas according to the earth–sky axis, a disorder not compatible with life in our hypothesis (Fig. 20.1).

We detail the distinction between hydrostatic and permeability-induced pulmonary edema in a devoted paragraph in order to avoid repetitions (see below).

Pulmonary Embolism

Vessels occlusion is not supposed to be accessible using surface ultrasound examination. Pulmonary embolism does not yield interstitial change. A normal anterior lung surface is expected (apart from previous ARDS). In reality in our series of 260 patients,

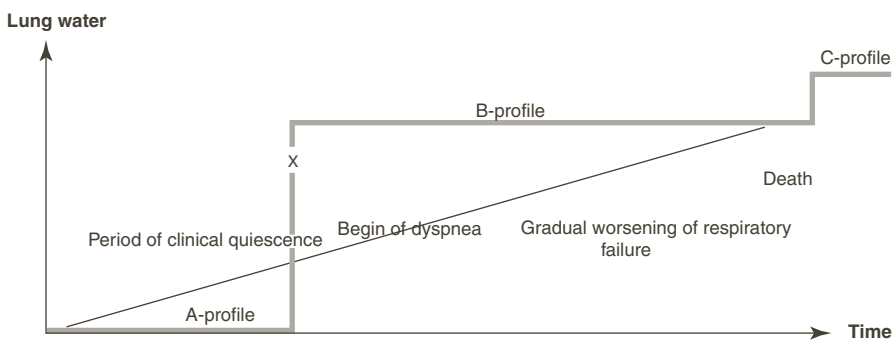

Fig. 20.1 Ultrasound dynamic of pulmonary edema. This figure shows that as a function of time, the B-profile suddenly appears, independently from the clinical status, which gradually worsens. In this figure, the first clinical signs appear once a B-profile is present. Maybe in some patients the line *X* could be shifted to the right (although not logically). Mostly, this figure shows that patients with the same ultrasound profile (the B-profile) can have a wide range of clinical presentations, from mild dyspnea to acute respiratory failure. This diagram also highlights the hypothesis that the C-profile is theoretical in hemodynamic pulmonary edema and should occur only at a very late stage (if occurring at all)

and of 120 who had no A-profile, only one had pulmonary embolism. And none of 92 patients with anterior interstitial patterns (B, B′ and A/B profile) had pulmonary embolism. The A-profile is really a sensitive sign of pulmonary embolism, although far from specific: 20 of 122 patients with the A-profile had a pulmonary embolism.

The positive predictive value of deep venous thrombosis alone was 89%, but 94% if associated with the A-profile. This shows that the search for venous thrombosis must be done after lung analysis showing an A-profile.

The C-profile can be seen with pulmonary embolism (although infectious causes were 18 times more frequent): anterior infarction area is always possible. The C-profile was seen in one patient with embolism and was surrounded by normal lung surface. Splitting C-profiles with underlying lung rockets or underlying normal A-lines would have complicated the design of the BLUE protocol. PLAPS were frequent (50% of cases).

COPD and Asthma

These diseases involve bronchial disorder. The bronchi (surrounded by air) are inaccessible to current noninvasive ultrasound. The main sign is indirect: absence of lung rockets in a dyspneic patient – normal lung surface.

Pneumothorax

It yields abolished lung sliding, A-lines and a lung point (see devoted Chap. 18).

Pneumonia

Pneumonia has to be considered apart. Whereas there is only one pulmonary edema, one pulmonary embolism, one asthma, one pneumothorax, there are many pneumoniae, due to multiple various microorganisms, generating several profiles. This requires a little more attention.

These profiles are described here without comment but we invite the reader to read below the heading about hemodynamic versus permeability-induced pulmonary edema.

We explain the abolition of lung sliding (*B′-profile*) by inflammatory adherences due to exudate, generating acute pleural symphysis. This disorder, long described [14], seems frequent in massive pneumonia and ARDS. Whereas the transudate is a lubricant that does not impair lung sliding, exudate is a biologic glue. We assume that each exudative B-line acts as a *nail*. Since B-lines are numerous, these multiple nails should appear sufficient for sticking the lung to the wall. Some key (for the science) cases allowed us to demonstrate the inflammatory adherences. An acute pleural symphysis should logically impair lung expansion and generate acute restrictive disorder in ARDS. Patients can be on mechanical ventilation or spontaneously breathing. Note that abolished lung sliding shows low specificity for pneumothorax (27% positive predictive value here). Of 83 cases of pneumonia, 23 had abolished lung sliding.

Pneumonia can be found in a wide variety of locations, making asymmetry a major feature: latero-lateral asymmetry (A/B profile), anteroposterior asymmetry (A/PLAPS profile). Anterior alveolar location is again highly specific to infectious phenomena. Note the main difference between pneumonia with A/PLAPS profile and hemodynamic pulmonary edema: absence or presence of anterior interstitial syndrome.

Physiopathological Approach by the Signs

A-lines indicate air, which can be physiologic (normal lung surface seen in COPD, asthma, pulmonary embolism and posterior pneumonia) or pathological (pneumothorax).

Anterior lung rockets indicate interstitial syndrome. Hemodynamic pulmonary edema and some cases of pneumonia display anterior and symmetric lung rockets.

Alveolar and pleural changes are usually posterior (defining PLAPS) and are common to pulmonary edema, pneumonia, pulmonary embolism (therefore not of major discriminating potential if used alone). Anterior consolidations are typical of pneumonia. PLAPS not associated with anterior interstitial changes

are seen in pneumonia and pulmonary embolism. PLAPS are interesting only in patients with A-profile and without venous thrombosis: this provides a BLUE diagnosis of pneumonia.

Lung sliding is present in hemodynamic pulmonary edema, pulmonary embolism, and COPD. We saw it present in asthma, although one may expect from very severe asthma a certain limitation of amplitude.

Lung sliding is abolished in many cases of pneumonia (usually associated with lung rockets), history of pleural disease, and pneumothorax (with no lung rocket).

The Decision Tree of the BLUE-Protocol

To get a 90.5% accuracy in a few minutes, we first check for anterior lung sliding. Its presence discounts pneumothorax (Fig. 20.2). Anterior B-lines are then sought. The *B-profile* calls for pulmonary edema. *B′-, A/B-,* and *C-profile* call for pneumonia. The *A-profile* prompts a search for venous thrombosis. If present, pulmonary embolism is the BLUE diagnosis. If absent, PLAPS are sought. Their presence (*A-profile plus PLAPS*) calls for pneumonia, their absence (*nude profile*) for COPD or asthma.

Practical Use of the BLUE Protocol

The raison d'être of the BLUE protocol, which uses ultrasound *alone* for a 90.5% accuracy, is to be inserted in the first stages of the usual management.

In the traditional management of the dyspneic patient, we can consider three steps (Fig. 20.3).

1. *Step 1:* The physician receives the patient and, time permitting, learns the patient's history and makes the physical examination. This step is decisive. A young dyspneic patient with fever does not have the same disease as an apyretic elderly cardiopathic patient etc.
2. *Step 2:* Simple tests are done, like EKG, D-dimers and basic *venous* blood tests (see below).
3. *Step 3:* With all these elements in hand, the doctor decides whether a sophisticated examination will be ordered. This is usually the time to ask for a CT scan or a sophisticated echocardiography.

The BLUE protocol should be added between Step 1 and Step 2. Its 90.5% rate of accuracy will be enhanced using basic data. Therefore, the need for the traditional Step 3 becomes less mandatory (see below).

The BLUE protocol is usually done at Stage 1′ (semirecumbent patient), allowing one to rule out pneumothorax and interstitial syndrome in a few seconds. Facing a B-profile (i.e., at the four anterior BLUE-points), an A/B-profile, a C-profile (one point is enough, in terms of specificity), or a B′-profile, the protocol is over. The rest of the lung will of course be analyzed, but this is made outside the protocol (searching for PLAPS after detecting a B-, B′-, C- or A/B-profile is redundant for the diagnosis). Same remark for the venous network (see below). The A-profile calls, using the same probe, for a venous analysis, beginning, in a patient coming from home, by the V-point (lower femoral area). If no venous thrombosis is detected (2 min), the diagnosis of pulmonary embolism is not ruled out of course, but the user comes back to the lung and scans the PLAPS point (posteriorly), priorizing the diagnosis of pneumonia or simple COPD in a few seconds. Facing an A′-profile, the lateral areas of the lung are scanned, searching for a lung point. Once the BLUE protocol is over, the physician decides if this information is in agreement with Steps 1 and 2 and initiates active therapy (or goes into more details, up to Step 3 if necessary).

We routinely make a comprehensive venous analysis in patients without an A-profile or in patients with one area of thrombosis (making the BLUE-protocol over), but this is done outside the protocol, again.

The BLUE Protocol and Rare Causes of Acute Respiratory Failure

We did not consider the diseases whose frequency was <2% in our Parisian institution. This allowed our protocol to remain simple. Among 269 patients benefiting from a solid diagnosis, the frequency was as follows:

- 97% of the causes included pneumonia, pulmonary edema, COPD, asthma, pulmonary embolism and pneumothorax
- 1.4% were regarded as exacerbation of chronic interstitial disease (CID) (see below)

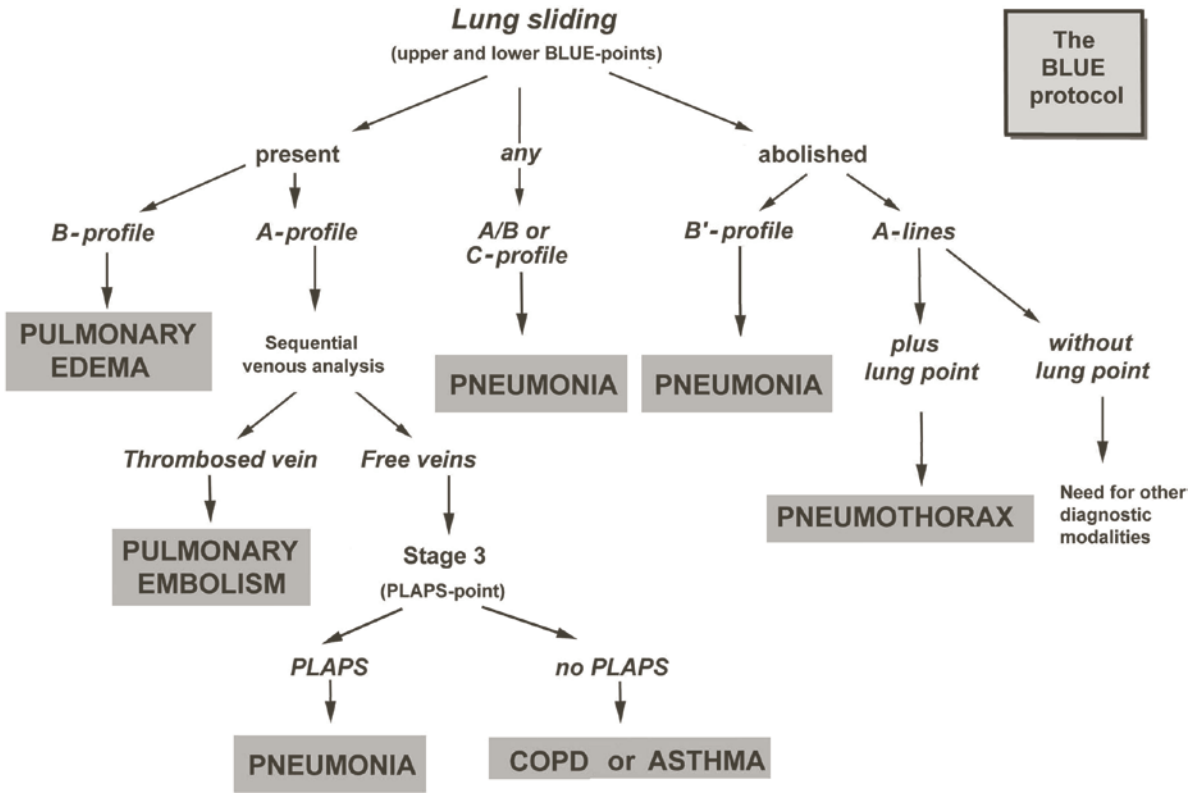

Fig. 20.2 Decision tree. A decision tree utilizing lung and venous ultrasonography to guide the diagnosis of acute respiratory failure: the BLUE protocol. (Adapted from Chest 2008;134:117–125, with the authorization of Chest)

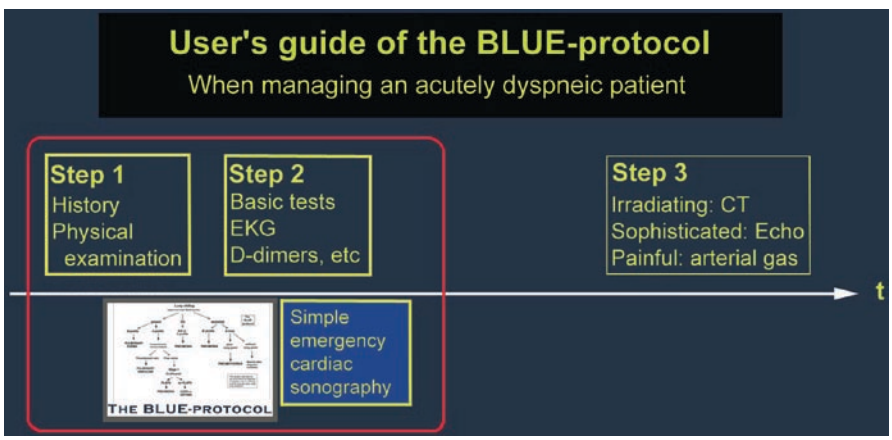

Fig. 20.3 Integration of the BLUE protocol within traditional management. This figure illustrates the usual steps of management of an acute respiratory failure, and the place that the BLUE-protocol and the simple emergency cardiac sonography can take, between the clinical examination and first paraclinical tests. One main aim of the BLUE protocol is to relieve the patient before – or in substitution to – the usual late tests (Step 3). We aim at making the simple clinical examination, the BLUE protocol, the simple cardiac sonography and the initial current basic tests be the "fab four" in acute respiratory failure management

- 1%: massive pleural effusion as causing agent
- 0.3%: tracheal stenosis
- 0.3%: fat embolism
- 0%: pericardial effusion

Rare causes have usually their profile. Rare causes do not mean difficult diagnoses (see below the example of massive pleural effusion)

Tracheal stenosis usually yields characteristic clinical signs. An anterior location of granuloma (usual location) should be searched using ultrasound. Massive atelectasis yields numerous signs (see page 145 of Chap. 16). Acute dyspnea includes acute respiratory failure and many other causes. Metabolic dyspnea, acute hypovolemia, acute gastric dilatation, etc., usually yield a *normal profile*. We can imagine infinite causes of dyspnea, such as hemodynamic pulmonary edema due to myocarditis complicating an infectious pneumonia. These patients will likely have the appropriate B-profile. Thoracic disorder occuring in the child and the neonate is discussed in Chap. 21.

What Can Change by Using the BLUE Protocol

It should affect three fields.

1. The *lung* should be admitted in the court of ultrasound.
2. The *veins* should benefit from a completely adapted protocol, resulting in a simple and fast use.
3. The *heart* will be the definite winner. Combining our lung and veins approaches should result in considering the use of a simplified cardiac sonography.

Physical examination, BLUE protocol, emergency cardiac sonography and basic tests (without arterial puncture) should summarize the investigation of most patients (Fig. 20.3).

Note that the venous analysis takes the most time (2 min of a 3-min examination), which is nonetheless short, since we use a simple machine with fast start-up, the same microconvex probe, time-saving maneuvers, only one setting, a contact product that allows major time-savings. This was described in Chap. 13 and will be repeated below again, intentionally.

We mainly appreciate the possibility to relieve immediately the acutely dyspneic patient by providing appropriate therapy. The rates of death that are the immediate or remote consequence of initial errors should decrease.

The decrease of requirement for Step-3 examinations (mainly CT) is our second main aim (see the drawbacks of CT page 182 of Chap. 19). The familiar arterial puncture was placed in Step 3. The simple perspective of decreasing such a test would have fully justified our 18-year research. This test is painful: patients remember it. So the question becomes: "Why do we need blood gases?" We guess that these blue patients are hypoxic. Determining the CO_2 level as a diagnostic aid indicates the depth of our scientific deprivation, facing acute dyspnea. We keep this test for monitoring sedated patients with circulatory failure. As to expert echocardiography-Doppler, we see no disadvantage in performing this test, provided the team is already equipped and trained, in a patient who already received the initial therapy, and in the countries where this option is feasible.

By the way, the BLUE protocol should favor development of simple machines.

Frequently Asked Questions About the BLUE protocol

Why isn't the heart featured in the BLUE protocol? This is the most-asked question. Obviously, we take a look at the heart – but it is done as a complement of the BLUE-protocol. The lung analysis is a *direct* approach in a patient suffering from the respiratory function. Showing absence of B-profile answers to the question of the left heart function: normal (or, not the actual problem). The BLUE-protocol does not search for a left heart anomaly, but for the clinical consequence of this anomaly. The detection of the B-profile has shown high accuracy for the diagnosis of hemodynamic pulmonary edema (with rare cases of pneumonia and exceptional cases of CID). The detection of a non-B-profile, which occurred in two-thirds of our acutely dyspneic patients, was correlated with absence of pulmonary edema.

Note that combining the BLUE protocol with simple items from Step 1 (age, exposure, temperature, etc.) and Step 2 (white cells, CRP, etc.) makes the accuracy even nearer to 100%. At this high level, a simple emergency cardiac sonography (carefully described in

Chaps. 22 and 23) increases again this high level. The B-profile in a young person with fever, no cardiac history, and with a well-contracting left ventricle will be immediately recognized as a "failure" of the BLUE protocol (because it professes a 90.5% accuracy, not 100%). This patient will benefit from antibiotics (plus maybe intubation, since exudate long remains) rather than from diuretics (plus maybe CPAP, since transudate quickly vanishes).

We therefore advise to begin the analysis of a blue patient with the lung (confirming edema), then simple cardiac sonography. This inversion of priorities provides more time because lung ultrasound needs shorter training, has fewer operator dependencies, fewer patient dependencies and is cheaper. In the same time, the physician is free to initiate a training in traditional echocardiography, which will allow better understanding and management of situations where more information is required. It would also indicate, for instance, the need for emergency valvular repair, but these are not frequent settings.

In fact, the therapeutic management is usually decided at the end of the BLUE protocol, with a slight subtlety. The moment when the nurse prepares the therapy (heparin, fibrinolysis, inotropics, diuretics, beta-agonists, antibiotics, low or high flow oxygen, CPAP or endotracheal tube, etc.) is the time for initiating our simple emergency cardiac sonography – enhanced by the lung approach. Apart from exceptional cases, an acute respiratory failure with a hypokinetic left ventricle but with an A-profile will be considered as a pulmonary dyspnea occuring in a patient who has a quiescent chronic left heart disease. In actual fact, the sequence is: lung – veins – nurse – heart.

Sophisticated Note: For optimizing cost savings, the nurse is trained to break the costly ampoules (fibrinolytics) *last*. If the cardiac sonography happens to find, for instance, a pericardial effusion, it is still time to say "Stop" to the nurse – time for some reflexion for building a story of – for example here – pulmonary embolism complicating a history of neoplasia responsible for hemorragic pericardial effusion. Using this approach, not many fibrinolytic ampoules will be broken for nothing.

Not only the BLUE protocol but also our limited investigation of acute circulatory failure described in Chap. 23 favors the lung, making it equal to the heart. The absence of a B-profile indicates a pulmonary artery occlusion pressure <18 mmHg, with direct consequences on hemodynamic management [15].

Other reasons why the heart information was deleted from the BLUE protocol are discussed in the last section of this chapter.

Is the BLUE Protocol Only Accessible to an Elite? This approach should be compared with many techniques that indeed are reserved for elites (TEE first, etc.). The development of the BLUE protocol may appear complex, but the final use is simple. Many details make a training curve efficient for large-scale training (see below, and first lines of Chap. 31). The BLUE points are accessible to any student. The venous analysis may take longer to master, although each step is elementary.

Note that intensive care medicine is a discipline for an elite. *Even if complicated*, the BLUE protocol should be mastered by such an elite.

Are Three Minutes Really Possible? Some colleagues were intrigued by such a timing [16]. These 3 min (let us concede "less than four" for simplifying) were done by experienced users, precisely with the aim of not interfering with the traditional management. Of course, novice doctors are free to take more time. The 3-min examination was an average timing, possible when using the fast protocol we have defined since 1992: one smart machine, one universal (microconvex) probe, one setting, no Doppler and our substitute for gel are the keys. The lung is superficial. Time for finding windows (unlike at the heart area) is negligible. Detection of A-lines or B-lines is immediate. The timing is shortened each time the BLUE protocol does not require venous analysis or posterolateral lung analysis: B-, B′-, A/B- or C-profile occur in 46% of cases and make the duration of the BLUE protocol less than 1 min.

We use the same fast protocol for searching for deep venous thrombosis, using the same probe, the same settings, cross-sectional scan, Carmen maneuver, etc. (see page 99). Using our contact product makes the time between two regions of interest (e.g., lung and calf veins) <5 s. We just keep our compress near our scanned field, and can do flash scanning. No time is lost in taking the traditional gel bottle, squeezing it and applying the gel to areas distant from each other (and wiping after).

What Should One Think of the "Missed" Patients of the BLUE Protocol? In 25 of 260 included patients, the BLUE protocol yielded a profile that was not in agreement with the final official diagnosis (9.5% of cases). We must consider two groups.

1. Some are real limitations (n = 10).

Pulmonary embolism without visible venous thrombosis (4 of 21 cases) is a typical limitation, which the BLUE protocol does not pretend to solve, but see below. Pneumonia with the B-profile (6 of 83 cases) looks like hemodynamic pulmonary edema. For these two situations, particularly, we repeat that the principle of the BLUE protocol is to be combined with the clinical and basic tests, allowing a decrease of the error margin. For pneumonia with B-profile, simple signs (history, fever, white cells, etc.) and simple emergency cardiac sonography immediately correct this error (see above about the heart).

2. The careful analysis of the other cases (n = 15) makes one consider possible weaknesses in the final diagnosis built on traditional tools.

A patient with blatant ultrasound signs of alveolar consolidation who receives the final diagnosis of simple exacerbation of COPD is a likely victim of a failure in the traditional diagnosis (radiooccult pneumonia). There were five such cases in our study. Patients with the B-profile who were thought to have COPD were likely other victims (three cases in our series). Patients without the B-profile and considered as severe pulmonary edema (two cases in our series) should also raise the question of a possible error.

All in all, we had to accept the final diagnosis as a "gold standard", but strongly believe that our 90.5% rate of correct diagnoses is below the reality.

Can the BLUE Protocol Allow a Distinction Between Hemodynamic and Permeability-induced Pulmonary Edema? It definitely can solve this daily problem. The BLUE protocol included 64 cases of acute hemodynamic pulmonary edema and 83 cases of pneumonia, seven of which initiated an ARDS. They were included as "pneumonia" for keeping the decision tree simple: the overall therapy is roughly similar. Patients with hemodynamic pulmonary edema had the B-profile. Six patients with ARDS had either the A-, the A/B-, the C- or the B′-profile. Only one had a B-profile.

To simplify, fluids in hemodynamic pulmonary edema are submitted to hydrostatic pressure and move up actively to the anterior areas through the interlobular septa – toward the sky. Fluids in permeability-induced edema passively descend to the dependent areas, explaining that the B-profile is less frequent: 97% sensitivity in acute hemodynamic pulmonary edema versus 14% in pneumonia initiating ARDS in the BLUE protocol.

The exudate invades the subpleural interlobular septa and nails the lung to the chest wall with exudative secretions. This explains the frequent B′-profile. Facing a patient with diffuse interstitial edema, the BLUE-protocol distinguishes patients with lung sliding (suggesting a transudative process) from those with abolished lung sliding (indicating an exudative process).

Anterior consolidations (the C-profile), frequent in ARDS, cannot be seen in hemodynamic pulmonary edema (see physiopathologic discussion, and Fig. 20.1).

Asymmetric disorders can be seen (if the disorder comes from one lung infection). This explains A/B-profiles. Note that unilateral cases of hemodynamic pulmonary edema are, first, very rare, and second, they come from a radiologic definition – our very few observations showed more PLAPS at the edematous side, but a symmetric B-profile.

Briefly, the detection of a non-B-profile in a patient with white lungs on X-ray gives a strong argument for ARDS.

We do not mention the measurement of the consolidation volume, nor the pleural tap, since they are not included in the BLUE protocol (but are in an extended protocol, see below).

How About Patients With Severe Pulmonary Embolism and no Visible Venous Thrombosis? When the clinical setting points to a possible embolism, explorations should go further, up to Step 3. A young patient who has no history of asthma, has a recent orthopedic concern, complains about sudden chest pain and acute respiratory failure, and displays an A-profile, with positive D-dimers and pathologic EKG, is a perfect suspect.

The BLUE protocol is an opportunity to decrease referral to helical CT. First, CT is done because it allows one not only to rule out embolism but also to see another cause (pneumonia, edema, etc.). Yet ultrasound also provides this diagnosis. Second, a nude profile (half of the cases of embolism) makes a perfect opportunity to ask, not helical CT, but a simple scintigraphy – more elegant and far less irradiating. Usually, doctors do not ask scintigraphy for the fear of having a noncontributive test. A nude profile allows one to foresee that the scintigraphy will be easy to read.

What About Pulmonary Edema Complicating a Chronic Interstitial Disease? This was argued as a possible limitation [16]. The B-profile usually indicates pulmonary edema, rarely pneumonia, exceptionally CID. Considering pulmonary edema complicating an exceptional disease indicates a really exceptional condition. Concluding on these cases would, therefore, imply years of international multicentric studies. Meanwhile, in a known CID patient, left ventricle hypocontractility should suggest additional left heart decompensation. Another point, PLAPS are not supposed to be present in simple CID. Their presence would be an argument for a complication: edema, pneumonia, embolism, or rare causes (tumor). Similarly, a C-profile would indicate a pneumonia, the absence of lung rockets a possible pneumothorax, etc.

Didn't the Exclusion of Patients Create a Bias Limiting the Value of the BLUE Protocol? These patients were advocated to be the very ones generating a clinical dilemma [16]. Let us take these issues one by one.

1. Patients excluded for absence of final diagnosis (16 of 302 patients). Such cases could not be included in our study. The BLUE protocol was designed to provide *one* profile, yielding *one* ultrasound diagnosis, subsequently correlated with *one* final diagnosis, which we retained as the gold standard. For this methodological reason, patients who did not benefit from a clear final diagnosis could not be included. Of interest, *all these patients* had a precise BLUE profile (read response to ref. 16). The BLUE protocol provided original information, and we bet that it will be useful in the future precisely for such patients.
2. Patients excluded for more than one diagnosis (16 of 302 cases) raise interesting methodological issues. When two diseases are suggested (pulmonary edema and pneumonia being the most frequent), does each mechanism generate exactly 50% of the cause of respiratory failure? One rate may be 51% or it could be up to 99% (meaning 1% for the other suspected disease), and can be assessed by no perfect gold standard nowadays. The BLUE protocol gave one of the two diagnoses with the same accuracy as in the regular population of 260 patients that had one diagnosis: 87.5% (read response to ref. 16). Therefore, the BLUE protocol, indicating at least one of the two incriminated diseases, was not misleading.
3. Patients excluded for rare causes (nine of 302 cases). These patients were advocated to be the most difficult, and their exclusion as creating a bias [16]. But why should *rare* diagnoses mean *difficult* diagnoses? As a best example, a dyspnea explained by a massive pleural effusion makes no major diagnostic difficulty. Doctors do not even need the BLUE protocol for such patients. The diagnosis is easy using usual tools, including traditional ultrasound. For CIDs, in most the clinical history is sufficient. The doctor aware of this history will interpret the B-profile as a chronic and not acute interstitial pattern. The probability of facing a CID in the emergency room is low (1% in our data), and the probability that the patient comes for the first episode, i.e., with diagnosis yet unknown, is even lower (<1%). At this step, making a simple cardiac sonography should show right anomalies and left normality, making difficult cases even lower (far less than 1%). We could have built a more sophisticated algorithm, for little advantage. Rare diagnoses were excluded in order to keep it simple, prioritizing daily problems.

To say it differently, the BLUE protocol works always, even when it is not used. When rare or double diagnoses are suspected by the usual approach, the BLUE-protocol can be enriched with other data. This extended BLUE-protocol (see below) would increase ultrasound's potential, although to the detriment of simplicity. The native BLUE-protocol makes nothing but adding decisive points to the usual management. Used this way, we are accustomed to work with the correct diagnosis.

What About the Mildly Dyspneic Patients (Simply Managed in the Emergency Room)? They are not in the scope of the BLUE-protocol.

Roughly, COPD, asthma, pneumonia and pneumothorax will not rapidly change their profile.

Mild cases of pulmonary embolism should yield more C-lines, since minor emboli are more able to generate pulmonary infarctions [17].

Pulmonary edema possibly deserves a specific approach. We assume that the patient has a normal lung profile before any event. He quietly digests his seafood on the armchair, watching TV. The excess salt is extracted from the GI-tract and little by little penetrates the circulating compartment, increasing its volume. When the heart function reaches the sharp portion of the Franck-Starling curve, the end-diastolic left ventricle pressure increases, increasing on return

the capillary pressure. The transudate quietly invades the interlobular septa, gradually filling the interstitial compartment. The physiopathology of pulmonary edema indicates that the interlobular septal edema is an early phenomenon, which precedes alveolar edema [10,11]. Our patient is still watching his favorite TV series. Possibly, his anterior lung surface is already invaded by "silent" lung rockets. At one moment, the whole interstitial compartment is saturated, and the lymphatic resorption is insufficient. The transudate now invades the alveolar space. We assume this is the moment where the patient feels a discomfort. His wife calls the doctor in an emergency. When the doctor visits the patient, still mildly dyspneic, we assume that the B-profile is present. We also assume that later stages, on blue patients, will always have the B-profile.

So to speak, the anterior interstitial compartment initiates a race with the posterior alveolar compartment, according to the earth–sky axis. The question is: does the excess fluid first reach the anterior subpleural septa, or does it begin to pour into the posterior alveoli before the anterior septa are saturated? In the first hypothesis, lung ultrasound will detect pulmonary edema before the clinical, alveolar stage. The second hypothesis could explain mild cases of clinical edema without B-profile (see below). Figure 20.1 shows that the clinical course evolves gradually, whereas the ultrasound profiles change suddenly – pointing out that, possibly, patients with the B-profile may have no clinical sign of pulmonary edema. Look at Fig. 17.6, page 155. In a standard thorax, the postero-anterior column is roughly 18 cm. An 18-mmHg PAOP is equivalent to a 24-cm- high water-column of pressure, decreased by the impedence gradient. Again, the zero hydrostatic reference is not at the posterior wall but at the heart level. In other words, an 18-mmHg capillary pressure (threshold for interstitial and not yet alveolar edema) would easily create anterior septal thickening, against gravity. One should imagine a 24-cm-high geyser (pressurized by definition).

Some authors have found absence of B-profile in some cases of mild pulmonary edema – finding instead lateral lung rockets [18]. This hypothesis may be explained by the physiopathology of pulmonary edema since fluids flow against gravity, yet our concept assumes that interstitial syndrome is complete before the patient complains. Rarely called for mildly dyspneic patients, we cannot make an opinion. Possibly, such patients initiated a beginning of recovery. Possibly, giant bullous dystrophy with anterior bullae partly explain this. Possibly, such studies may have had the same irreducible proportion of wrong final diagnoses. We remind that our gold standard was the diagnosis made by an academic team of medical intensivists on hospitalized patients from a university-affiliated hospital. One can imagine that in an emergency room, the conditions for an accurate diagnosis will not be more favorable.

The lateral chest wall was not included in the BLUE protocol. In our series of severely dyspneic patients, this information was redundant. Associated with the B-profile, lateral lung rockets were redundant for diagnosing pulmonary edema. Associated with B′-, C- or A/B-profiles, they were redundant for diagnosing pneumonia. Associated with the A-profile, they were redundant with PLAPS for always demonstrating pneumonia (seven cases). Briefly, in a severely dyspneic patient, if an A-profile plus lateral diffuse lung rockets is seen, pneumonia should be considered before hemodynamic pulmonary edema.

Challenging Patients? One major strength of critical lung ultrasound is to be feasible by any weather. An anterior approach makes immediate detection of lung rockets, even with a 7-cm-fat, thick chest wall. The PLAPS point will always be strictly defined using simple elements. The high impedence gradient between air and gas means the PLAPS is usually visible. Venous analysis can be more difficult at the deep trunks (iliocaval areas mainly).

Will the BLUE Protocol Work Everywhere? We assume not. In many parts of the world, there will be more pneumoniae, such as tuberculosis. There again, many deprived people do not reach the age for developing modern chronic diseases (COPD, coronary obstructions, etc.). In areas with no care but low exposure to modern life and pollution, such as Amazonian areas, maybe the rate of infectious diseases is paradoxically lower. Our next edition should clarify these basic points.

One additional but critical aim of the BLUE protocol is to provide to physicians who have no access to radiographies and basic tests a tool for low cost and high accuracy.

What Happens When the BLUE Protocol is Performed on *Non-BLUE* Patients? The BLUE protocol is designed for severely dyspneic patients.

A healthy subject will have the BLUE profile of an asthma or a COPD.

A postoperative patient with simple basal atelectases has an A/PLAPS profile, i.e., a BLUE profile of pneumonia.

An "uncomplicated" ARDS patient (that is, pink, under pure 02) has B-, B′-, A/B- and C-profiles, sometimes an A/PLAPS profile.

An acute pulmonary edema becoming pink under appropriate therapy will have, at one precise moment, no anterior lung rockets, only bilateral lateral extensive lung rockets and usually PLAPS, i.e., a profile of pneumonia. The next step – after healing – will show only PLAPS, i.e., again a profile of pneumonia, until the thorax is completely dry, making a profile of COPD/asthma.

Will Multicentric Studies be Launched for Validating the BLUE Protocol? We actively work on this, trying to bypass multiple issues:

Training teams will be the least.

Having an appropriate, intelligent material may be another problem.

One substantial problem will be methodological: the final diagnosis must be as perfect as possible. By using an optimized tool (university-affiliated medical intensivists' reports), we had to accept some obvious imperfections. The emergency room will not do better.

But the main problem will be ethical: how shall we order randomized studies, i.e., not taking profit of the information from the BLUE protocol (built from published papers, using evidence-based medicine) in the management of asphyxic patients?

What is the Interest of the PLAPS Concept? The label PLAPS is first an onomatopoeia, which suggests a splash. What actually is this image of fluid and a tissue-like pattern with a shred border, instead of the rigid barrier of air artifacts? A frank consolidation with an uncertain image of effusion, or an effusion with ill-defined consolidation, or both, will have the same meaning: an acoustic window for ultrasound. Finely differentiating alveolar from pleural disorder does not influence our decision tree.

Said differently, the concept of PLAPS makes four signs into one sign, which is "absence of artifactual pattern." Therefore, the number of lung signs decrease from ten to seven. This concept uses the first principle of lung ultrasound – simplicity – and allows shorter training for the interested teams.

By the Way, Why "BLUE" Protocol? Blue is the dominant tone of these patients.

Blue is the color of the veins, also pointing to the fact that venous analysis is on the frontline.

We carefully checked that there was no space for confusion, and found that the term "BLUE protocol" did not refer to any particular known setting. Our wish was to create an automatism indicating at a glance that the user:

- Uses a fast protocol fully adapted to the extreme emergency of this setting
- Needs nothing but a very simple unit, without Doppler, switching-on in 7 s
- Analyzes the lung (which was supposed to be immune to ultrasound)
- Uses a few standardized points (the BLUE points)
- Uses only seven signs at the lung area
- Uses no more than seven profiles
- Gives an adapted vision of the veins, using the same probe and some technical peculiarities
- Uses a contact product without gel, allowing fast examination (<3 min)
- Permanently integrates this approach to the clinical context in order to increase its overall 90.5% efficiency

The acceptance of the BLUE protocol initiated the creation of the SLAM [19] (see Chap. 30 page 305, for knowing if BLUE is an acronym or not).

The Future of the BLUE Protocol

Its immediate future is to be widespread using appropriate teaching methods. Please refer to devoted Chap. 31.

Once colleagues are accustomed to its decision tree, it will be possible to sophisticate the approach. The extended BLUE protocol that we routinely use integrates simple clinical data, simple cardiac ultrasound, additional lung data, some simple procedures (pleural tap) and evolutive data. It allows one to make double diagnoses and rare diagnoses. Here are some examples:

Pulmonary edema plus pneumonia: the B-profile with impaired left ventricle contractility and large posterior consolidation invites to the double therapy.

Pulmonary edema plus COPD: the vanishing under therapy of the B-profile associated with a persistence

of respiratory failure suggests the diagnosis of remaining COPD.

Massive pleural effusion: a 5-cm PLAPS index indicates that the volume of the effusion is certainly responsible for the dyspnea.

With these ultimate sophistications, Step 3 should be again decreased to rare situations.

The Short Story of the BLUE Protocol

Having had the privilege of working in a pioneering institution in echocardiography for the critically ill since 1989, we had easy access to the heart. We quickly integrated elements from pleural, then lung and venous ultrasound, allowing us to propose the use of ultrasound in acute dyspnea since 1991 [20].

Our first mention of a decision tree for managing acute respiratory failure was available in 1995 [21].

It was rather comprehensive at this time, widely including the heart and inferior caval vein. The inferior caval vein was quickly withdrawn because it had little added value. Three cardiac items were featured up to the years 2000–2003: left heart contractility, right heart enlargement, and pericardial effusion [22]. Withdrawing the heart was not our initial intention. In fact, we were advised to remain far from this area (which was reserved for specialists). We then came deeper into our data, and rapidly saw three sequential points.

First withdrawing the pericardial state was not an issue (pericarditis generates pain more than respiratory failure, and is not on focus here).

As a second step, we observed that each blue patient without a B-profile had a disease able to generate right heart enlargment (embolism, pneumonia, COPD, etc.), and had no left heart anomaly with lung consequences. We could, therefore, withdraw the right heart analysis.

The third step regarded the left heart analysis, which only remained in our decision tree [23]. This was definitely the most interesting step. Aware of this challenge that we had to face, but wanting to remain simple and efficient, we carefully analyzed the files. In eight cases, the left ventricle analysis proved contributive, showing correct contractility with the B-profile and a final diagnosis of pneumonia. In nine cases, the left ventricle analysis provided misleading information, i.e., impaired contractility in patients whose final diagnosis was not pulmonary edema – none of them having a B-profile. More information was gained in terms of "pulmonary edema versus non pulmonary edema" than lost in terms of challenge, "hemodynamic versus permeability-induced pulmonary edema." Withdrawing the left heart was not only possible, simplifying our decision tree, but also slightly improved the accuracy of the BLUE protocol (90.3% including the left heart, 90.7% not considering it at all). Detailed results are featured in the on-line data from Chest 134:117–125. This was logical, as a central idea of the BLUE protocol is here: if a direct lung analysis shows absence of pulmonary edema, the need for a sophisticated heart examination should not generate exaggerated energy at the time of admission (see Chap. 23 for other details).

With population aging, a hypocontractile left ventricle is seen with increasing frequency, but it is not always the cause of the dyspnea. In patients without a B-profile, left heart anomaly is not expected unless there is a previous chronic disease that ironically does not participate to the acute failure. In other words, detecting a non-B-profile immediately informs on the *systolic left ventricular function*, the *diastolic ventricular function*, as well as the *mitral and aortic valve function.* None of them is impaired. Even if impaired, the cause of the respiratory distress should be elsewhere.

For being able to submit the BLUE protocol, it was necessary to publish the whole of the nomenclature for standardized analysis, i.e., simple papers about pneumothorax, pleural effusion (adding criteria for this not so standardized application), alveolar consolidation, interstitial syndrome, etc. This resulted in roughly 30 rejections, making the story last between 1991 and 2008. All this effort was made to the detriment of countless other applications (meanwhile published by other teams) and taking away any leadership role we could have provided. The manuscript about the BLUE protocol itself was rejected by three international journals (our usual rate). These factors explain why we were able to share our approach in the peer-review literature only 13 years after its first public mention.

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Applications of Lung Ultrasound in the Critically Ill: 3 – Lung Ultrasound in the Neonate

21

We had promised our readers a whole chapter devoted to the child in this new edition. This chapter was an emergency. Here it is, from the privilege given of having managed critically ill, ventilated neonates.

Here, more than in the 20 previous chapters (tacitly devoted to the adult), ultrasound should be envisaged as a priority, especially lung ultrasound. The radiation hazards caused by CT are not acceptable in neonates [1–4]. We will see in this chapter why it is possible and urgent to implement lung ultrasound, despite the absence of study conducted with traditional – but not suitable – "gold standards".

A 5-MHz microconvex probe will not be sufficient for this investigation in the critically ill neonate. Frequencies such as 8–12 MHz should be preferred. The use of a high frequency delivers the finest resolution.

Lung Ultrasound in the Newborn: A Major Opportunity

The child is not a miniature adult in usual fields of medicine. We wanted to see if this traditional assertion was valuable regarding lung ultrasound.

Would the neonate's lung behave like the adult's lung for the same elementary syndromes? In particular, would the edematous interlobular septa of a neonate (10- or 20-times smaller than the adult) generate the same B-lines? Interstitial changes are even hardly visible in adult radiographies (and their ultrasound detection is indirect, based on a fluid-air artifact). Would pneumothorax generate the same signs?

Few authors have had the opportunity to overcome the obstacle of the reviewing process in this sensible setting [5], while we were stuck with the task of simply submitting the signs of lung ultrasound before being able to reach the following step: showing their relevance [6–8]. We hope this has helped the community to begin to form an opinion.

We analyzed newborns (up to 35 days old) admitted to a PICU after cardiac surgery, over 3 years. We used the technique, stages, and semiotics as described, assessed, and standardized in the adult.

We took maximal care avoiding crossed infections. This is quite impossible with most machines, either traditional or so-called hand-held, since the profusion of buttons and probes makes any attempt at cleaning futile.

We avoided the use of Doppler, since we are still not reassured on the absence of side effects [9–11].

We had to use a Philips Sonos 5500 (Philips, Andover, Netherlands) unit with a phased array 12-MHz probe. This material was not ideal for many reasons and we found some difficulties. Having no choice and fully exploiting our previous experience, it was possible to draw conclusions. A novice user would rapidly have been discouraged using this material.

The Design of Our Study

We assessed whether the 10 signs that made lung ultrasound in the adult were found again in the newborn:

1. The pleural line (with the bat sign)
2. The A-lines
3. Lung sliding (with the seashore sign)
4. The quad sign (with the lung line)
5. The sinusoid sign
6. The tissue-like sign

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7. The shred sign
8. The B-lines
9. Lung sliding abolished (with the stratosphere sign)
10. The lung point

Basic Technique

The mamillary line (which was a practical landmark in the adult) is located high in the neonate. After having used the mid-distance between the lung apex and lower costal border as a basic landmark, we eventually used the technique of the BLUE hands, which was simpler (Fig. 21.1). See description on page 118 (Chap. 14).

Lung ultrasound in the neonate is easier than in the adult. The 8-cm length of the probe is relatively long here for the PLAPS-point investigation, but the light weight of the baby makes the slight rotation easier (keeping in mind the endotracheal tube).

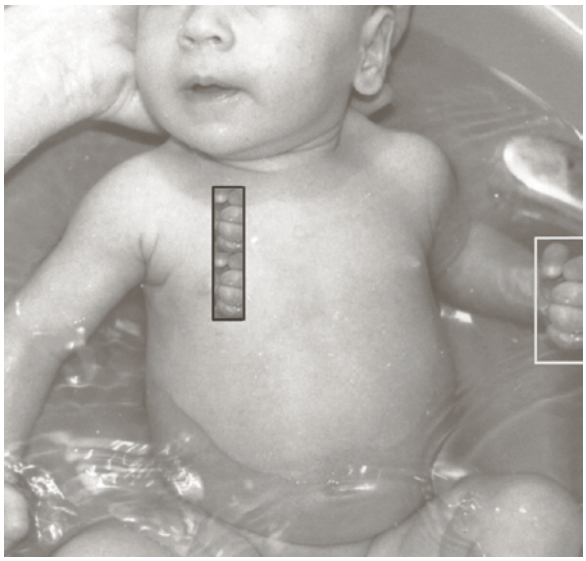

Fig. 21.1 Newborn BLUE hands. This figure shows a simple way of determining the anterior chest wall. One takes the two hands of the baby, side by side, from the lower border of the clavicula (without the thumbs). The lower fifth finger indicates the lower end of the lung [note that the left hand (*white frame*) is in a nearer plane, and we corrected the projection of the hand for the need of the picture]. Another way is taking the half distance of the thorax (from apex to inferior costal border)

Basic Normal Patterns: Signs 1–3

The pleural line (with the bat sign) was found in all examinations (Fig. 21.2).

Lung sliding was recorded, with the seashore sign, in most cases. Lung sliding was abolished in some cases.

The A-lines were visible in enough cases to note that a newborn lung surface was able to generate A-lines.

Pleural Effusion: Signs 4 and 5

The quad sign and the sinusoid sign were found in some cases (Fig. 21.3). It was possible to make precise measurements. Further studies should convert these measurements into volumes, using standardized points.

Alveolar Consolidation: Signs 6 and 7

All the signs described in the adult were present, i.e., the tissue-like sign, the shred sign, the air bronchograms, the dynamic air bronchograms, fluid tubulograms (Fig. 21.3). They were seen in more than half the cases. A consolidation index was available for each.

Interstitial Syndrome: Sign 8

The characteristic sign of interstitial syndrome, i.e., the disseminated anterior lung rockets, were recorded in nearly all cases (Fig. 21.4).

Pneumothorax: Signs 9 and 10

Abolished lung sliding, A-lines and, above all, the lung point were present, in the same manner as in the adult, observed in a few cases.

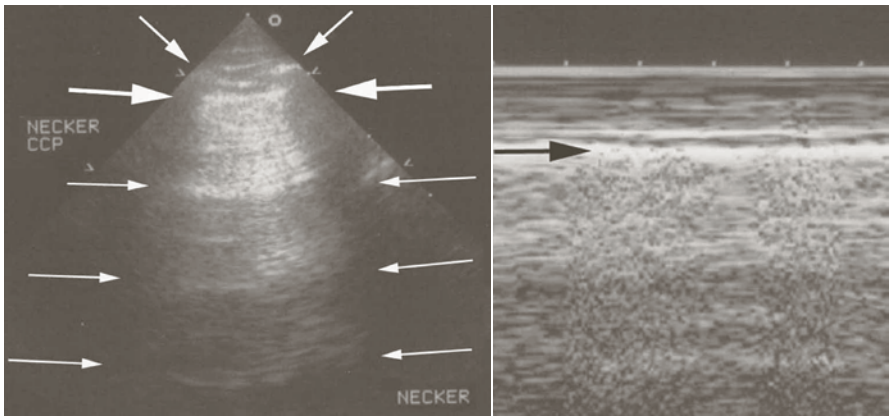

Fig. 21.2 Normal neonate lung surface. *Left*: As in the adult, the ribs of the mature neonate give acoustic shadows, and a bat sign can be depicted, with proportions identical to the adult. In this child, the pleural line between two ribs is visible through 9 mm, and the rib line/pleural line distance is 2.5 mm. The *fine horizontal arrows* indicate A-lines. *Right*: A seashore sign, exactly similar to an adult's one. Note the discrete mangrove variant (below body of *arrow*, which indicates the pleural line). Image acquired with a Hewlett-Packard Sonos 5500

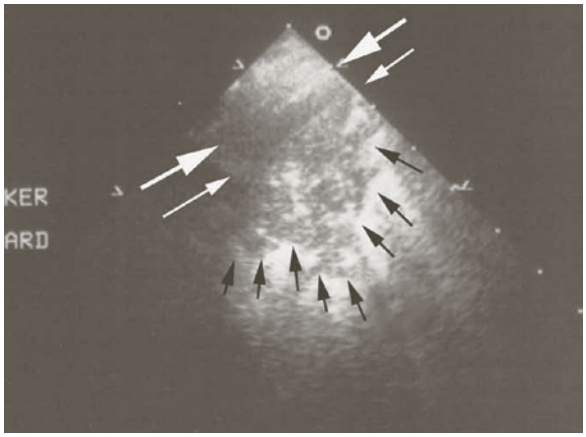

Fig. 21.3 PLAPS. From top to bottom: the *large arrows* indicate the pleural line. The *small white arrows* indicate a lung line (small pleural effusion). The tissular pattern arising from the lung line is limited by the *black arrows*, outlining the shred sign. Example of PLAPS (detected at the PLAPS point). Once again, note the poor resolution quality. Image acquired with a Hewlett-Packard Sonos 5500

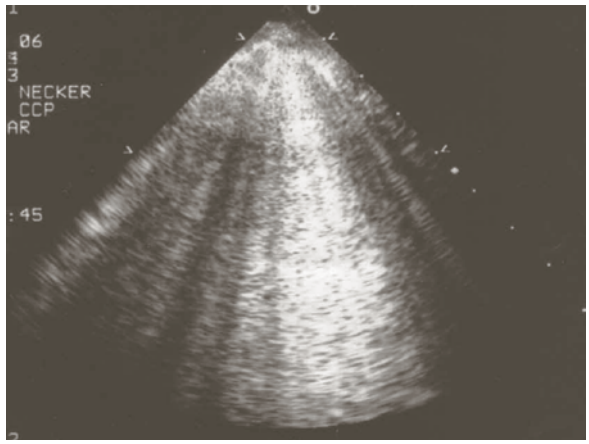

Fig. 21.4 B-lines. Multiple B-lines at a neonate's lung surface, as in the adult, indicating an interstitial disorder (inflammatory lung syndrome after cardiac by-pass). Image acquired with a Hewlett-Packard Sonos 5500

Results: Ultrasound Compared with Bedside Radiography

Bedside chest radiography is the usual tool used for assessing the neonate's lung. We found in this series roughly the same discrepancy as the one long-highlighted in the adult (where CT clearly demonstrated ultrasound's superiority). In light of this major gap and of the absence of official gold standard (CT) in the neonate series, we expect many rejections of our data (a manuscript about the value of bedside chest radiography is under submission).

Demonstration of the Potential of Ultrasound to Replace Bedside Radiography as a Gold Standard

When two tests disagree, one is right and one is wrong, without space for intermediate possibilities in one

given patient. Here is a ten-step demonstration that, in spite of the absence of CT correlation, the discrepancy found between radiography and ultrasound favored ultrasound.

Step 1: The ultrasound signs assessed in the adult are exactly the same in the neonate

Our 3-year experience in a neonate ICU showed that the *ten* basic, standardized signs that were assessed in the adult (see above) were all found again in critically ill newborns. During all this observation, we did not see any "new" sign particular to the neonate that had not been observed previously in the adult.

Step 2: A discrepancy between ultrasound and radiography is highlighted in the critically ill neonate

Our experience in neonates showed that the correlation with radiography (read by skilled, blinded radiologists) made a discrepancy appear in roughly the same proportions as the one long-observed in adults between ultrasound and radiography – where CT clearly showed ultrasound's superiority.

Step 3: The anatomic features of each syndrome (pneumothorax, etc.) are the same in both adults and neonates

Regarding the assessed disorders, no radiologic distinction was made (to our knowledge) between adults and children [12]. There is no physiopathologic argument for assuming that these two populations should generate different radiologic patterns [13]. The same reasoning is valuable for ultrasound. This is the only speculation of our demonstration.

Step 4: Adult bedside chest radiography is imperfect

The limitations of radiography have been clearly demonstrated in the adult [14–23] (Table 21.1).

Step 5: Ultrasound has an accuracy close to that of CT in the adult

As opposed, ultrasound proved in the adult a sensitivity and a specificity close to that of CT [21–28] (see Table 19.3 page 185), and was on occasion superior [29].

Table 21.1 Accuracy of radiography compared with CT in the adult ARDS

	Sensitivity (%)	Specificity (%)
Pleural effusion	39	85
Alveolar consolidation	68	95
Interstitial syndrome	60	100

From Anesthesiology 100:9–15

Step 6: Bedside radiography in the neonate is a tool that has not been evaluated

No work to our knowledge has assessed chest radiography's value in neonates. Some reports comment on the interest of daily routine radiographs in the PICU when showing unexpected findings [30–32], but none have investigated the interpretation of negative findings (as well as critical appraisal of positive results).

Step 7: In the adult, bedside radiography is more specific than sensitive

Assessment of bedside radiography in critically ill adults highlighted a low sensitivity [21]. The specificity was better. False-negatives are six-times more frequent than false-positives (Table 21.1). This will provide a major argument in our study.

Step 8: If compared with radiography, ultrasound in the neonate seems more sensitive than specific

In our experience, if taking radiography as a gold standard, ultrasound showed five-times more false-positive cases than false-negatives. The overall false-positive/false-negative ratio was 5.3. This similarity rate will now be exploited.

Step 9: In the present study, ultrasound had the worst results in the areas where radiography is known for having precisely the worst results

We now use the Step 3 speculation. Demonstrating that a method (lung ultrasound in the neonate) has apparently low specificity precisely in the areas where radiography showed poor sensitivity (in the adult) amounts to saying that ultrasound false-positives would have been, in fact, true-positives if compared with a solid gold standard. Our experience showed that ultrasound had the *worst* specificity precisely in the areas where radiography had the *worst* sensitivity.

Radiography's specificity is good for pneumothorax [28] and interstitial syndrome [21]. In these fields where radiography can be considered a reliable gold standard, ultrasound showed high sensitivity.

Step 10: Our few CT correlations

They have no statistical power, but they show precisely what had to be demonstrated. At this very beginning of definitive proof, cases of alveolar consolidation that were frank on ultrasound and absent or uncertain on radiograph were clearly proven – as expected – on CT.

Finding again the ten assessed standardized ultrasound signs is not due to hazard or artifactual construction. Conceptually, it is not possible to imagine which disease can mimic a sinusoid sign if not a pleural effusion (or a lung point, if not a pneumothorax, etc.).

Among theoretical limitations, if it can be demonstrated that alveolar consolidations in the neonate do not reach the wall in the same proportion as adults, i.e., 98.5% of cases, this would decrease ultrasound sensitivity. Our few CT correlations indicate the opposite conclusion: consolidations have the same look as in adults, with large parietal contact.

An explanation is available for each of our results (see Tables 19.1 and 19.2 page 183).

Bedside radiography lacks sensitivity. Mainly, bedside radiography in supine neonates misses small and retrodiaphragmatic alveolar consolidations. When they are visible, but only slightly (cul-de-sac blunting), they are easily interpreted as pleural effusions. Bedside radiography misses small pleural effusions (that are easily seen on ultrasound), subtle interstitial changes, incipient pneumothoraxes when the pleural line is not tangential to the X-ray beam. Precisely, the children in our series had postoperative chest tubes. This generated a small size of pleural effusions, well detected on ultrasound, missing on X-ray.

Bedside radiography lacks specificity in precise cases: it proceeds by summation. The summation images can confuse alveolar and pleural disorders – not a problem with ultrasound, a method which does not make any summation.

As opposed to radiography, ultrasound has both a high sensitivity (since nearly all the disorders abut the surface and usually have extensive contact) and a high specificity (since there is no summation effect, mainly). Minute pleural effusions are identified at the PLAPS point. Minute pneumothoraxes are identified at the BLUE points. For alveolar consolidations, the problem is slightly different, since their location is not standardized (an incomplete scanning can miss some), and some (1.5% in the adult) do not abut the wall. Not surprisingly, it is here that we found most false-negative ultrasound results when compared with radiography.

The case of interstitial syndrome is the most interesting. We first saw that the exact seven-point definition of the B-line was present at the neonate's chest wall (Fig. 21.4). But nearly *all* of our first cases had ultrasound interstitial patterns not seen on X-ray, creating a high rate of false-positive ultrasound for interstitial syndrome. We were first worried about the hypothesis of whether B-lines were possibly a physiologic sign in very young lungs. In actual fact, systemic (and by the way pulmonary) inflammatory response is a common disorder after cardiopulmonary bypass [33] – which *all* children in this post-cardiac surgery PICU had received. Therefore, a high prevalence of interstitial changes was expected. We conclude that ultrasound detects a pattern that is most of the time missed by bedside radiography. The anterior Kerley lines, which are almost never detected on anteroposterior bedside radiographies, are immediately accessible using ultrasound. B7-lines as well as B3-lines were observed, suggesting that ultrasound can differentiate simple septal edema from ground-glass lesions also in the neonate. This will perhaps have a future impact for therapeutic decisions.

Limitations of Lung Ultrasound in the Newborn

A hypertrophic thymus may appear as a tissular image located in a standard area, which is the anterior, parasternal area. We expect here to see a regular posterior limit, i.e., absence of a shred sign, distinguishing this mass from a parasternal alveolar pattern. We did not see too many images of the thymus, since they had been most often withdrawn by our cardiac surgeons. Note that this distinction can be a challenge with the front radiography.

The limitations found in adults will be the same in the neonate (parietal emphysema, dressings).

Safety of Lung Ultrasound in the Newborn

We are cautious of any issue that may surround the use of critical ultrasound. For asepsis, we have described our policy in Chap. 3, and will describe our reluctance for usual laptop keyboards in Chap. 30. For the issues of bad training, we warrant the conditions for an efficient training in Chap. 31. For Doppler [9–11], we answered by not using this sophistication. For the possible side effects of simple ultrasound, we have no knowledge of a particular disease generated by ultrasound since 1951. Which kind of disease should be generated by the way? Yet, for anticipating any issue, we can specify that lung ultrasound can be done without any decrease of quality with the control button of emission power settled at the *minimal* position.

For the fussy users, we add that a few seconds of analysis are necessary for determining lung sliding, lung rockets, and PLAPS. We remind that a lung analysis in critical conditions can be done at the upper BLUE point, the lower BLUE point, the phrenic point, and the PLAPS point. Such a fast protocol can, moreover, be recorded and quietly read subsequently.

Non-pulmonary Critical Ultrasound in the PICU

As for the adult, there is a wide field to discover. We were deeply handicapped with our equipment, which was a classical echocardiography machine – not typically our cup of tea. Our next edition will fill this present gap.

Head

The transfontanellar approach is a natural and highly developed field. Much is available in the literature.

Neck

Correct placement of endotracheal tubes is a basic application.

Veins

Central venous line insertion will be greatly facilitated. Their correct placement can also be checked, with the same limitations as in the adult.

Heart

The heart as a target is a matter of specialists (congenital malformations). The heart as an indirect marker of hemodynamic phenomena is accessible to a simple technique (see Chaps. 22 and 23).

Circulation and Volemia

The problem of volemia control is a sensitive issue in these small organisms. We see around us various options, from the clinical assessment, done for lack of anything better, especially in small weight neonates, to PICCO devices, not easy to implement in small weight babies. We are currently exploring on this theme, assuming that the parameter offered by lung ultrasound, i.e., the B-line as a direct marker of pulmonary artery occlusion pressure, should be extrapolated in the neonate [8].

Abdomen

The organs of the adult are present, at the same locations: aorta, inferior vena cava, GI tract, liver, spleen, kidneys, pancreas, adrenals, gallbladder, bladder, etc. Some fields are more characteristic of the child, such as intussusception [34], but here we get too far from the subject (which could include all various digestive malformations: a whole discipline).

Diaphragm

Its anatomy and function can be precisely analyzed.

Lung Ultrasound in the Neonate, Conclusions

Our observations clearly showed that the ultrasound signs described and standardized in the adult were found again in the newborn. This invites us to consider that for ultrasound, the newborn's lungs are small adult lungs [7].

The high degree of standardization of the signs (see figures) makes ultrasound a reasonable bedside noninvasive reference test for the critically ill adult and, even more so, the neonate. The implementation of lung ultrasound in the child or the neonate must be considered as a priority target [35].

Opening the field with the neonates was time-saving, since it can now be extrapolated that sucklings, toddlers, young children, teenagers, etc. will benefit from the same semiotics.

In addition to providing immediate and accurate data, this will result in decreasing radiation doses.

We await proof that only CT can provide. We expect that some cases, gathered here and there, will give the necessary statistical power. Meanwhile, we invite pediatric physicians to read the chest radiographies with caution, especially if ultrasound shows discordant items.

Critical ultrasound has accustomed us to surprises. Why was it not used sooner? Why was the lung so strictly prohibited? Why do they use this sticky gel? Why this craze for Doppler? Why laptop machines in hospitals? And so on. When the problem involves a new life, all these questions must be answered seriously and academic opinions must be balanced, since the real emergency is here, in the pediatric and neonatal ICUs.

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Simple Emergency Cardiac Sonography

22

The heart, this organ that prevents us to examine the lung...
Ph. Biderman (December 26, 2007)

An introduction is necessary here because cardiac sonography has a symbolic place.

The term "sonography" in the title was chosen on purpose: sounding different to "echo," traditionally reserved for the echocardiography Doppler approach of the cardiologist, and different to "ultrasound," which is associated with traditional abdominal examination by the radiologist. *Cardiology* and *radiology* are two worlds. *Critical care* is another world.

We could have placed the heart first or last (another mark of respect). The heart is a vital ultrasound-accessible organ, like others, and its place can be considered here. Having accrued experience in a pioneering institution in echocardiography in the ICU since 1989 [1], the authors have come to the tentative conclusion that therapeutic procedures can be deduced from the observation of simple phenomena. The heart is a perfect example of the principle of simplicity used throughout this book. Simple signs, a simple technique, and a holistic approach define a field different from the traditional cultures.

Prestigious comprehensive textbooks are available from the traditional cardiologist field [2], the pioneering intensive care field [1], many honorable sources [3,4], recent trends [5–7] and a host of sources we cannot cite, for which we humbly apologize for the lack of space and culture. We also apologize for those valuable references that are not featured in this chapter (many are featured in Chap. 23, however).

We raise two questions about cardiac sonography: *How* to see the heart, which is modestly described in this chapter; and *Why* does the intensivist want to see the heart, which is another critical question that should be answered in the light of the emergence of new developments, such as lung ultrasound. For respiratory failure, this basic question received an answer in Chap. 20 (the BLUE protocol), showing that pulmonary edema is a lung diagnosis. Facing circulatory failure, Chap. 23 will give clues showing again that lung ultrasound provides the direct parameter for fluid therapy. The present chapter should prepare the reader to think differently in order to profit from the next chapter.

Sophisticated echocardiography will be necessary, as a second step, in order to refine the analysis. This gives space for the concept of a simple emergency cardiac sonography, heralded in our 1992 edition, and aimed at the very first minutes of management. The concept has been extended recently by several protocols with elegant acronyms. Let us cite the dynamic RACE developed by Maclean, the FEER [8], the FATE [9], the FOCUS. Although our simple approach did not include any acronym (it was not necessary nor the fashion in 1992), we are happy to see that it has opened the way for these developments.

Deliberating on echocardiography without mentioning Doppler or transesophageal approaches in 2010 may appear bold. Chaps. 20, 23, and 30 comment on this intentional approach. We will see how a simple two-dimensional (2D) use of the heart, *integrated into other applications* (lung in particular) improves the level of information: the amount of information lost in terms of a Doppler or transesophageal approach will possibly be balanced using direct lung data. The reader therefore should not take offense if transesophageal echocardiography (TEE) is not featured in this chapter.

All the figures provided (apart from two) come from using technology dating from 1982 (ADR-4000).

In simple emergency cardiac sonography, measurements are rarely made. This is a visual medicine. The

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diagnoses are visual, simply. These life-saving diagnoses can be made without compromise with our 5-MHz microconvex probe and our gray-scale machine.

Heart Routes

The parasternal route lies in the left parasternal area (Fig. 22.1). The apical route corresponds to systolic shock. The left positioning is not easy in a ventilated patient. Mechanical ventilation often creates a hindrance to the transthoracic approach of the heart, and the subcostal route has been widely used in sedated supine patients. This is an abdominal approach, with the probe applied just to the xiphoid, the body of the probe applied almost against the abdomen (see Fig. 9.12 page 72).

Even if the heart is not fully accessible, many approaches are available.

- In the parasternal approach, for instance, waiting for the end-expiratory phase makes it often possible to obtain – even if only for a fraction of a second – a dynamic image sufficient for a rough evaluation of the left heart status. If needed, one can lower the respiratory rate for a short time in order to prolong this instance.

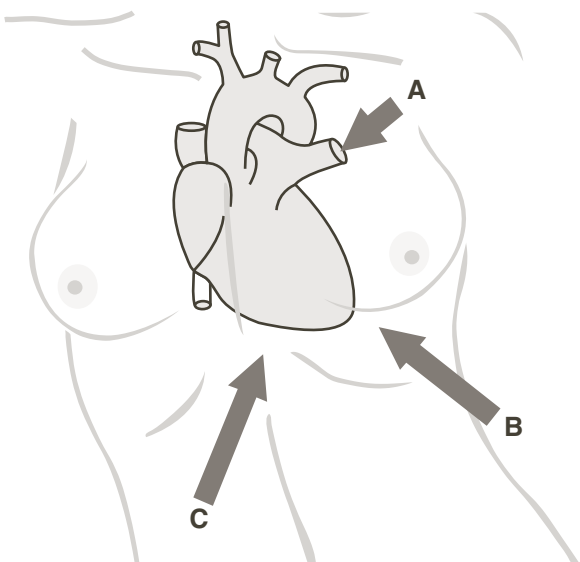

Fig. 22.1 The classic routes of the heart. (*a*) The parasternal route. (*b*) The apical route. (*c*) The subcostal route, a basic approach to the ventilated patient

- The quality of the subcostal route is improved if the hepatic parenchyma is used as an acoustic window. Therefore, in some instances the probe should be moved far from the heart. A right intercostal approach through the liver can analyze the auricles, or even more (personal routes).
- A right parasternal approach can show dilated right chambers extending to the right.
- When nothing works, one can look at the lung instead of the heart.

Notions of Ultrasound Anatomy of the Heart

The heart is a complex mass, which can be schematized from the left ventricle. The left ventricle is an egg-shaped mass with a long axis pointing leftward, downward, and forward. It has a base (where the aorta and left auricle are located), an apex, and four walls: inferior, lateral, anterior, and interventricular septum. The right ventricle has more complex anatomy, requiring more experience. Its apex covers the septum, its base (infundibulum) covers the initial aorta. It has a septal wall and a free wall. The main intracavitary structures are the valves and the left ventricular pillars. The auricles are visible behind the ventricles. The cardiac muscle is echoic. The chambers are anechoic (except in cardiac arrest).

An efficient way to learn heart anatomy is to use ultrasound. Paradoxically, ultrasound helps to locate the heart in the space.

The parasternal route, long-axis view, studies the left ventricle (except the apex), left auricle, initial aorta, right ventricular infundibulum, and dynamics of mitral and aortic valves (Fig. 22.2).

The parasternal route, short-axis view, studies the two ventricles and the septum at the bottom (Fig. 22.3). Higher up, it shows a view where the right auricle, the tricuspid valve, the basal portion of the right ventricle, the pulmonary artery and its two division branches, which surround the initial aorta, are visible (Fig. 22.4).

The apical route provides an overview of the four chambers (four chambers view). This view shows the heart in its true symmetry axis: ventricles anterior, auricles posterior, left chambers to the right, right chambers to the left (Fig. 22.5). The lateral

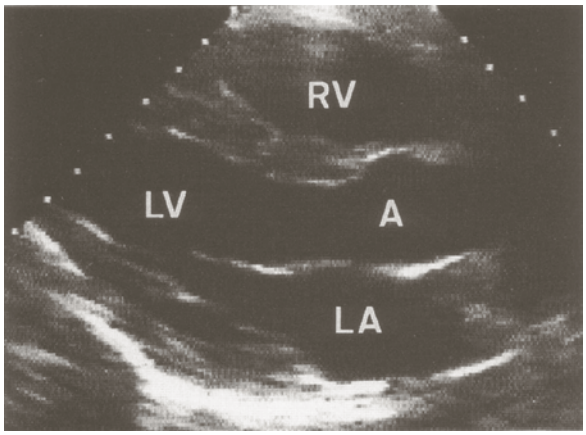

Fig. 22.2 Long-axis view of the heart, left parasternal route. A concession to cardiology was made, since this figure is oriented with the patient's head at the right of the image. *LA* left auricle, *LV* left ventricle, *RV* right ventricle, *A* initial aorta

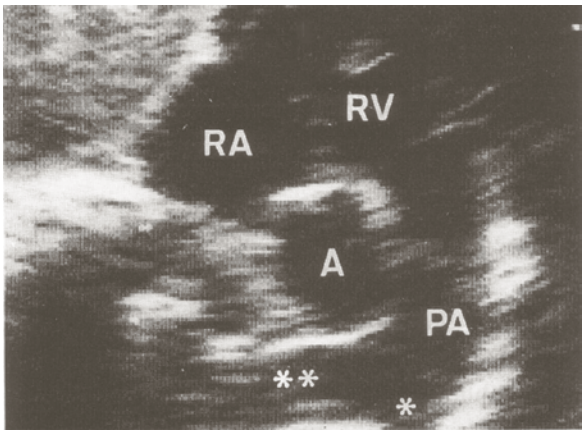

Fig. 22.4 Small-axis parasternal view of the base. *RA* right auricle, *RV* right ventricle, prolonging by the pulmonary artery (*PA*), which surrounds the initial aorta (*A*). Right (**) and left (*) branches of the pulmonary artery – sites where massive cases of pulmonary embolism occur – should be looked for

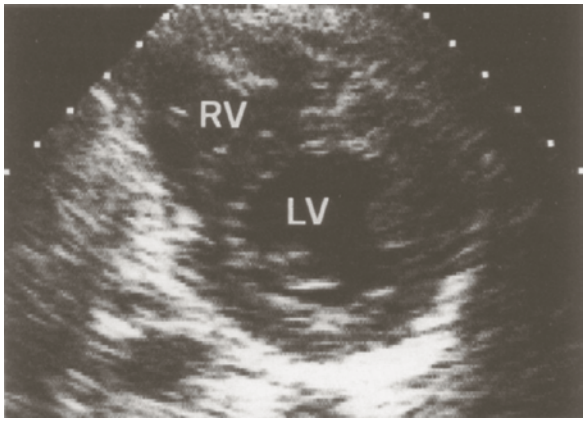

Fig. 22.3 Small-axis biventricular parasternal view. The left ventricle (*LV*) section is round. The two prominent structures are the pillars of the mitral valve. The right ventricle (*RV*) surrounds the septal wall of the left ventricle

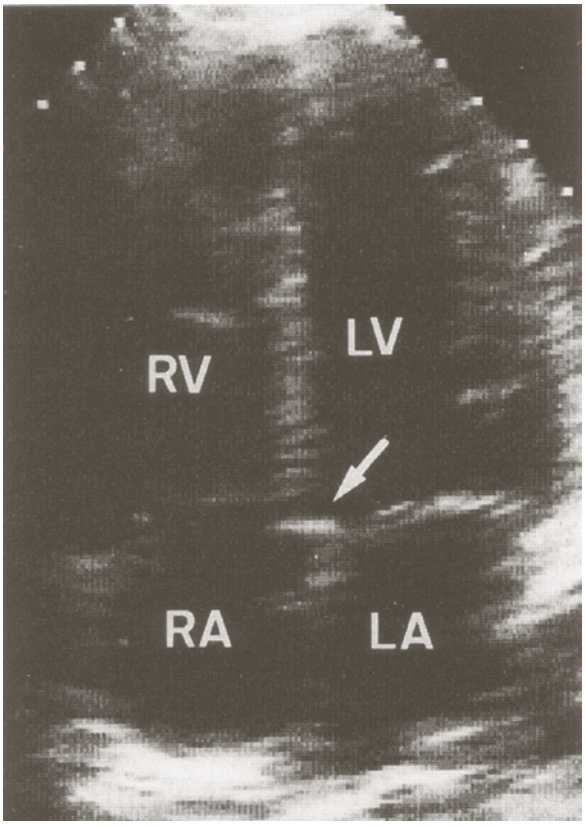

Fig. 22.5 Four-chamber view, apical window. Here, the heart seems to be a symmetric structure. *LV* left ventricle, *LA* left auricle, *RV* right ventricle, *RA* right auricle. This incidence allows immediate comparison of the volume and dynamics of each chamber. Note that the plane of the tricuspid valve is more anterior than the plane of the mitral valve. Right auricle and left ventricle are in contact (*arrow*), a detail which allows correct orientation

and septal walls and the apex of the left ventricle are visible. It is the best for appreciating right ventricule size.

The apical route, two-chamber view, is obtained by rotating the probe 90° on its long axis. This allows analysis of the anterior and inferior walls of the left ventricle.

The subcostal route gives a truncated view of the heart, not fully suitable for rigorous measurements, but of major interest since it is accessible in a critically ill patient. This gives an overview of the chamber volume and myocardial performance (Fig. 22.6).

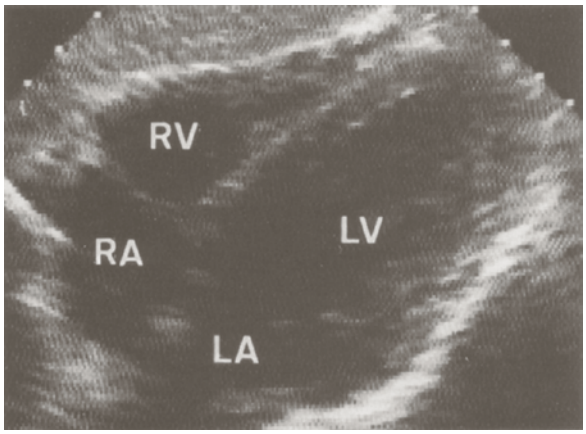

Fig. 22.6 Subcostal view of the heart. This approach is a classic in the intensive care unit. It is a truncated equivalent of the four-chamber apical view in Fig. 22.5. *RV* right ventricle, *RA* right auricle, *LV* left ventricle, *LA* left auricle. The operator should move the probe from top to bottom (Carmen maneuver in fact) to acquire a correct three-dimensional representation of the volumes. The pericardium is virtual here

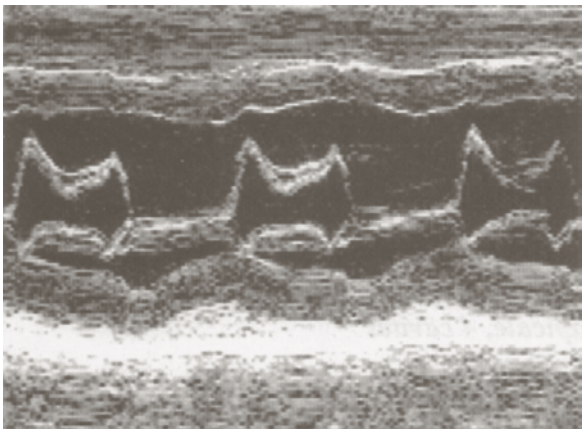

Fig. 22.7 M-mode recording of the mitral valve. The letter *M* is displayed inside the left ventricle. Long-axis parasternal view

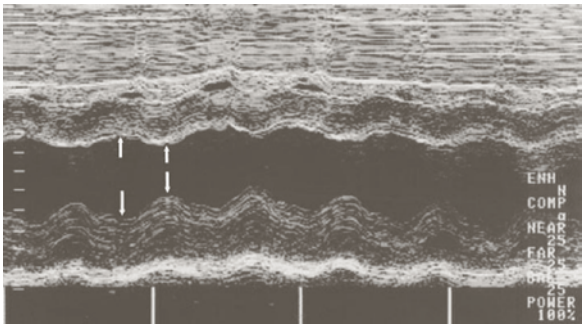

Fig. 22.8 Normal heart. When the left ventricle is bisected by the M-mode line (see Fig. 22.3), its contractility can be measured on paper. The narrower the sinusoid wave, the more the contractility is decreased. If precise data are preferred to a visual impression, a rigorous technique is required, using a perfectly perpendicular axis, thus avoiding distortions due to tangency, and a measurement between pillars and coaptation of the mitral valve, a reproducible area. The *arrows* indicate diastolic then systolic diameter of the left ventricle. The contractility is still normal here (shortening fraction, 28%). Muscle thickness variations may also be measured on this figure

All the routes allow analysis of the pericardium, normally virtual or quasivirtual.

Only rough estimates of measurements will be given. In a short axis at the pillar level, the left ventricular walls (septal or posterior) are 6–11 mm thick in diastole. The left ventricle chamber caliper is 38–56 mm. The right ventricle free wall is less than 5-mm thick. A precise measurement of the right ventricle volume should include subtle criteria, since the shape of the right ventricle is complex. In an apical four-chamber view, the right ventricle size is less than that of the left ventricle.

Real-time analysis allows assessment of the ventricular contractility and, more secondarily for us, wall thickening and valve movements (Fig. 22.7).

An M-mode image through the ventricular small axis can measure (Fig. 22.8) the left ventricular chamber dimension in diastole, which indicates a dilatation. This dimension in systole defines contractility. The difference between these two values, divided by the diastolic dimension, defines the left ventricle shortening fraction, a basic parameter of the ventricular systolic function. It is normally 28–38%. This information can replace the ejection fraction, because it is easy to obtain and clinically sufficient in the emergency situation. It is also rapidly possible to roughly appreciate that a left ventricle is hypo-, normo-, or hypercontractile without measurement.

The parietal thickening fraction (the ratio of the difference of diastolic and systolic thickening over diastolic thickening, normal range from 50% to 100%) is less useful in our daily (and, above all, nightly) routine.

Cardiac Arrest

This is detailed in Chap. 29 (see Fig. 29.3 page 283).

Left Ventricular Failure

When systolic function is impaired, global contractility is decreased, with low shortening fraction (Fig. 22.9). This profile is seen in left ventricular failure of ischemic origin, dilated cardiomyopathies (Fig. 22.10), septic shock with heart failure, and some drug poisonings with heart tropism.

The impairment of the diastolic function is more difficult to detect without a sophisticated approach including Doppler. In some cases, diastolic dysfunction is due to myocardial hypertrophy. This profile, accessible with simple 2D ultrasound, can provide an argument for this etiology (Fig. 22.11).

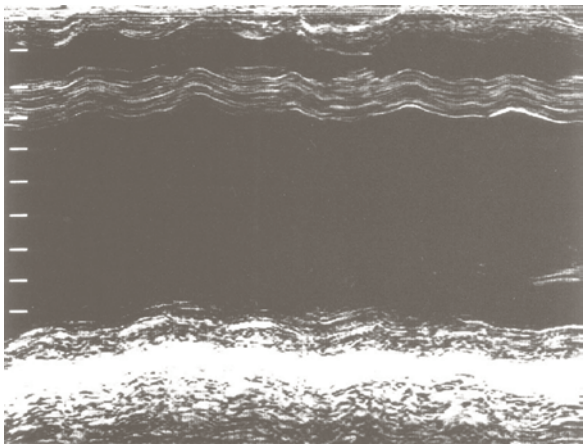

Fig. 22.9 Left ventricle hypocontractility. The sinusoid wave has low amplitude in this patient with dilated cardiomyopathy (diastolic diameter, 67 mm)

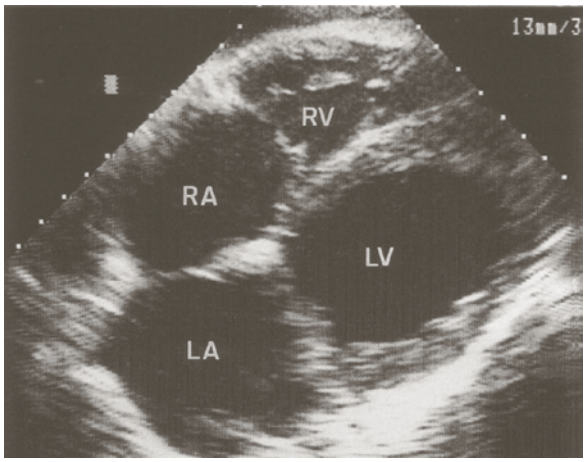

Fig. 22.10 Dilated cardiomyopathy. Massive enlargement of the four chambers

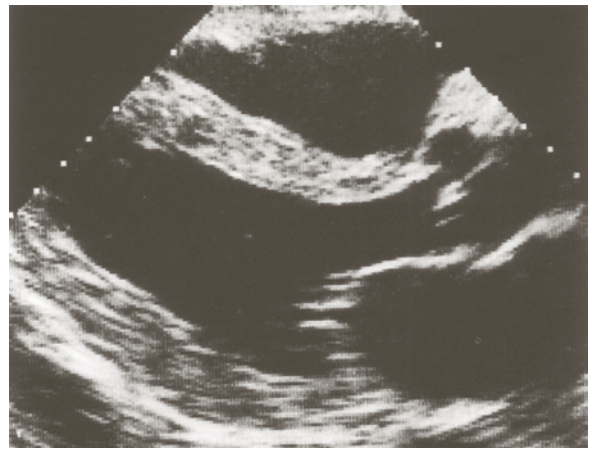

Fig. 22.11 Left ventricle hypertrophy with parietal thickness at 20 mm. A sort of parietal shock was perceived in this patient (not reproduced here for lack of M-mode acquisition). It was synchronized with the auricle systole and probably indicated a sudden increase in pressure in a chamber whose volume could not increase. Long-axis parasternal view

It should be stated here that in a patient suspected of pulmonary edema, the usual procedure is to search for cardiac failure. Left ventricle contractility can be a field rich in subtleties, conditioned by the preload and afterload status, the cardiac window, and operator experience. An initial step can avoid wrong notes: first checking for the reality of pulmonary edema. This is ensured by searching for the B-profile (see Chap. 20). An absence of lung rockets indicates the absence of pulmonary edema.

Right Heart Failure

The right ventricle normally works under a low-pressure system. Any hindrance to right ventricular ejection, as seen in severe pulmonary embolism, but also severe asthma, ARDS, extensive pneumonia (etc.), will promptly generate dilatation [10]. Acute right heart failure associates early right ventricular dilatation (Figs. 22.12 and 22.13), a displacement of the septum to the left, and a tricuspid regurgitation. This can be demonstrated without Doppler at the inferior vena cava when there is a spontaneously echoic flow. The free wall of the right ventricle is thickened in case of chronic obstacle, like in COPD (Fig. 22.14).

An acute right heart failure should yield an hypocontractility of the free wall with correct contractility of the apex. When the right heart is not accessible to

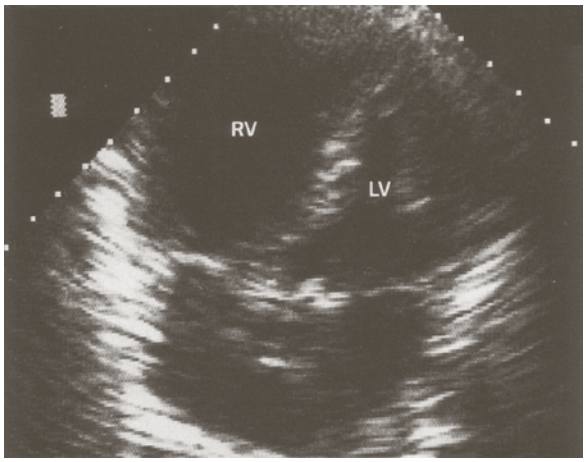

Fig. 22.12 Massive pulmonary embolism. Substantial dilatation of the right ventricle in a four-chamber view using the apical route

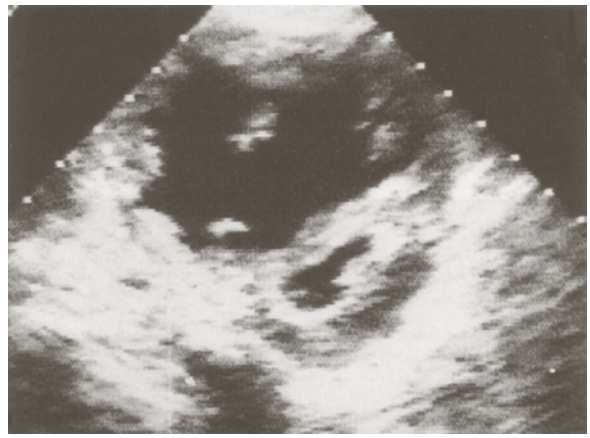

Fig. 22.14 Major right ventricle dilatation. Note the squashed left ventricle, and the substantial thickening of the free wall of the right ventricle. Short-axis parasternal view

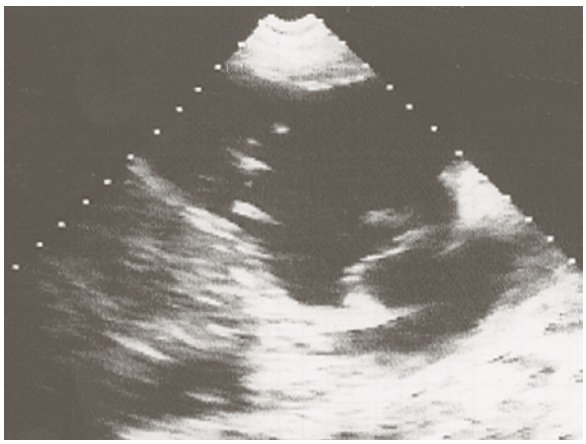

Fig. 22.13 ARDS. A peculiar pattern, evoking a royal python's head. Parasternal long-axis view of a markedly dilated right ventricle in this young patient with aspiration pneumonia

transthoracic echography, one can use either the transesophageal approach or a lung approach, which gives immediate information. Absence of B-profile in a patient with acute respiratory failure immediately indicates that right – not left – heart anomalies are expected – unless a major septal interference impairs the left heart function (but read Chaps. 20 and 23).

Pulmonary Embolism

Echocardiography is a traditional site for providing the diagnosis. The tools and approaches that we use (lung and venous approach), described in Chaps. 13–19, were exploited in Chap. 20. A synthesis is done in Chap. 29. The combination of a normal lung pattern with venous thrombosis in a patient seen for acute respiratory failure has a 99% specificity [11]. The diagnosis of pulmonary embolism in a patient with ARDS, an apparent challenge [12], will be solved on page 285 in Chap. 29.

Pulmonary embolism yields signs of acute right heart failure (see above). Admitting that the pulmonary arteries are part of the cardiac sonography, we always try to expose them. The parasternal short axis tries to expose the main branch. Using our microconvex probe, which has an ideal shape and resolution, a suprasternal route shows in favorable cases the right pulmonary artery, in the concavity of the aortic root (Fig. 22.15). The rare detection of a frank, mobile blood clot using these routes gives anyway a direct proof. TEE also tries to detect this direct proof, when the embolus is located in the main branches [13].

Note that the place of Doppler, major here for years, gradually decreases, since reports have shown that the severity of pulmonary embolism is correlated with the degree of obstruction, a situation that appeared little correlated with pulmonary arterial pressure (not always elevated in severe cases of embolism), but better correlated with the volume of the right ventricule (and the left/right ratio), i.e., a 2D acquisition [14].

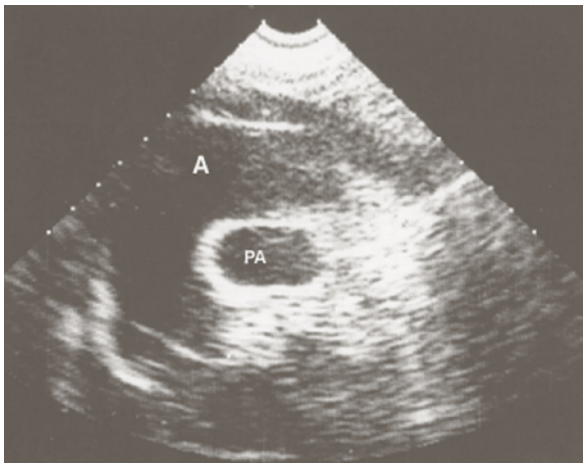

Fig. 22.15 Pulmonary artery. Transverse scan of the right pulmonary artery (*PA*), surrounded by the aortic arch (*A*). Suprasternal scan (only short footprints can achieve this route). Floating tissular pattern can here directly demonstrate acute pulmonary embolism in an extreme emergency

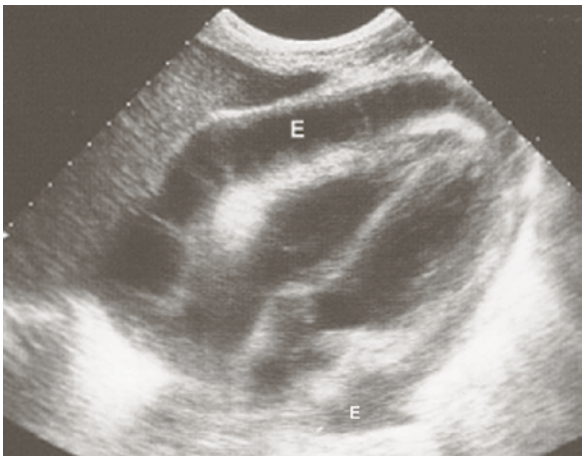

Fig. 22.16 Fluid collection in the pericardial space (*E*). The septations indicate an infectious cause. Note that the effusion surrounds the entire heart: it is visible anterior to the left ventricle in this subcostal approach (*smaller E*). Pleuropericarditis due to *Pneumococcus*

Pericardial Tamponade

This diagnosis is a main illustration of simple emergency cardiac sonography – the one which should be within every intensivist's reach.

The two layers of the pericardium are separated by a collection. Its thickness varies during the cardiac cycle – shaping a kind of sinusoid. The fluid first collects posterior to the left ventricle, then anterior to the right ventricle, becoming circumferential. The fluid can contain echoes (purulent pericarditis, hemopericardium, etc.), septations (Fig. 22.16). Pericardial fat is usually limited anteriorly, contains echoes, and makes no sinusoid pattern.

When pericardial effusion is detected in an unstable patient, tamponade is likely. A pericardial tamponade is abundant and circumferential (Fig. 22.17), except in some postoperative cases where small effusions located on strategic places can impede hemodynamics. Within a distended pericardial sac, the heart appears to be swimming (sometimes swinging). The right chambers have decreased volume and can in extreme cases be undetectable.

Some signs in rhythm with cardiac and respiratory cycles can be observed in the spontaneously breathing patient, but their analysis should not delay the management. Inspiration facilitates venous return, and the right ventricle dilates at the expense of the septum, which is more compliant than the free wall. The septum is shifted to the left and compresses the left ventricular

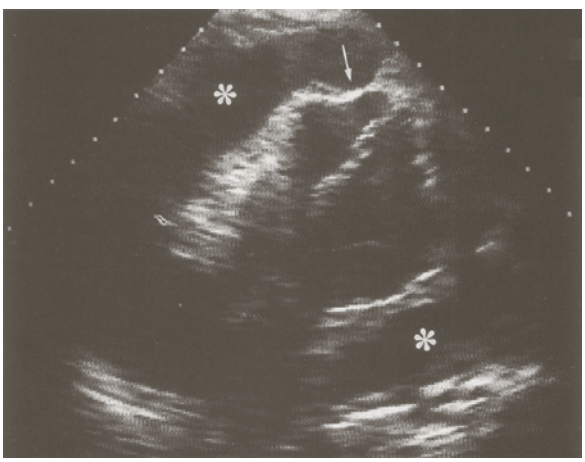

Fig. 22.17 Pericardial tamponade. The heart is surrounded by an abundant fluid collection (*). A swinging pattern was visible in real-time. The right chambers are collapsed, especially the right ventricle free wall (*arrow*). This subcostal figure also shows the route for a life-saving pericardiocenthesis

chamber. Diastole creates a decrease in intracavitary pressures, whereas intrapericardial pressure remains constant. The right chambers are thus collapsed by the surrounding pressure. The right auricle wall collapses first, then the right ventricle. Right-chamber collapse is amplified by hypovolemia.

The description of signs using Doppler data would have a beneficial effect: showing physiopathologic patterns. It may also complicate the design, if the needed

logistics are not present on site (trained operator, sophisticated unit). Inserting a needle, under ultrasound guidance, in an unstable patient with abundant pericardial effusion will be less often missed than any academic loss of time. In unstable traumatized patients with pericardial fluid and small right chambers, there is little place for other diagnoses. Our approach is based on the current rarity of pericardial tamponade (trauma excepted – and yet, also considering the decrease in number of trauma patients).

Ultrasound allows a bedside, safe pericardial tap. A minor fluid withdrawal can improve the circulatory status. We again use our multipurpose material, described in Chap. 26 (see Fig. 26.2 page 265). One can also use a larger caliper if viscous fluid is suspected. One can use a material devoted to thoracentesis. We keep our materials permanently in a dedicated place on our cart (thereby reducing interest in the ultraminiature laptop technology if there is no cart providing storage space).

The pericardium is best approached via the subcostal route. The probe is applied next to the needle. The asepsis is adapted to the clinical situation, with a simple but sufficient skin disinfection in the case of cardiac arrest (the disinfectant will be used for gel contact, saving precious seconds, and will not damage the probe if used very rarely). The progression of the needle can be followed through the liver parenchyma (Fig. 22.18). We try to aim at the auricle rather than the ventricle. A millimetric Carmen maneuver allows one to permanently locate the tip of the needle. When it is located for fluid collection, one aspirates, while firmly maintaining the needle under permanent control on the screen, since the heart is not far (some prefer two-operator techniques). If blood is withdrawn, it can be reinjected, firmly holding the syringe. If this blood originated from the pericardial sac, this maneuver creates echoic turbulence within the collection. This turbulence cannot be seen if the needle is in a heart chamber – but such a situation should not occur using visual guidance. Microbubbles (contrast echography) can also be used, time permitting.

Hypovolemic Shock

Usually, in a shocked patient, the heart is the main target. The typical profile includes hypercontractile left ventricle, with small end-diastolic cavity and sometimes virtual end-systolic volume (Fig. 22.19).

Doppler signs and the TEE approach will not be described here. Instead, we rather look at the lung – especially in extreme emergency if no cardiac window is available. Comments on this role of whole-body ultrasound in assessing needs for fluid therapy are available in Chap. 23. See also comments about the

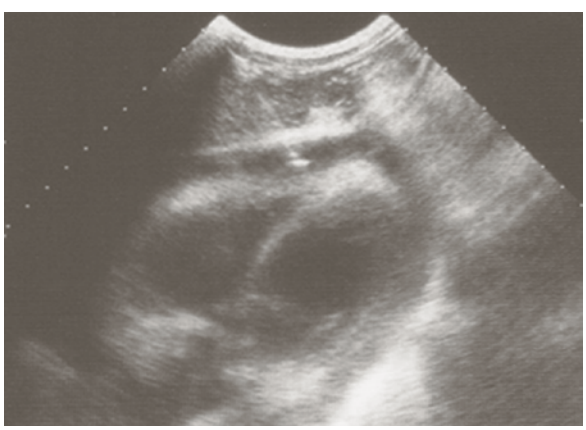

Fig. 22.18 Ultrasound-guided pericardial tap. The subcostal approach was used. The needle has penetrated the hepatic parenchyma then the pericardial space, and has been withdrawn. Here, the entire length of the needle is visible, along with its plastic end connector. Purulent pericarditis due to *Pneumococcus*; sequel of Fig. 22.16

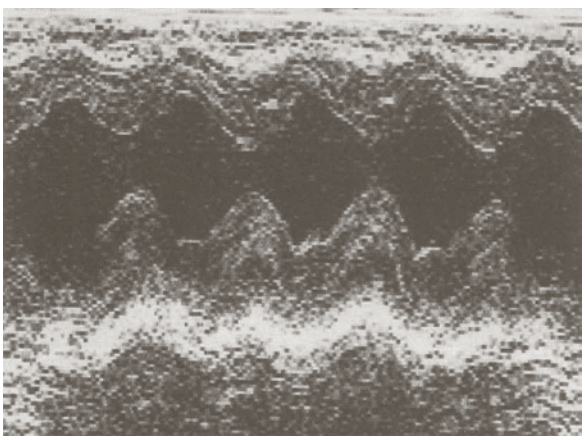

Fig. 22.19 Possible hypovolemia. Hypercontractile pattern of the left ventricle. M-mode acquisition in a short-axis parasternal view. Small diastolic chamber. Quasivirtual systolic chamber. Tachycardia. This shocked patient had abdominal sepsis. Hypovolemia is probable since the further images improved (contractility, size, frequency)

SESAME-protocol, in Chap. 29, whose principle is to define hypovolemic shock also in the presence of massive free fluid.

Chapter 23 will detail the hemodynamic power of lung ultrasound for defining the volumes of fluid therapy and assessing the risk of pulmonary edema.

Gas Embolism

It yields large, hyperechoic echoes, with posterior shadow (Fig. 22.20). They are highly dynamic. In a supine patient, these gas bubbles transiently collect at the anterior part of the right ventricle and travel little by little in the pulmonary artery – unless the patient is promptly turned to the left lateral position. Gas embolism complicating the central venous line insertion can be predicted (see Chap. 12 page 93).

Gas Tamponade

With the ultrasound unit available in this critical situation, it is possible to immediately detect collapsed chambers, without pericardial effusion. The subcostal approach is usually the only contributive one. This pattern will contrast with enlarged jugular veins. Searching for tension pneumothorax completes this exploration (or can be done before, facing imminent cardiac arrest, see the SESAME-protocol in Chap. 29).

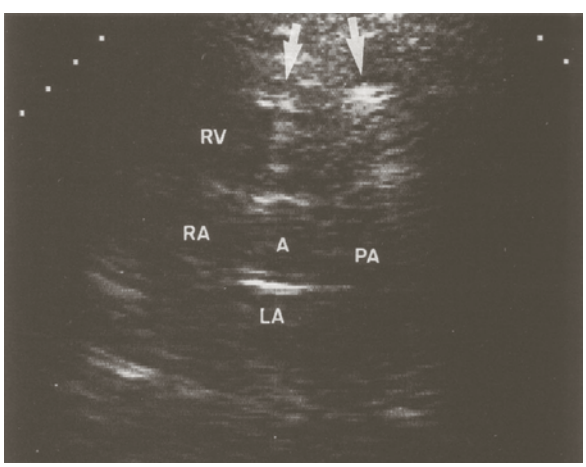

Fig. 22.20 Gas embolism. In this short-axis parasternal view of the base, real-time visualization allows immediate diagnosis of hyperechoic images (*arrows*) identified at the roof of the right ventricle (*RV*), highly mobile, as gas bubbles can be within a dynamic hydraulic circuit. They repeatedly appear and progressively are drawn toward the pulmonary artery (*PA*). Suboptimal quality figure, obtained in an extreme emergency setting. *RA* right auricle, *LA* left auricle, *A* aorta

Endocarditis

This is a rare diagnosis. Endocarditis can be suspected when an echoic image, arising at the free end of a valve, can be detected (Fig. 22.21). The "gold standard" is the transesophageal approach and there is no space for arguing this. However, in our experience, all cases we have encountered gave signs that were already suggestive, sometimes specific, before being confirmed by semi-invasive procedures. Endocarditis is the typical indication, in our opinion, for DIAFORA logistics, a sophisticated examination by a specialist, scheduled during open hours the day after, during the traditional interval for the hemoculture series.

Intracavitary Thrombosis or Tumor

Intracardiac thromboses can be identified (Fig. 22.22). They give a regular echoic pattern, sometimes mobile, of

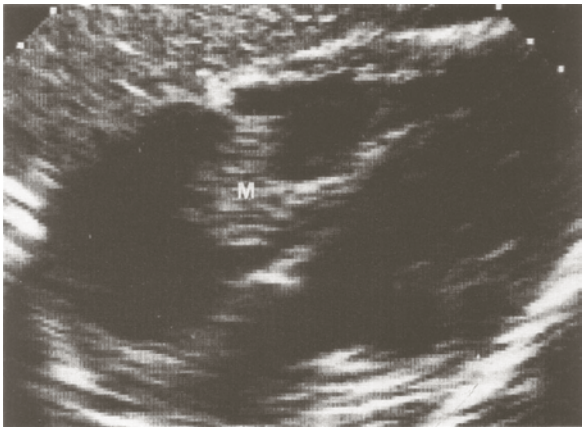

Fig. 22.21 Endocarditis. Tissue-like mass depending on the tricuspid valve. A diagnosis of endocarditis in a young drug addict was immediately made using this subcostal ultrasound view, quickly confirmed by positive hemocultures (*Staphylococcus*). *M* vegetation

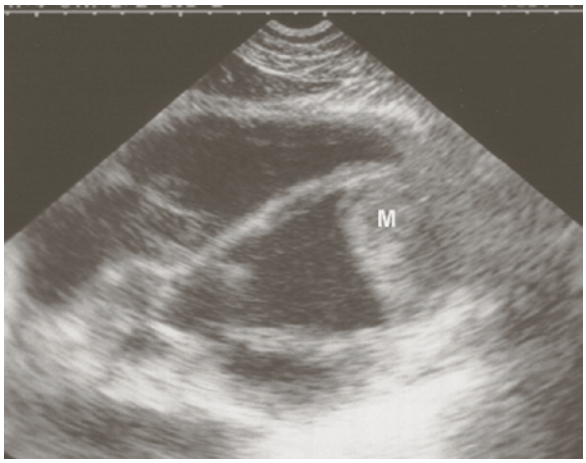

Fig. 22.22 Voluminous thrombosis (*M*) at the left ventricle apex. Subcostal view

high specificity. For the sensitivity, transesophageal approach should give better results (if simple approach did not answer). Tumors are so rare that we do not develop this (see Fig. 22.25). Do not confuse right ventricle normal structures (papillary muscle etc.) with thromboses.

Intracavitary Device

A too long distal end of a catheter should be searched for in the right chambers, provided the acoustic window is correct. Interesting was the ability to check, in real-time, the progression of the Swan-Ganz catheter through vena cava, auricle, ventricle, pulmonary artery, etc. (Fig. 22.23). One sterile operator inserted the material, the other guided the distal end of the catheter using the subcostal approach. Asepsis could be efficiently controlled. The position of a electrosystolic probe can be checked in the right ventricle.

Myocardial Infarction

The diagnosis of segmental anomalies is subtle and requires expertise. Although the movement of the walls may be more important, their systolic thickening is under focus. In characteristic cases, the ischemic wall is motionless, in contrast to the normal or exaggerated dynamics of the other walls (Fig. 22.24). The investment is worthwhile if it is accepted that ultrasound anomalies are

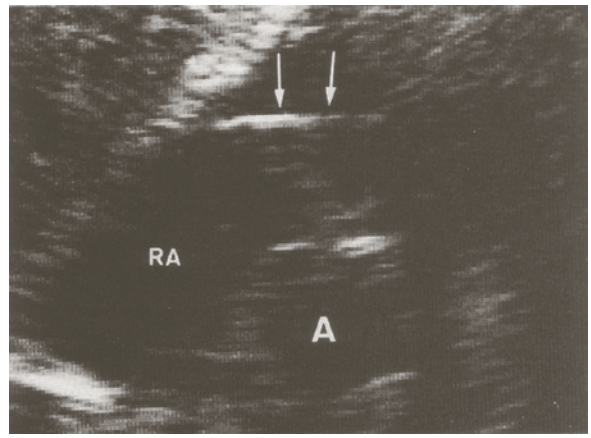

Fig. 22.23 Swan-Ganz catheter (*arrows*) in the right ventricle. The balloon inflation and the route of the catheter toward the pulmonary artery can be followed on the screen. RA right auricle, A aorta

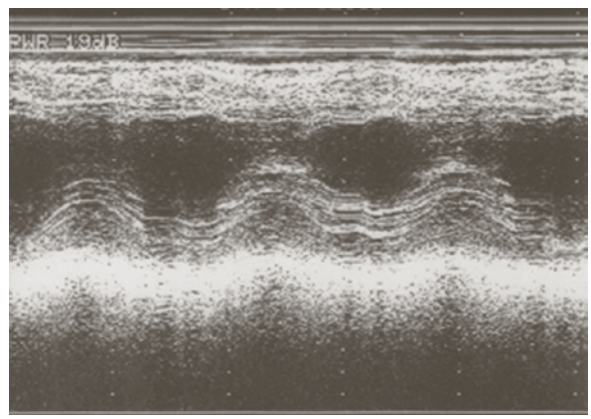

Fig. 22.24 Myocardial infarction. Frank akinesia of the anterior wall of the left ventricle. Short-axis parasternal view, M-mode. Note the hypercontractility of the inferior wall, located opposite. Incipient infarction seen after 3 h

visible early, thus modifying immediate management [15]. Right ventricle dilatation may suggest right ventricle infarction. Critical ultrasound in a patient with suspected myocardial infarction has the merit of immediately ruling out other diagnoses, such as pericarditis or sometimes aortic dissection, whose management differs.

Miscellaneous

Many anecdotal situations can be encountered in the emergency room or the intensive care unit, but their

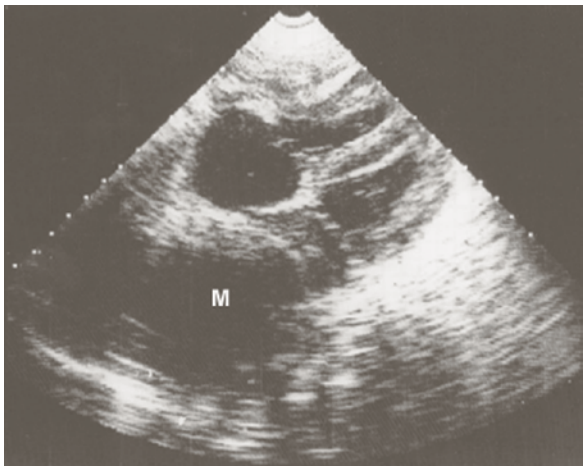

Fig. 22.25 A thorny case. Subcostal view of a young woman in shock with white lungs. A mass is visible at the location of the left auricle (*M*). This is an esophageal abscess which complicated minor esophageal surgery performed weeks before. The shock was septic (with positive hemocultures) as well as cardiogenic, because of a hindrance to pulmonary venous return. We reassure the reader: the diagnosis was just suspected here. It was rather perioperative (an emergency transesophageal ultrasound examination was also performed, and failed to be fully contributive)

exhaustive description would overburden this book. For instance, in a young lady admitted for severe shock with massive pulmonary edema, transthoracic ultrasound showed a retroauricular mass compressing the left auricle (Fig. 22.25). Emergency surgery revealed an esophageal abscess, which was responsible for both septic shock and hemodynamic left failure due to impairment of pulmonary venous return.

In echoic patients, many data can be extracted from the examination of the valvular system using our simple machine. Mitral prolapsus, valvular thickenings, even without Doppler data, can be diagnosed at low cost.

Cardiac sonography can inform on nearby organ diseases [16].

Valvular diseases, problems with mechanical valves, some mechanical complications of myocardial infarction, septal rupture, hypertrophic asymmetric cardiomyopathies are rare, and would be beyond the scope of this book. Specialized techniques such as transesophageal Doppler echocardiography, used by specialists, will here provide the best logistic [17].

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23 Simple Critical Ultrasound Considering Hemodynamic Therapy: Our Limited Investigation

The potential of lung ultrasound in detecting interstitial syndrome allows avoid drowning the lungs of a critically ill patient, and keeping this patient in deep occult hypovolemia.

Using with a simple approach considering a focused part of cardiac sonography, a focus part of venous sonography, and this simple part of lung ultrasound that visualizes a direct parameter, one can allow to define alternative decision trees for hemodynamic therapy.

The bedside work of the intensivist is to provide adequate oxygen output to tissues in acute circulatory failure. The present chapter was the main reason for launching this new edition. We have taken care to make it as moderate and open as possible to any criticism. We just invite different thinking by introducing some thought processes in a field where no perfect "gold standards" are available. For this, we will propose the consideration of a parameter that can be as debatable as all the other tools, but whose particularity is to assess *directly* the question of fluid therapy.

Evolution of Concepts Considering Hemodynamic Therapy in the Critically Ill

Before intensive care units were created (in the 1950s–60s), patients with circulatory failure died. The physicians in charge of these new units did their best, helped only by the central venous pressure (CVP), until the Swan-Ganz catheter was developed in the early 1970s [1].

This tool provided precise data, which gave the users a feeling of going in a direction that was assumed to be the good one. After decades of use, the Swan-Ganz catheter ran into a difficult period due to some possible side effects, questionable usefulness [2–18], or a suboptimal use of a potentially interesting method [19–21]. Alternative techniques, mainly transthoracic and transesophageal echography (TEE), were consequently advocated [22–32], making Swan-Ganz an obsolete option. Since TEE was not easily accessible (cost, training), although in use since 1976 [33], manufacturers rapidly developed other tools – mainly continuous cardiac output devices for assessing lung water (PICCO), esophageal Doppler, pulse pressure variation, pulse contour analysis, pulse analysis of the arterial pressure, sophisticated oxygen transport assessment, and also for microcirculation assessment and derived applications, such as gastric tonometry, sublingual capnometry, laser Doppler flowmetry, near-infrared spectroscopy, gravimetry, etc. [34–45]. This is a familiar curve of many innovations: an initial enthusiasm, followed by more balanced conclusions after prolonged use. For example, the supranormal value of oxygen delivery in septic shock was an honorable target [46], before being discredited [47]. For some authors, the return to more simplicity remains a valuable option [48]. Supporting this option, some have suggested simple maneuvers [25, 49].

All in all, the number of available techniques may disconcert some intensivists (Table 23.1). It possibly reflects the absence of an absolute gold standard. The successive methods, up to the most recent, are compared with previous ones, which were not solidly assessed. Often, authoritative behavior replaces scientific evidence. In fact, large randomized controlled studies are

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Table 23.1 Usual data and usual therapeutic possibilities in shocked patients

Data derived from various approaches	Therapeutic consequences
– Aortic blow velocity	
– Arterial pH	Fluids or not
– Arterial pulse pressure	
– Arterial systolic or pulse pressure variation	Inotropics or not[a]
– Capillary wedge pressure	
– Cardiac output	Vasopressors or not[b]
– Cardiac index	
– Central venous pressure	
– Central venous oxygen saturation	
– Color Doppler regurgitant flow assessment (mitral regurgitation)	
– Continuous wave Doppler velocities of tricuspid insufficiency	
– Continuous wave Doppler velocities of pulmonary insufficiency	
– Cardiac output change following passive leg raising	
– Delta PP	
– DTE, deceleration time of mitral Doppler Es wave	
– E/A waves	
– E = maximal Doppler velocity of early diastolic mitral wave	
– A = maximal Doppler velocity of late diastolic mitral wave during atrial contraction	
– E/E′ – Pulsed wave Doppler recorded at the tip of the mitral valve (E)	
– E′ = Maximal tissue Doppler velocity of early diastolic displacement of the mitral annulus	
– End-diastolic left ventricular dimension	
– End-diastolic left ventricular area	
– Expired CO_2	
– Esophageal Doppler	
– Extravascular lung water	
– Gastric tonometry	
– Global right ventricle size	
– Global right ventricle systolic function	
– Global left ventricle systolic function	
– Heart rate	
– Heterogenous left ventricle contraction	
– Inferior vena cava collapsibility index	
– Intracardiac shunts	
– Intrapulmonary shunts	
– Laser Doppler flowmetry	
– Left ventricle end-diastolic pressure	
– Left ventricular diastolic elastance: active relaxation and passive compliance	
– Lactic acid	
– Mottled skin	
– Near-infrared spectroscopy	
– Output impedence	
– Paradoxical septal motion	
– Pulse wave Doppler velocities of right ventricle outflow	
– Pulse contour analysis,	
– Pulse analysis of the arterial pressure	
– Pericardial fluid assessment	
– Pulmonary artery diastolic pressure	
– Pulmonary artery mean pressure	
– Pulmonary artery occlusion pressure	
– Pulmonary artery systolic pressure	
– Pulsed wave Doppler recorded in upper left pulmonary vein	
– Pulse pressure variations	
– Respiratory systolic variation	
– Right ventricular end-diastolic area	
– Right ventricular elastance	
– Right ventricle outflow Doppler patterns	
– Restrictive flow (E/A ≥ 2, DTE < 120 ms) at the pulmonary vein	
– Systemic resistances	
– Systolic fraction of the pulmonary vein flow	
– Systolic blood pressure	
– Systolic pressure variation	
– Stroke volume variation	
– Sublingual capnometry	
– Superior vena cava collapsibility index	
– Respiratory variations of maximal Doppler velocity of aortic blood flow	
– Urine output	

[a]Usually decided from two-dimensional left ventricle analysis
[b]Usually deduced from other parameters

currently missing [31]. Most techniques have drawbacks [50]. See Table 23.2. Every point can be debated, even the place of familiar parameters such as cardiac output – since it is not universally admitted that targeting it affects a patient's outcome [51], up to expert opinions not recommending its routine measurement [52].

The confusion increases when we consider complex disorders of septic shock, where microcirculation alterations, capillary leak, interstitial and endothelial cell edema, hyperchloremic acidosis, coagulopathy (etc.) are mingling; time for multiple organ failure [53, 54]. In this setting, it is not even clear whether the tissues really require supplementation with oxygen. Knowing at any price that the cardiac output of a given shocked patient increases under fluid therapy is questionable if it is of little benefit to this patient. The confusion now worsens with the recent recognition of the old concept of abdominal compartment syndrome [55], which is increasingly taken into consideration [56]. For septic shock (a main part of this chapter), we will consider the step of admission for which the question of fluid therapy should not be raised [57], i.e., time for urgent and liberal fluid therapy (but nobody specifies up to what quantity). We will then consider the step in the ICU [58] for which the effects of excessive or insufficient fluid therapy create daily occult changes leading to microcirculation disorders, with the evidence that when they are present, the usual strategies for hemodynamic optimization are of limited efficiency [59].

The question of hemodynamics fills the intensive care congresses with complex discussions and pro/con debates between venerable experts. The struggle for or against PAC, TEE, PICCO, etc., comes to a chronic state, whereas new methods appear each day. But all this creates a dynamic concert favorable to exciting brainstorming.

We fully understand that simple ultrasound is introduced in a delicate setting, still open for some [60], but not for others who found solid solutions [61]. While carefully listening to all positions, we feel free to think that any new idea that can find a place in this symphony should be carefully considered – if it can provide any minor help, or more. Our idea is to take, again, our 29-cm-wide, gray-scale ultrasound unit with our simple microconvex probe, the one which we have used already for making hundreds of life-saving applications.

Can a different approach be considered for the long-standing problem of hemodynamic therapy?

Can our beloved principle of simplicity be used in such a complex field?

How Can the Problem of Hemodynamic Therapy in the Critically Ill Be Simplified?

An anxious intensivist willing to using all available tools for active management of a shocked patient would benefit from an impressive list of data (Table 23.1 *left*). Hemodynamic assessment is a complicated field since no direct parameter is available.

We also consider discussions about disobstructive therapies. Embolism and tamponade are not really in focus, since simple ultrasound made the diagnosis, and nothing but a specific therapy can withdraw the obstruction. In addition, we do not consider specific therapies of sepsis (hemofiltration) that are not obtained from technical hemodynamic measurements.

The common bond between the numerous data of the left part of Table 23.1 is the precise moment where the physician gives instructions to the nurse. Suddenly, complex things become extremely simple. An impressive list of data is reduced to a surprisingly simple range of decisions, as shown on the right side of Table 23.1. The information the nurse needs is not

Table 23.2 Drawbacks of some methods, comparisons

	Cost	Invasiveness	Technical easiness	Monitoring possibilites	Overall length[a]	Direct approach to pulmonary edema
PAC	Moderate	High	Relative	Yes	Long	No
TEE	High	Relative	Long training	Limited	Long	No
PICCO	Relative	High	Easy	Limited	Long	No
Our limited investigation	Low	Nil	Easy	Easy	Some min	Yes

[a]Including sterilization, dressings to the patient, etc.

about the value of the left ventricle end-diastolic pressure, etc., but, pragmatically, which therapy she must quickly initiate. There are not many (Table 23.1 *right*). The nurses's choice is between volumic, inotropic, and vasoactive agents.

Just three options.

Whatever the sophistication of the methods used initially, only these three options are available for improving the circulatory status. And now, one can simplify again the debate. The intensivist must document:

Step 1: The inotropic needs. This is accessible thanks to simple cardiac sonography.

Step 2: The needs in fluid therapy (see below).

Step 3: The resistance values, not directly measured, but inferred from the two previous steps.

As can be seen, what only remains from the hemodynamic debate is reduced to the need for fluid therapy. This is a major step, which raises the heaviest issues since no gold standard can be considered [62]. Although it is agreed that early and massive fluid therapy is beneficial in septic shock [57], physicians do not possess the key indicating the endpoint. They hesitate to provide too liberal fluid therapy, fearing pulmonary edema – one of the main issues [63].

Therefore, tools have been developed for identifying those who will increase their cardiac output by more than 15%. Those who do not would have only the risk of pulmonary edema, for no benefit. This originated the concept of fluid responsiveness [29, 34, 41, 64–66]. This fundamental and elegant concept is based on a solid physiopathologic approach of fluid dynamics, and is used daily for anticipating lung damage due to ineffective fluid therapy. It has one drawback, however: it is not able to demonstrate this lung damage. Consequently, the initial volume of fluid is given blindly.

We all admit that no isolated, static parameter measurement of preload status is valuable for predicting fluid responsiveness [67]. This assumption acknowledges the fact that we do not have the direct parameter – the one which tells us that we create damage to the interstitial tissues, lung first. Fluid responsiveness was a concept possibly created for lack of anything better. This is, for sure, one of the best approaches. Yet like the many other available tools (pressures, Doppler, PICCO, etc.), it does not take into account the lung tolerance to fluid therapy. All give indirect data.

To our knowledge, two major questions did not receive clear scientific answers.

1. What is the lung tolerance, its capacity of receiving fluid therapy? Is fluid therapy risky for this given patient?
2. Once a fluid therapy has been initiated, how should the endpoint be determined when this given patient has received optimal fluid quantities?

This perspective was the starting point of our protocol of limited investigation considering hemodynamic therapy.

Our investigation is "limited." We are open to any criticism, but it should come from documented gold standards. Precisely, these gold standards are not available for the usual tools, and we feel therefore equal, so to speak. Our limited investigation does not aim at being compared with these techniques in terms of parameters (e.g., value, or evolution, of cardiac output, etc.) – this should be meaningless since our approach is completely different – but in terms of therapeutic choice. Our approach speculates that the intensivist is somehow blind in this most important step of the critically ill management (Appendix 1).

Our protocol proposes a direct parameter of volemia for giving a different vision, extracted from lung ultrasound. It considers also the pump (left heart systolic behavior). The pump and the oxygen extractor do the main work. In addition, we will consider the routes (vessels).

For performing our limited investigation (i.e., simple heart, lung, inferior *and* superior vena cava), our 5 MHz microconvex probe is usually perfect.

First Step: The Inotropic Option. The Place of the Simple Emergency Cardiac Sonography

The choice of the word "sonography" was made to avoid confusion between the traditional territories of "echo" (prestigious cardiac approach of the cardiologist) and "ultrasound" (abdominal approach of the radiologist).

In the BLUE protocol (acute respiratory failure), the heart analysis was not included. In acute circulatory failure, it holds a major place. We use the best of Chap. 20 on the heart that we wrote in our 1992 edition, pages 125–136. The left ventricle hypo-, normo- or hypercontractility can be measured or roughly appreciated – one admitted step toward simplicity. In acute circulatory failure, left ventricle hypocontractility, either from

cardiogenic or septic shock, invites inotropic support [68]. A normal or exaggerated contractility suggests that the inotropic option is not to be considered, and, according to the principle of the communicating vessels, that the probability increases for the remaining options: vasopressors, fluid.

The left heart volume can be measured, but see below.

The right ventricle volume gives also basic information. Small, it suggests hypovolemia. Enlarged, it suggests pulmonary embolism (or fluid overload, or respiratory disorders more usually found in acute respiratory failure).

Pericardial tamponade is not in our protocol, since this (rare) disorder is immediately seen. This is not really part of the usual debate of hemodynamic assessment.

At this step, interestingly, we did not yet have to push on the Doppler button.

Second Step: The Fluid Option. The Place of the Fluid Administration Limited by Lung Sonography – The FALLS Protocol

Now we consider the question of giving fluid or not.

The heart is a traditional site for answering this question. We have respected this vital organ by dealing with it first. Yet looking at the heart dimensions (or Doppler values of restrictive flows) to determine the volemic status may appear to be an indirect approach. Our limited investigation considering hemodynamic therapy suggests to place lung ultrasound immediately after the simple look at the heart.

We present a direct parameter for assessing volemia.

In the crucial minutes of shock management, the main danger of inappropriate fluid therapy is drowning the lung with excessive fluid. Yet the other major risk is to keep the patient under deep occult hypovolemia, especially if vasoactive drugs are initiated.

The artifact analysis is helpful in this field for separating those lungs that are dry from those that received too much fluid.

Chapter 17 showed that interstitial edema was an accurate application of ultrasound [69] with practical clinical uses [70,76]. We now study the role of the lung rockets for assessing the lung tolerance to fluid therapy, i.e., fluid administration limited by lung sonography – the FALLS concept. It allows one to answer to these two basic questions, which we purposefully recall. Can fluid therapy be initiated in this patient? If yes, can the endpoint, where the risk is superior to the therapeutic aim, be determined?

Reminder of Our Study

The Swan-Ganz catheter used the pulmonary artery occlusion pressure, or PAOP [1,71]. The PAOP provides information on left ventricular end-diastolic pressure [63,71–73], which classically guides fluid therapy [74] and defines risk for hydrostatic pulmonary edema [63,75]. A prospective study compared lung ultrasound and PAOP value (Appendix 2). We slightly adapted the nomenclature of the BLUE protocol [76], defining the A-predominance as predominant areas of A-lines in Stage 1. An A/B-profile (unilateral lung rockets, unilateral A-lines) was classified as A-predominance. The B-predominance was defined as predominant areas of multiple B-lines in Stage 1. The notion of C-profile and lung sliding was not integrated, for simplification. The probe was applied on the BLUE points using the Carmen maneuver.

Our data (Fig. 23.1) showed that for a PAOP value ≤ 18 mmHg, the A-predominance had a 98% specificity and a 97% positive predictive value (sensitivity was 50%, negative predictive value 24%). For those interested by a value of PAOP ≤ 13 mmHg, the specificity was 93% and the predictive positive value 91% [77]. Multiple B-lines were seen in a wide range of PAOP value, precluding conclusions on this value.

Pathophysiologic Basis of the Concept of Fluid Administration Limited by Lung Sonography

Schematically, B-lines correspond to wet lung, i.e., pulmonary edema, from hemodynamic (with high PAOP) or permeability-induced (with low PAOP) cause, whereas A-lines correspond to dry lung.

Pulmonary edema combines respiratory and hemodynamic phenomena. Acute hemodynamic pulmonary

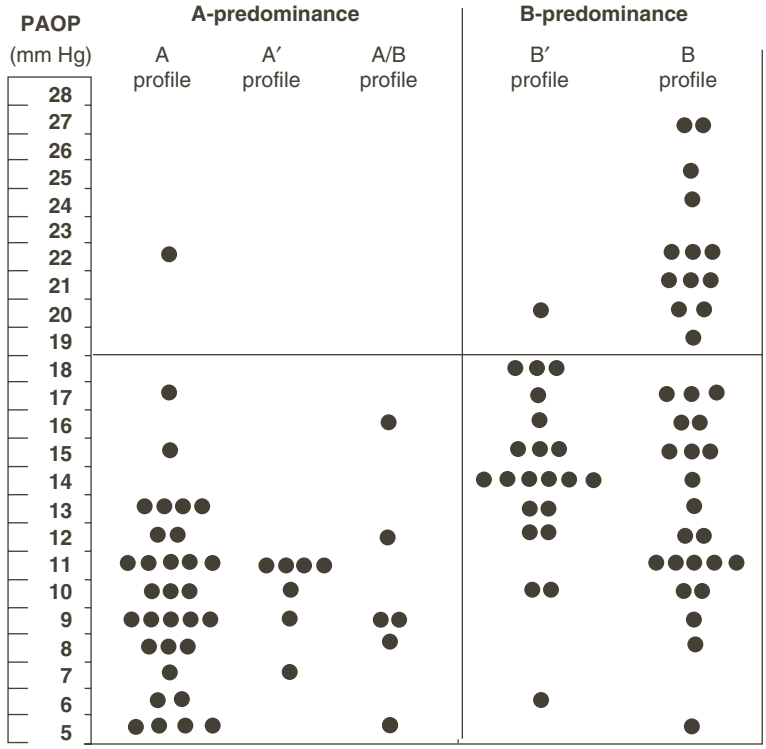

Fig. 23.1 Lung ultrasound and PAOP. This graph indicates a quasi-desert area in patients with low PAOP and absence of B-predominance. As expected, B-predominance, indicating either hemodynamic or permeability-induced pulmonary edema, is seen in high and low PAOP (From Chest 2009;136:1014–1020)

edema constantly yields increased PAOP with constant interstitial edema [63, 78, 79], a *silent step* that precedes alveolar edema [80, 81]. We remind the reader that the excess fluid first accumulates along the interlobular septa, a part of the interstitial lung tissue which is not involved in gas exchanges: they occur at the alveolocapillary membrane [82]. The fluid under pressure reaches the nondependent, anterior septa. When lymphatic resorption capacity is exceeded, fluid pours into the alveoli [83, 84]. This step initiates alveolar edema, with clinical signs (dyspnea, rales), radiologic changes and gas exchange impairment, i.e., the step that no intensivist wants to reach. Ultrasound interstitial edema is present before this step.

The FALLS protocol benefits from a double level of dichotomy, which makes the approach providentially simple.

1. There is no intermediate state between the A-line and the B-line. A-lines are dichotomous to B-lines, without space for other patterns (after 19 years of observation). This clearly demonstrates that the B-line is generated all of a sudden – like an umbrella when we push the button. This allows a dichotomous triage.
2. Observation in our critically ill patients shows that, in a wide given territory (lateral, anterior), there is little space for intermediate, patchy patterns. Under the influence of hemodynamic changes, many septa are simultaneously invaded by the hemodynamic edema. Focusing on the anterior area in a critically ill patient, lung ultrasound offers a qualitative, dichotomous approach: A-predominance versus B-predominance.

Clinical Implication of the FALLS Concept

Lung ultrasound indicates that the subpleural interlobular septa are saturated, allowing the physician to benefit from a step ahead for limiting fluid therapy, in other words, from a *safety margin* (Fig. 23.2): a notion similar to Guyton's concept of a safety factor but using more modern tools [83].

In a patient with acute circulatory failure, an A-predominance does not indicate that this patient must receive fluids. It indicates that he or she *can*. Even though this notion does not appear academic,

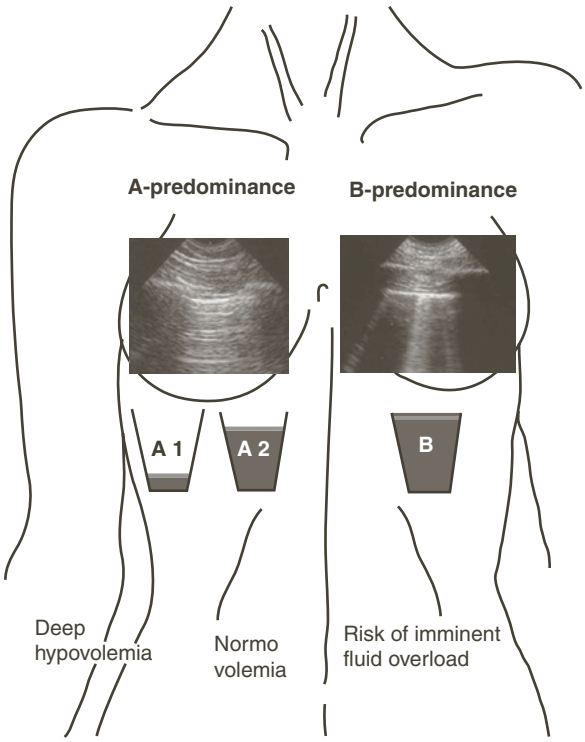

Fig. 23.2 The FALLS protocol. The patient's right lung shows an A-profile, supposed to be bilateral. The FALLS concept invites to consider a patient in circulatory failure with such a profile as able to receive fluid therapy. The left lung is an image of the same patient arriving at the interstitial step under fluid therapy. This step does not provide alveolar edema, and invites limiting fluid therapy. But possibly the patient improved meanwhile. The three containers, schematizing three volemic states, summarize the spirit of the FALLS protocol. Glass *A1* indicates deep hypovolemia. Glass *A2* is probably the ideal volemia. *A1* and *A2* give an A-predominance. Glass *B* indicates that the endpoint has been reached. Here, additional fluid can overflow. The aim of the FALLS protocol is to avoid situation *A1* (deep hypovolemia) and to stop at situation *B*. The image displayed (right lung A-lines, left lung B-lines) would be an example of an A/B-profile in the BLUE protocol

it refers here again to the Grotowski law, which we use daily to make a more simple and efficient medicine. Using the principle of the communicating vessels, a shocked patient who can receive fluid is possibly a patient who needs fluid. Since a cardiogenic shock has been excluded (using left ventricle contractility and mostly the notion of A-predominance), the probability of the few other options for shock management is increased.

Initiating a fluid therapy with an ultrasound probe in the hand, the physician enters into the FALLS protocol. Two events can occur.

1. Under fluid therapy, the shock decreases (mottles vanish, urines appears, etc.). The fluid therapy can be interrupted. The target was reached, correcting the clinical signs of shock while remaining in an A-predominance.
2. Under fluid therapy, the shock resists. Eventually, a B-predominance is detected, replacing the A-predominance. This recent interstitial syndrome *likely* indicates acute interstitial edema, i.e., *likely* hydrostatic edema: the endpoint has been reached (or another explanation should be provided). This is the time to stop fluid therapy and read below about vasopressor use.

This setting does not regard cardiogenic shock, where the B-profile is common on admission, helping in addition in the diagnosis [76].

Lung ultrasound is nicely positioned to safeguard against the use of abusive fluid administration, a detail that cannot be achieved by using PAC, PICCO,TEE, or any traditional tool (CVP, etc.). In reality lung ultrasound provides this direct indicator of interstitial edema, i.e., the initial anatomic disorder of the fluid overload, as a rule radio-occult. The main advantage of the FALLS protocol is to provide a parameter that is not only direct, but above all completely independent from all the limitations of the other methods (needing subtle calculations, ponderations, consideration of transmural pressures, cardiac rhythm, etc.). In this respect, maybe lung ultrasound allows to better approach the value of the capillary pressure, a basic value that PAOP tries to reflect.

We have used the FALLS protocol since 1996, as derived from our 1994 publication on pulmonary edema, and described in our 2002 edition [85]. Page 130 inspired cardiologic settings, where the label of "lung comets" appeared. Comets or rockets are not the main problem, provided the same notions are used with homogeneous description. Our study focuses on critically ill patients and uses a dichotomous protocol that allows to define in a few seconds a characteristic profile, considering a limited, anterior, chest area. The comprehensive counting of B-lines, a fastidious task, can be interesting for subtle results in non-time-dependent patients.

Additional Interest of the FALLS Protocol

Three good reasons can be considered.

1. The learning curve is short (90 min for a 95% efficiency).
2. A few seconds are sufficient for initiating a therapeutic decision (finding an even unilateral A-profile indicates the A-predominance).
3. The suitable machine is simple and cost-effective, thus acquired in a few months.

Limitations of the FALLS Concept

Lung rockets seen on admission can be related to hemodynamic or permeability-induced pulmonary edema, or to rare chronic interstitial diseases. To keep this chapter simple, we do not consider the potential of the B′-profile. Particular cases of patients in hypovolemic shock displaying B-lines or particular cases of massive pulmonary edema can benefit from fluid therapy: suddenly acquired white lungs can obviously coexist with severe hypovolemia (communicating vessels). Usually, a B-profile present on admission is a limitation since the PAOP cannot be appreciated. Here, our limited investigation begins with caval veins analysis.

The present approach is qualitative. We did not focus on the posterior B-lines, since they may indicate gravitational changes [82]. For lateral changes, see below.

Seven Anticipated Questions Regarding the FALLS Protocol

1. What about using the PAOP as a reference value?

This choice can be debated, although regularly advocated [75,86]. PAOP values do not reflect left ventricle performance, such as stroke volume index, cardiac index, the fluid responsiveness [18,74,87–91]. Yet, see above our comments about the limitation of the concept of fluid responsiveness, as regarding lung tolerance to fluid therapy. Obsolete or not for reflecting downstream pressures, the PAOP still indicates the risk of pulmonary edema. For many, the PAOP remains a precious tool, valuable when restrictions are applied (as for any technique), and is missed by numerous physicians who are now devoided of the Swan-Ganz catheter but have no access to TEE. Our approach will be appreciated by those intensivists who envision fluid therapy based on low PAOP values and consider that the concept of a safety factor provided by lung ultrasound is logical.

2. When a B-profile appears, is not the heart already on the flat slope of the Starling curve?

We assume such a question may concern readers. Filling a shocked patient and creating a B-predominance means probably that the heart initiates difficulties, even if gas exchange is not yet impaired.

The first question should be to assess whether the danger is real (and not hypothetic) using well-profiled studies. Simply note that physicians who make a fluid responsiveness maneuver usually do not check for the absence of initial B-profile.

Second point: apart from stopping fluid therapy, purists would appreciate being able to withdraw the slight excess of fluid. Several solutions are available. A traditional hemodiafiltration is one of them, but such a heavy maneuver for withdrawing so little fluid would be questionable. Our solution is to ask to the nurse, simply, for some blood tests. Especially lactic acid, an excellent marker of the evolution of shock, but also some hemocultures – several in fact, enough for "cleaning" the B-lines, initiating a modest but genuine *blood-letting* – this was, at the time of Molière in the 1630s, the acknowledged – (and efficient) therapy of fluid overload (the French term was "fluxion de poitrine"). Our suggestion may appear provokative at the modern era of recombinant human activated protein-C therapies and multibeam transesophageal echocardiography. Some would find it questionable to withdraw blood in a patient with, for instance, hemorragic shock. This kind of patient will not, precisely, have a B-predominance: our FALLS protocol will improve the patient's condition, *before* the endpoint is reached. The third solution, for those who would be reluctant to withdraw any blood volume, is the extended FALLS protocol: simply raise passively the legs of your patient with the A-predominance, check that this maneuver does not generate a B-predominance, then fill the patient, until a B-predominance appears, and then lay the legs down again. Using simplicity, the extended FALLS protocol allows noninvasive optimization of volume therapy.

The advantage of our concept is that this patient receiving fluids, initiating B-predominance, and benefiting from a slight blood withdrawal would be perfectly

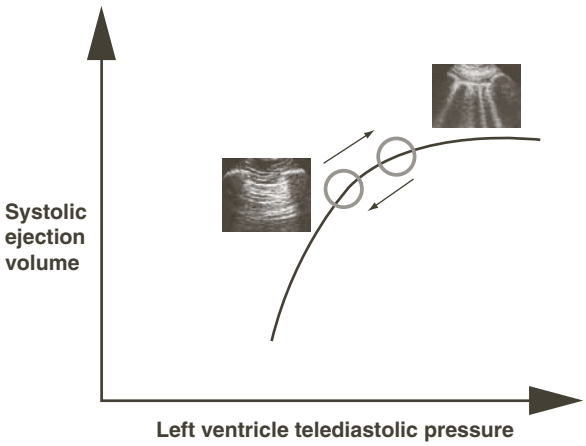

Fig. 23.3 FALLS protocol and cardiac function curve. Since the fluid therapy is controlled by the physician, the moment where a B-predominance appears can be considered as a low point in the flat portion of the ventricular function curve (*upper target*). A minimal fluid withdrawal will move the target to the lower point (*lower target*), i.e., the ideal portion

positioned in terms of volemia: just before the flat portion of the ventricular function curve (Fig. 23.3). We speculate it will improve the overall prognosis of shock.

3. How will the FALLS protocol work in massive pulmonary embolism?

In this setting, no therapy, but disobstruction, is a solution. Fluid therapy is often considered to be double-edged, and many recommend modest volumes – in order to avoid septal interference with hindrance to left ventricle filling. Is the limited investigation failing in this case, in the first minutes when the diagnosis is still uncertain? It could be argued that the balance between the advantage offered by the fluid therapy and the drawback linked to the impairement in cardiac output has not been assessed. More pragmatically, we speculate that a left ventricle failure induced by septal interference will have one consequence: an increase of the LV pressures, even slight if there is an upstream limitation of pressure, but which will spread to the left auricle, the pulmonary veins, and eventually the pulmonary capillaries – an increase of pressure sufficient for initiating a mild interstitial syndrome – the one which is precisely detected using ultrasound.

See also the Section Synthesis.

4. Why not search for lateral, or even posterior B-lines during fluid therapy?

Why not, in actual fact? The FALLS protocol was our first step, for sharing a simple message. Yet it can be sophisticated since lateral approaches will inform on even lower values of PAOP.

5. In the Fig. 23.1, the B′-profile seems associated with a low PAOP. Can this be exploited?

The mechanism of the abolition of lung sliding is explained on page 192. Standstill lung rockets are a sign allowing distinction between hemodynamic pulmonary edema and ARDS. For simplifying (and favoring the acceptance of our manuscript), we did not bring this item on the first line, but further studies will assess the potential of this isolated finding – in the setting of hemodynamic therapy.

6. But how about the cardiac output? Can one really manage a critically ill patient without this fundamental parameter?

Without a problem. See Table 23.1 and consider first that the nurse, who does the major work, will take advantage of not knowing the cardiac ouput, but one of the three-oriented actions (fluid, inotropic, vasopressor). We assume that knowing the cardiac output will not change the decision tree of our limited investigation, but we are open to comparative studies (using a solid gold standard). Meanwhile, we strongly assume that patients with an acquired B-predominance will no longer increase their cardiac output (and will be nonresponders, to use traditional wording). Consider again that the very value of the cardiac index in a given septic patient can be meaningless: for instance, high, but not high enough. Consider lastly that the cardiac output is supposed to be low (in absolute or relative values) in a shocked patient – this does not really inform on the mechanism of the shock.

7. And how about the right ventricle status?

The FALLS-protocol privilegiates - apparently - the left circulation, assuming the major problem is pulmonary edema. What happens if the weakest pomp is the right ventricle? Fluid therapy is supposed to make more harm than good (septal interference, conduction troubles). The FALLS-protocol has anticipated most issues. In the case of ARDS, the usual presence of B-lines decreases the problem (see heading Limitations of the FALLS-concept). Major septal interference will theoretically create a B-profile (see Question 3 just above). In the case of post-operative opened pericardium, or primitive pulmonary hypertension, two rare settings where right ventricle dilatation can be major, particular care is given to this analysis, precisely obtained from a simple, two-dimensional approach, i.e., exactly the spirit of the Limited Investigation. Yet there is no drawback here to associate traditional hemodynamic tools, time permitting, choosing among invasive and less invasive ones.

Note

Until now, Doppler was not used. We are still using our simple gray-scale unit.

Second Step of Our Limited Investigation if the FALLS Protocol Cannot Be Applied: Caval Vein Analysis – (1) The Inferior Caval Vein (IVC)

If a B-predominance, associated with absence of ventricular dysfunction, is present on admission, the lung cannot be used for guiding fluid therapy (for simplifying, we do not evoke the case of standstill lung rockets). We here use the venous tool. It is not a direct parameter for assessing the endpoint for lung tolerance. Yet for figuring out a volume, i.e., the volemia, measuring dimensions of a vessel that drains half of the venous return is clearly more direct than pressures (CVP, etc.). Remember that 65% of the systemic blood circulates in the venous system.

A fast assessment of this area was long suggested [92] and is the focus of Chap. 13 in our 1992 edition. The IVC was the privilege of our unique work cosigned by François Jardin. In this study, we compared the IVC with the CVP. A caliper <10 mm was correlated with a CVP <10 cm H_2O with a 95% specificity and a 84% sensitivity [92]. The correlation was narrow with small caliper values (Fig. 23.4). IVC caliper changes proved parallel to CVP changes, under fluid therapy (Fig. 23.4). Some works conducted in this field came from cardiology [93–95], studying ambulatory, spontaneously breathing, laterally positioned patients (the weight of the liver possibly squashing the IVC), measuring at the hepatic vein level, making comparison difficult. The study by Jue et al. [96] dealt with ventilated patients, showing that a caliper <12 mm always predicted a CVP < 10 mmHg.

Measurement Technique and Observed Patterns

A transversal scan at the epigastrium in a supine patient immediately detects the IVC. We found the left renal vein to be a reproducible landmark, making in addition the measurement remote from the frequent hepatic bulge (Fig. 23.5). This level produces our correlation with the CVP [97]. Measurement should be from face to face (not from border to border), on expiration (see below). An indexation with surface body is risky (meaning weighting unstable patients on admission) and useless (IVC dimensions are not correlated with the patient's size according to Sykes' study of 1995).

The caliper normally increases on inspiration in ventilated patients because the positive thoracic pressure slows down venous return. It decreases in inspiration in spontaneously breathing patients because the negative thoracic pressure attracts the flow. The expiratory caliper is almost unmodified after intubation and sedation, as opposed to inspiratory caliper. The collapsibility index – in spontaneous ventilation – is now a popular datum [98,99]. Inspiratory collapse (Fig. 23.6) can be explained by hypovolemia, or dyspnea with use of accessory respiratory muscles, since

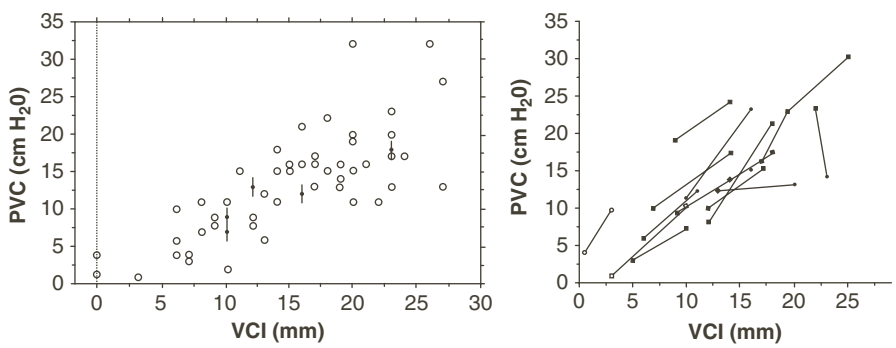

Fig. 23.4 IVC and CVP. *Left*: Correlation between expiratory caliper of the IVC (*VCI*) at the left renal vein and CVP (*PVC*) in 59 ventilated patients. *Right*: Caliper of the IVC when the CVP is altered

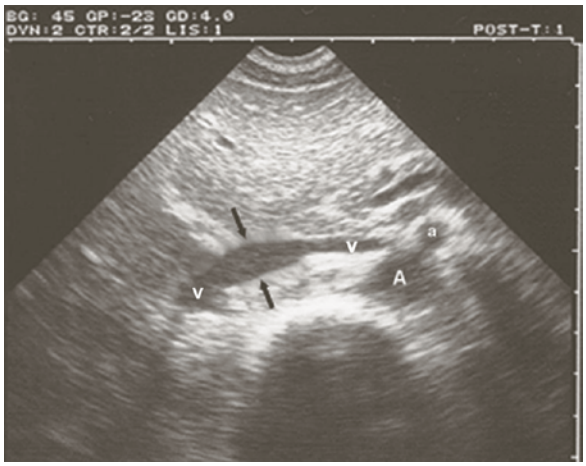

Fig. 23.5 IVC and left renal vein. This transverse epigastric view shows the point of arrival of the renal veins (*v*). The left renal vein (*v*) is particularly visible, passing between the aorta (*A*) and the superior mesenteric artery (*a*), the point where we measure the IVC caliper. Here, an expiratory caliper of 8 mm (*arrows*) indicates low CVP. Note that these *arrows* follow the slight obliquity (20°) of the vein, in order to have a meaningful measurement. See the renal veins in frontal view in Fig. 13.1 page 100

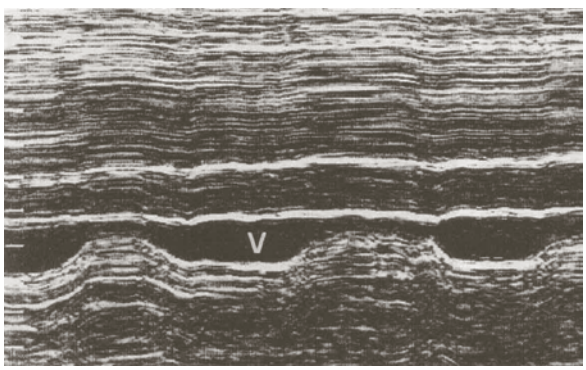

Fig. 23.6 IVC in M-mode. Inspiratory collapse of the IVC, showing a 12-mm diastolic caliper (*V*) that collapsed to 4 mm at inspiration in a spontaneously breathing patient with major bleeding

the inspiratory collapse of thoracic pressure creates aspiration of the systemic blood, with Venturi effect. This situation is striking in acute asthma (where fluid therapy is not contraindicated).

A flattened IVC in a shocked patient indicates low CVP (Fig. 23.5). We consider an irregular, moniliform profile as low caliper (Fig 23.7). An enlarged expiratory IVC (see Fig. 7.5 page 55) is seen in right heart failure or hypervolemia, or it can again be normal, and is sometimes seen with low CVP (Fig. 23.3).

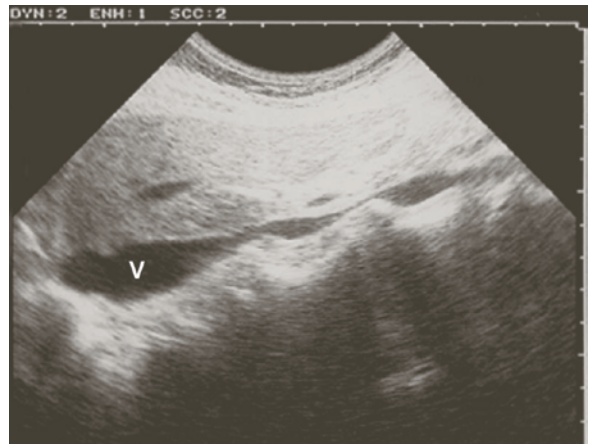

Fig. 23.7 Moniliform IVC. Irregular pattern, mostly collapsed. Supposedly hypovolemic patient. Note the bulge (saber profile) at the left of the image (where the letter *v* is located): the area where precisely we do not measure IVC caliper

Usual Errors Seen

(1) Making abdominal compression for hiding the gas decreases the IVC caliper. (2) The hepatic vein syndrome: we often see colleages measuring an hepatic vein instead of the IVC (see Figs. 4.2 and 4.5 page 28). (3) The palsy syndrome: the hand of the operator seems stuck to the heart, unable to make a slight movement for getting far from it. It is usually seen in doctors trained only in echocardiography, and results in measuring the IVC too near to the heart. At this area, the saber profile (a bulge where the IVC receives the hepatic veins) is frequent (Figs. 23.7 and 4.2 page 28). Measuring at this bulge does not give our correlations. The IVC is an embryologic puzzle, with venous tissue near to cardiac tissue in this area. We were politely asked to publish using the bulging area, just near the heart, for the fear that getting far from the heart for a renal vein would frighten intensivists trained in echocardiography, but we did not think this was a fully scientific process.

Limitations

Considering a flattened IVC as a sign of hypovolemia is not correct. CVP values range normally from 12 to 0 mmHg. Although CVP has long be considered a valuable tool [48], considering the CVP as fully reliable would present the discordant cases as a failure of

ultrasound. CVP is a "dynamic" concept. Only its evolution is of consideration, meaning implicitly that an isolated measurement has a limited value. CVP has many constraints (definition and control of hydrostatic zero, supposed location of right auricle depending on habits, need for interrupting drugs flow for each measurement).

Caval Vein Analysis – (2) The Place of the *Superior Caval Vein (SVC)*

The IVC rapidly became a popular tool in many ERs. Then came the superior caval vein, which was nearer to the prestigious heart than the inferior caval vein, lost around stinking guts. In this respect, maybe the superior caval vein is superior. Its analysis has been shown to be of prime importance for diagnosing hypovolemia [27]. The message was obtained using TEE. Keeping our usual distance, since the gold standard is still not defined, we are open anyway to this elegant potential, taking once again our 5-MHz microconvex probe and just positioning it at the neck (Fig. 23.8). We obtain a noninvasive measurement that can be done successfully in a few seconds in roughly 75% of the patients. We benefit from at least one dimension from medial to lateral border (Fig. 23.8) and assess a possible inspiratory collapse. Only a microconvex probe has the ergonomy and the resolution suitable for this use. Correlations with the semi-invasive method (TEE) are ongoing.

The Place of Other Parameters

Our next edition will deal with still unpublished simple ultrasound data that may indicate whether the cardiac output is sufficiently increased, and mainly, whether it is in adequation with the tissular oxygenation – using a *direct* parameter. We will also deal with clues directly measuring (not inferring) the vascular resistances, at the bedside, which could prompt faster use of vasopressors.

The physical examination, which provides critical information, surrounds our limited investigation. Simple signs, such as capillary refill time, somehow forgotten since the advent of TEE, etc., can become really relevant.

The Last Step of Our Limited Investigation: Time for the Vasopressor Option

At this very step of our protocol, the inotropics were given or not, and the effective volemia has been optimized. Noting the patient as unresponsive, it is now

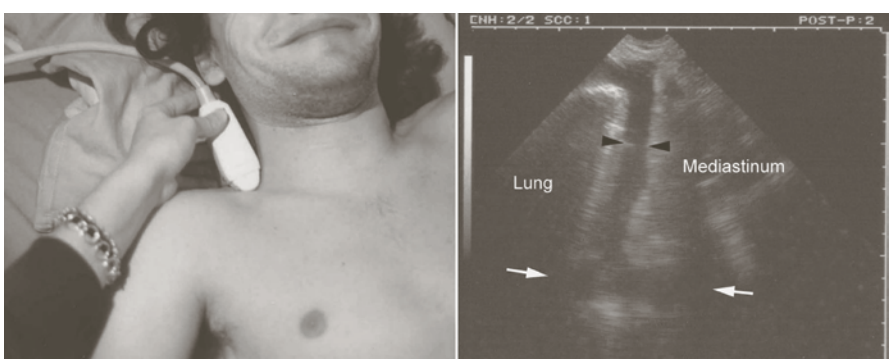

Fig. 23.8 Superior caval vein (SVC) without invasion. *Left*: This figure shows how we search for the SVC. In practice, we take the internal jugular vein in a transversal approach, descend to the SVC, then progressively position the probe parallel to the neck long axis. The rear part of the probe is slightly oriented backward for exposing the SVC. *Right*: The SVC (*arrowheads*) is seen through its entire length (8–9 cm) in this view. The right pulmonary artery posterior to the vein is a landmark *(arrows)*. The *arrowheads* indicate a 10-mm laterolateral caliper, information obtained immediately. Respiratory collapse can be detected. No probe but a microconvex one can be applied on such a narrow area and provide this image quality. This is an alternative for all those who cannot afford the transesophageal approach

time for initiating the vasopressor therapy – in a patient definitely protected from the side effects of vasopressors given in occult hypovolemia. The work of the limited investigation is, in principle, achieved.

A Synthesis of the Limited Investigation Considering Hemodynamic Therapy

The main words summarizing our limited investigation are simplicity, rapidity, and logic. In this time-dependent patient, time is lacking for sophisticated or academic considerations.

How do we proceed in practice? We are called at the emergency room, or we see a patient in our ICU suddenly worsening, with acute circulatory failure. Our machine switches-on in 7 s. The look at left ventricle contractility takes at best less than 20 s. The detection of A- or B-predominance takes less than 15 s. The venous analysis includes two distinct parts: caval veins analysis, facing a B-predominance, for assessing volemia. Or comprehensive venous analysis facing A-profile, dilated or nonaccessible right ventricle, for diagnosis of embolism. The venous analysis takes less than 150 s. The overall timing is ≤3 min. Since 1982, this timing has allowed the assessment of venous, inotropic, and pulmonologic targets (a VIP protocol, so to speak) in a logical, bedside management.

For simplification, we consider separately obstructive shock (only required disobstructive maneuver). The remaining options (not more than three) yield eight mathematical combinations (Table 23.3). Here is our schematic synthesis (Fig. 23.9).

Table 23.3 Combinations of therapeutic options in shock

Fluid therapy	Inotropics	Vasopressors	Mechanism of shock
+	–	–	Hypovolemic shock
+	–	+	Septic shock
–	+	–	Cardiogenic shock
–	–	+	Septic, vasoplegic shock
–	+	+	Septic shock with heart impairement
+	+	–	Sometimes considered but not fully logical option
+	+	+	Not fully logical option
–	–	–	Not an option, but a frequent reality (meaning also calling the family)

Cardiogenic Shock

Usually, critical ultrasound provides a consistent bunch of information. The association of a constant B-profile and left heart hypocontractility makes a rapid diagnosis in this shocked patient. There is no place for any FALLS protocol. If the intensivist decides to initiate fluid therapy, other rules should be followed. Subtle cases with valvular disorder or exclusive diastolic dysfunction will not be detected by our simple emergency cardiac sonography, but they will be suspected anyway using the B-profile. We remind the reader that the distinction between hemodynamic pulmonary edema and ARDS is accessible to lung ultrasound – especially facing B′-, A/B- and C-profiles, which are never seen in hemodynamic pulmonary edema. Read about the BLUE protocol, page 197 [76].

Hypovolemic Shock

A typical profile associates an A-predominance, small hypercontractile ventricles, and flattened caval veins. The FALLS protocol should be sufficient for giving appropriate fluid volume and relieving the patient before any B-predominance.

Septic Shock: First Hours

We deal now with the initial, early step, before things complicate. We must consider that our goal is to provide early and massive fluid therapy, in accordance with current knowledge [57]. Therefore, the FALLS protocol should be used as described, until the endpoint is reached. Note that septic shock makes a subtle setting. For the cardiac part, the contractility can be impaired. For the lung part, if a pneumonia is the cause of the shock, precisely with bilateral anterior pure interstitial syndrome, we face an obvious limitation of the FALLS protocol (not considering the case of the B′-profile, to simplify). The caval veins should here be on focus. Once the cardiac contractility and the volemia have been

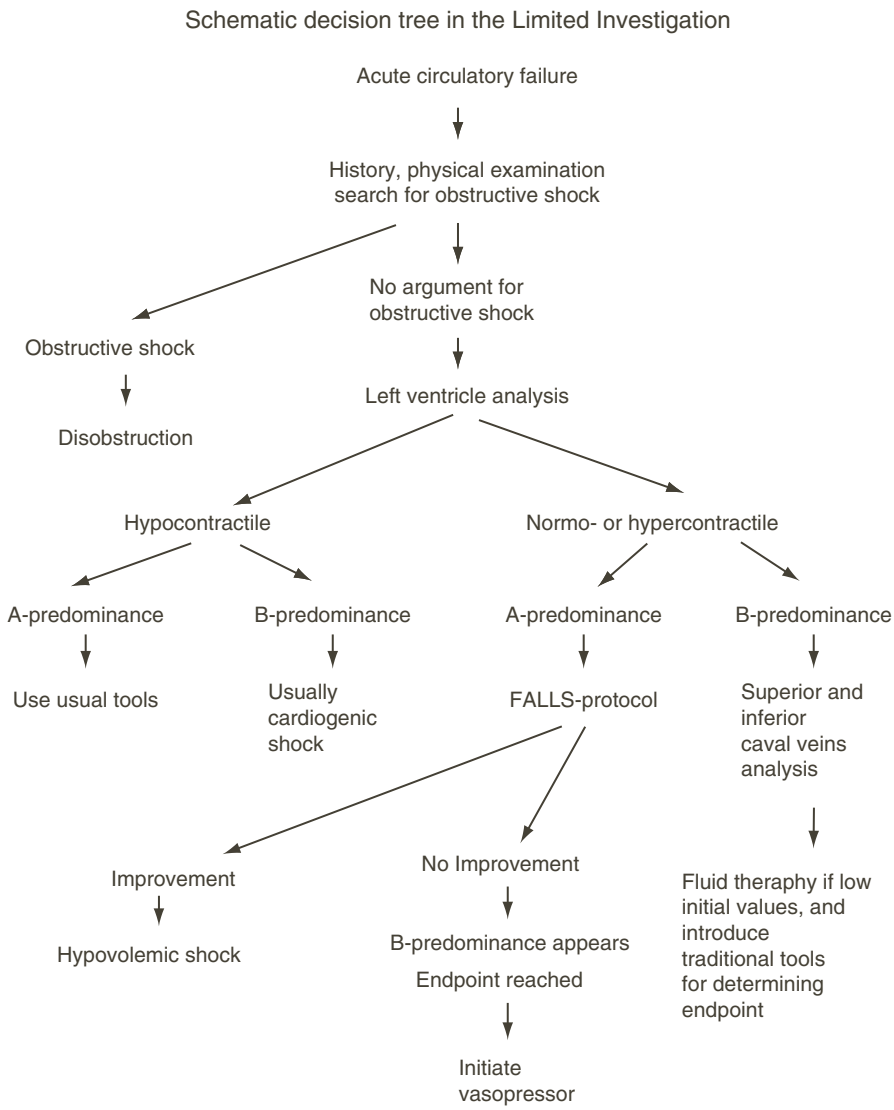

Fig. 23.9 The simplified decision tree of the limited investigation considering hemodynamic therapy. In order to make a readable decision tree, many branches were cut. Searching for obstructive shock is done using traditional cardiac ultrasound and/or the BLUE protocol. Withdrawal of fluid when the endpoint is reached (using blood tests or the extended FALLS protocol) is not featured. Impaired LV contractility and B-predominance can be seen in some cases of sepsis with ARDS

optimized, and provided the patient is not stabilized, this is time for introducing the vasopressor therapy.

Physicians long feared the side effects of vasopressors if hypovolemia was not corrected. Precisely, this will be well tolerated in those patients who have been "protected from hypovolemia" by the FALLS protocol. This is the major message of this chapter.

Septic Shock: Late Hours

Can there be a future for the lung approach in the management after the first 24 hours?

Here, the situation is more subtle, with microcirculation impairment, multiple organ failure, the period where the question is probably no longer about the quantity of fluid to administer, whatever the tool used for hemodynamic assessment. Since our limited investigation takes into account a direct parameter (interstitial saturation), nothing prevents the intensivist to, little by little, extend the patient management of the first hours to later hours. This debate will be passionate for sure. We assume that interstitial edema is an indicator of other organs edema, and may be of help for determining whether fluid therapy is toxic. Maybe B-lines could be this early sign predicting brain edema, or abdominal organs edema. In this eventuality, lung ultrasound would have a nice future in the late management of septic shock. We assume that the two cardiac pumps are symmetric, but if the right pump is the

weakest, signs of visceral edema should be taken into analysis.

Between protocols that are too soft, which keep the organism too dry, and ones that are too agressive, which drown the cells, the FALLS protocol may create the equilibrium possibly limiting the late complications. Cases of ARDS not displaying anterior B-lines may also benefit from this approach for detecting fluid overload [100].

Septic Shock: Golden Hours

Finally, what are these "golden hours," these decisive moments of management? Could an efficient fluid therapy of the first hours decrease the problems seen in the later hours, creating optimized conditions for a prompt recovery? Is the "golden place" in the obscure emergency room, or in the prestigious intensive care unit? We would appreciate a scientific answer, and hope to see improving prognosis of septic shock using well-profiled, randomized studies.

Obstructive Shock

The issue here was for a long time diagnostic, until portable ultrasound provided immediate diagnosis, since 1982. Once the obstructive shock is determined, the therapy is easy. Withdrawing fluid in a pericardial tamponade does not deserve extensive analysis. For pulmonary embolism, most of the cases are detected using *only* the BLUE protocol. It has demonstrated that, in a patient with acute respiratory failure, the combination of a normal anterior lung surface and a deep venous thrombosis has a 99% specificity for the diagnosis [76]. Therefore, the BLUE protocol can here be used as it is, especially since the right ventricle is not always accessible using transthoracic echo. This allows to envisage disobstruction (chemical, surgical, etc.) as the only logical therapy of this shock.

Here, the setting of circulatory failure is different from that of respiratory failure, although all intermediate cases can be seen. In pure circulatory failure, right ventricle enlargment gives a major supplementary argument. From the moment disobstructive therapy is initiated, fluid therapy (which was ordered in the first minutes of investigation by the FALLS protocol) has no raison d'être.

Case of a Patient in Extremely Severe Shock – The SESAME Protocol

The consideration of the lung as providing immediate hemodynamic information allows one to inverse some priorities. To lighten the present chapter, the case of imminent cardiac arrest is envisaged in Chap. 29 page 279. Briefly, our limited investigation is performed using a slightly different order: using the lung analysis (FALLS protocol) at first, to give after just a few seconds immediate instructions to the nurse, followed by simple cardiac sonography, becoming the SESAME protocol – a concept mingling mechanism and cause for the immediate diagnosis of shock. For instance, finding a hypercontractile left ventricle and/or massive peritoneal fluid yields the same reasonable conclusion: hypovolemic shock.

The Value of Our Limited Investigation Considering Hemodynamic Therapy

Mainly, it is to introduce for once a direct parameter, independent from the usual limitations of the traditional methods, allowing clearance for fluid therapy. We speculate that the major information provided by lung ultrasound is enough for counterbalancing the absence of Doppler data. We find here one more argument – not the least – for advocating our simple unit. Physicians already equipped with Doppler are free to combine both approaches.

One must accept that the validated concept of early and *massive* fluid therapy suppports our choice [57]. Unless solid gold standards invalidate the option of massive fluid therapy, the lung approach provides, in our opinion a unique and direct parameter for guiding our therapy.

How about comparisons? Our approach remains open to criticism, provided a consistent gold standard is proposed. We are currently planning a study in which one operator performs our limited investigation while a control operator prepares for a Swan-Ganz catheter insertion, or takes the TEE machine from the corridor. Not the data but the therapeutic options will be taken into consideration. Such a study will, for sure, raise methodological issues in order to correctly classify the discordant cases. The step for answering precisely this interesting issue will be to randomize the tools used and compare the duration of stay in the ICU.

Some History?

The authors have used their limited investigation since 1989 in a rudimentary way, which matured around 1996. Yet the main piece comes from the lung application. The authors had to stand countless rejections and wait the acceptation of several basic preliminary papers (from the description of the B-line [69] to its use in clinical settings [70] up to the BLUE protocol [76] and the neonate applications) before being able to submit the FALLS protocol. The authors made the decision to prioritize acute respiratory failure (since the conscious patient endures such suffering moments) and the neonate lung ultrasound (an absolute priority), with respect to acute circulatory failure, where the usually unconscious patient does not suffer. This choice created a huge delay for publishing the present information – but also an opportunity for other teams.

At last, the justification of lung ultrasound in the critically ill and the position of the author concerning simple equipment (without Doppler) find their place. Our limited investigation was an opportunity to prove that our simple gray-scale ultrasound unit of yesterday, without option (Doppler, etc.), is the stethoscope of tomorrow. The technology of 1982 allowed for a direct hemodynamic approach in the minutes following a patient's admission.

The Limited Investigation makes ultrasound a universal tool, suitable as well in a sophisticated ICU, as in less privileged areas of the world (see Appendix 3). The limited investigation yields not only decisions about the training and the material to use, but also the interest of simple whole body ultrasound as a definite tool for the critically ill.

The essential points of the Limited Investigation

The limited investigation considering hemodynamic therapy is a concept mixing a simple emergency cardiac sonography and a lung sonography called the FALLS protocol, basically.

1. The heart approach, mainly limited to left ventricle contractility, controls inotropic administration.
2. The FALLS protocol considers lung ultrasound artifacts as the direct data for indicating the stage where the fluid therapy should be initiated and interrupted.
3. When cardiac systolic function is optimized, and when fluid therapy has been optimized, if the patient did not initiate any improvement, this is time for ordering vasopressor therapy.
4. When the FALLS protocol cannot be applied, the analysis of the inferior and superior caval veins (first using simple equipment) is of value.

Appendix 1

Comments currently heard in our corridors:[a]

"This patient has already received 3,000 cc. I consider this is enough fluid."

"What is a good hemodynamic tool? It depends. Probably all of them. If you have a PICCO in your institution and not the other tools, you will use the PICCO. If you have two tools, you can choose, case per case. This given patient will be better assessed using a TEE."

" I don't believe too much in PICCO. What are my arguments? No precise argument, I just don't believe in it."

"I succeeded in maintaining this patient only at the price of massive doses of epinephrine and norepinephrine; he was definitely extremely severe."

"I lost this patient in spite of massive doses of epinephrine and norepinephrine; he was definitely too severe."

"Before sending the patient to CT (for a diagnosis), I stabilized him."[b]

" I don't care about the first value of this measurement (CVP, diameter, etc.). What I care about is the evolution under my therapy."

[a]All these comments have been heard, here or there (and even said by the young author). They are not inserted here in order to highlight the ignorance of certain intensivists, but rather to show, by the text, that the traditional tools are all indirect ones.

[b]Supposedly, blindly

Appendix 2

Methods and patients of the lung part of the limited investigation (Adapted from [77]):

A prospective 5-year study evaluated 102 critically ill ventilated and sedated patients (62 men, mean age 57, PEEP between 0 and 7 mmHg, mean tidal volume 7 ± 1 mL/kg, plateau pressure <32 cm H_2O, septic shock (n = 24), ARDS (n = 28), acute hemodynamic pulmonary edema (n = 13), severe trauma (n = 9), complications following various surgeries (n = 8), hypovolemic or anaphyllactic shock (n = 6), severe pulmonary disorders (n = 5), severe abdominal disorders or severe cardiac disorders or various (n = 9), with no case of pericardial tamponade) receiving a PAC in medicosurgical ICUs. Hemodynamic measurements were done at the discretion of the managing team faced with instability or complex hemodynamic situations.

The ultrasound operators, blinded to the hemodynamic measurements, checked for pressure head at the correct location, catheter line flushed, zero level, radiography, appropriate pressure traces surrounding balloon inflation. Only the PAOP curve displaying characteristic and logic curves (respiratory variations of PAOP remaining under respiratory variations of pulmonary artery diastolic pressure) was considered. The patients remained connected to ventilators.

Appendix 3

Application of the Grotowski law to the limited investigation considering hemodynamic therapy:

A shocked patient has spontaneously little chance to survive. Admitted into a hospital of any quality and taken in charge by an intensivist of any quality, the chances or survival dramatically increase, from zero to maybe 60% in low-level institutions (called B-series), and to 75% in the best institutions of the world, using TEE, etc. (called A-series). These numbers are the author's estimations. Accepting them, the differences between an A-series and a B-series ICU is roughly only 15 percentage points.

Let us suppose that a statistical study proves that, in a collective of shocked patients, systematic fluid therapy improves 51% or more of the patients – or the opposite, it will be concluded that these institutions would make more good than harm – or the opposite, in giving *systematic* fluid therapy. The 60% speculative rate is enhanced by one point.

Let us now introduce into these B-series institutions our simple gray-scale ultrasound unit. The simple analysis of the left heart contractility will give precious information on the need for inotropics, again enhancing the 60% rate by a few points.

Let us now introduce the FALLS protocol. Fluid given on the basis of A-predominance, and not given on the basis of B-predominance, would increase the rate of benefitial fluid administration – yielding additional points.

If we go on integrating simple data from our limited investigation, i.e., inferior and superior caval vein, etc., the B-series institution's performance would be enhanced by these four, five, or more percentage points of bonus. A question is now opened: up to how many points will these B-series ICUs be hoisted? Didn't they already reach the A-series ICUs? In this scenario, one speculates that, in those A-series ICUs, the definitive choice between either TEE, PICCO, PAC, or other tools will perhaps not be the critical point – as far as lung ultrasound is not used.

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Head and Neck

24

Here again, analysis of a field that is not yet routine in emergency ultrasound can provide unexpected services in the critically ill.

Using our compact unit and our 5-MHz 1- to 17-cm range microconvex probe can be sufficient and may be more useful, paradoxically, that some linear probes.

Maxillary Sinuses

Maxillary sinusitis is a familiar source of pneumonia in the ICU, in the ventilated patient [1], and a daily concern in the ER when meningitis is suspected. Radiographs with a vertical beam cannot detect air-fluid levels, whereas horizontal beam is not yet routine. The usual solution is, once again, referring the patient to CT. Once again, ultrasound will play a major role.

We saw in Chaps. 14–21 that ultrasound is able to cross the air. We will now see how it can cross the bones. The paranasal area is limited by the eye, the nose and the teeth. A (small) probe applied at this area shows an artifactual image. Yet this image is not an acoustic shadow such as with a bone, but a reverberation artifact, reminiscent of the pulmonary A-lines (Fig. 24.1, *left*). This proves that the bone is crossed, air then stops the ultrasound beam, generating this A-like line. This feature is explained because the maxillary bone is thin – as well as the scapula and iliac aisle. Let us now apply the probe on a maxillary sinus full of secretions: the exact image of the maxillary sinus appears, a pattern we suggested to call the "sinusogram" (Fig. 24.1, *right*).

The sinusogram can be frank: visualization of the three walls – two laterals, one posterior, all over the surface, and is called a complete sinusogram (Figs. 24.1 *right* and 24.3). It can be partial, i.e., visualizing only one wall, on a small surface, and it is then called incomplete sinusogram (Fig. 24.2).

It should be understood that, for providing a sinusogram, the fluid must be in contact with the anterior wall, which means, in a supine patient, complete opacification of the sinus.

We analyzed 100 maxillary sinuses in our ICU, comparing ultrasound with CT. For simple and clinically relevant correlations, it was necessary to use complex routes, comparing complete opacity with the air-fluid level, i.e., comparing sinusitis with sinusitis. The relevance of ultrasound is a function of the precision of the words used.

In a ventilated patient, a sinus can be normal, have mucosal thickening, have an air-fluid level, or be totally opaque. Only the last two need specific treatment.

"Pathological sinus" is a term referring to hypertrophy, the air-fluid level or total opacity on CT. This term is opposed to "normal sinus."

"Radiological maxillary sinusitis" is a term implying air-fluid level or total opacity on CT. This term contrasts with normal sinus and mucosal thickening on CT.

"Total opacity of the sinus" is a term implying a complete fluid accumulation. This term contrasts with "normal sinus," "mucosal thickening," but also with "sinusitis with the air-fluid level," a distinction necessary for precise data.

A dynamic maneuver means that the head, from the supine position, is raised in an upright position. The specification that no dynamic maneuver be done meant that the patients were studied with the head supine.

From these precise definitions, the 100 sinuses comprised 33 radiological maxillary sinusitis cases with 21 cases of complete opacity and 12 cases of abnormal air-fluid level, 14 cases of mucosal thickening and 52

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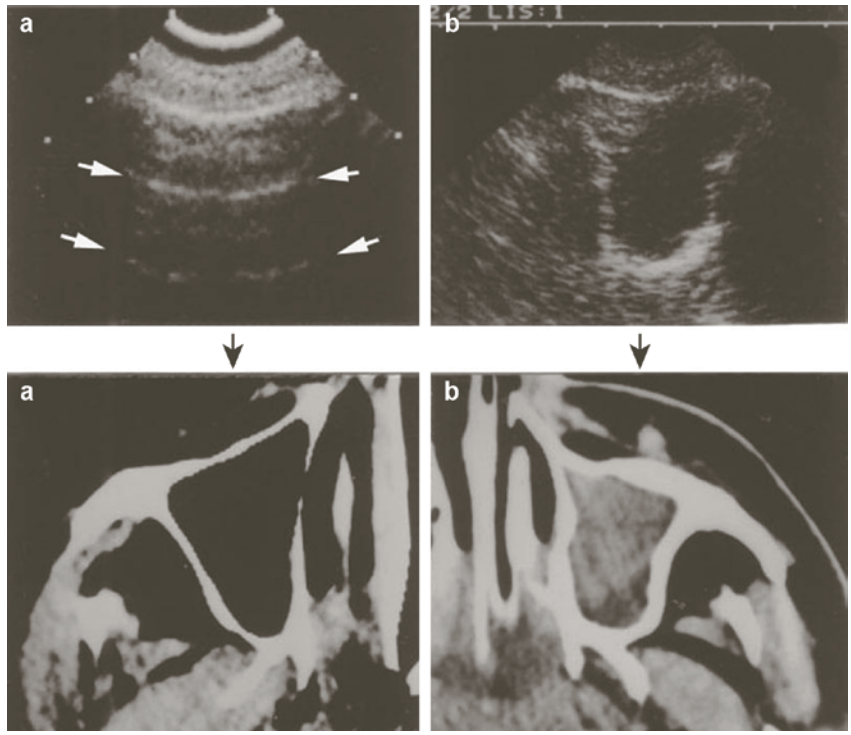

Fig. 24.1 The sinusogram. (**a**) Normal maxillary sinus. The ultrasound pattern (*top*) is made up of repetition artifacts (*arrows*), which indicate an air barrier. (**b**) Total opacity of the sinus. On ultrasound (*top*), the shape of the sinus is outlined: sinusogram in transverse scan. Note the frank pattern, which indicates the total opacity as seen on the CT scan (*top*)

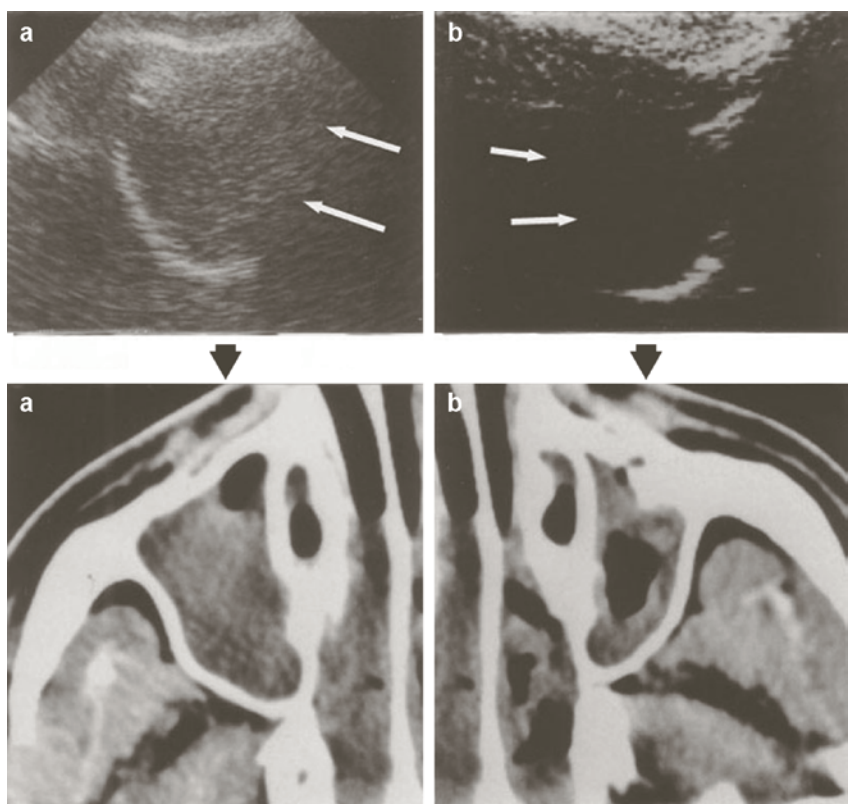

Fig. 24.2 Examples of incomplete sinusograms. (**a**) This image corresponds to subtotal opacity with a bubble trapped at the top. (**b**) This one is caused by substantial mucosal thickening. The *white arrows* designate the walls not visualized by ultrasound

normal sinuses. Ultrasound performance was as follows, with dynamic maneuvers not taken into account [2]:

1. A sinusogram diagnoses pathological maxillary sinus with a 66% sensitivity and a 100% specificity.
2. A sinusogram diagnoses radiological maxillary sinusitis (versus hypertrophy or normal sinus) with a 67% sensitivity and an 87% specificity.
3. A sinusogram diagnoses total opacity of the sinus, when compared with a partially opacified or mucosal thickening or normal sinus, at a 100% sensitivity and an 86% specificity.
4. A complete sinusogram (as opposed to incomplete or absent sinusogram) diagnoses total opacity of the sinus (if opposed to partial opacity, i.e., the air-fluid level, hypertrophy or normal sinus) with a 100% sensitivity and a 100% specificity (Table 24.1).

A sinusogram that is incomplete, or detected in a limited area, can indicate either subtotal opacity, with bubbles trapped against the anterior wall, or substantial mucosal thickening. In a supine patient, the absence of signal can indicate either a normal sinus or an air-fluid level which, although substantial, does not touch the anterior wall. When there is no signal, dynamic maneuvers (head erect) making a sinusogram appear (waiting a little since fluids can be viscous) improve ultrasound performance [3].

Unlike CT, ultrasound can differentiate tissue-like hypertrophy from fluid-like sinusitis (Fig. 24.3), a result CT rarely achieves. Like CT, ultrasound cannot predict the nature of the fluid (pus, blood, saline solution or any fluid). Ultrasound is being investigated to determine whether it detects the correct position of a sinusal drain by injecting sterile fluid.

Our data were preliminary and had the sole aim of describing a potential that seemed unknown. Consequently, time was not devoted to dynamic maneuvers. We found out later that that papers on the subject had been published previously [4, 5] (a detail that also escaped our reviewers), and we regret this lost time not invested on critical targets (lung, i.e., critical ultrasound). Now, this application has quietly developed in the ICU [6, 7].

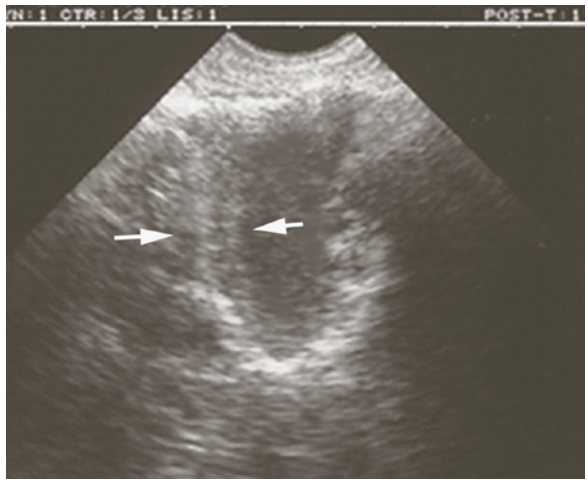

Fig. 24.3 Complete sinusogram. In this case of purulent sinusitis, a double pattern is visible: an internal anechoic area, an external hypoechoic regular frame 4-mm thick. This figure proves once again the superiority of ultrasound over CT, as it outlines this association of a mucosal thickening and a fluid accumulation

Optic Nerve and Elevated Intracranial Pressure

We deal with an old application that we described in our 1992 edition and never had time to submit.

Table 24.1 Ultrasound diagnosis of maxillary sinusitis

	Normal sinus	Mucosal thickening	Miscellaneous (large polyp)	Maxillary sinusitis (fluid level)	Maxillary sinusitis (total opacity)
Complete sinusogram	0	0	0	0	10
Incomplete sinusogram	0	8	1	2	11
No sinusogram	52	6	0	10	0

From Intensive Care Med 24:1057–1061

Principles

In any comatose patient, the question of elevated intracranial pressure should be raised. Sending any alcoholic coma or drug abuse to CT would not be realistic, but it would not be acceptable to miss a neurosurgical emergency in the same alcoholic patient (severe alcoholic states can create severe falls and easily break heads). The gold standard is the measurement of the intracranial pressure, using a direct transcranial device. This tool is invasive, needs a certain time, and does not seem to be perfect, in terms of practical efficiency, from various sources. One understands the potential interest of a bedside technique that would provide elements in a few seconds. The principle of using optic fundus examination was based on the fact that cerebral edema had a centrifuge extension along the optic nerve to the papilla, a clinically accessible area. Meanwhile, CT has replaced this antique examination, which was not sensitive enough. However, this means, once again, transportation of a critically ill patient, delay, etc.

The optic nerve is an evagination of the brain and is, therefore, surrounded by *meninges*. This space is normally virtual. It is logical that any increase in intracerebral pressure will distribute cerebrospinal fluid in all the possible centrifuge directions, including the optic nerve meningeal spaces, even a minute amount. The apparent caliper of the optic nerve will thus be increased. Like any macroscopic structure that is not surrounded by air or thick bone, the optic nerve is accessible to ultrasound. This is the opened door to a bedside immediate potential, with clear advantages:

1. Ultrasound provides in-depth visualization of the optic nerve, whereas optic fundus examination can only analyze the very end of the nerve. Ultrasound provides a *profile* view of the optic nerve, obviously more accurate that a simple *frontal* view that fundus examination provides. For comparison, for measuring the length of the nose, profile photographs should be more relevant than facial ones. The question now is: how far does this superiority of ultrasound over optic fundus bring ultrasound compared with CT in the search for elevated intracranial pressure?
2. Compared with optic fundus examination, ultrasound does not require atropine administration (time-consuming and possibly deleterious) and is not hindered by cataract.
3. It is a very simple technique. But does it really work?

Technique

The microconvex probe is applied on the eyelid, eye in the axis (for not scanning ocular muscles instead of optic nerve), eyes being closed. No pressure should be exerted on the eye so that any vagal reaction is avoided. As with any other examination, the probe is held like a *fountain pen*, the operator's hand lies firmly on the patient's face, and the probe is gently applied toward the eyelid. The progression of the probe ceases from the instant an image is obtained at the screen.

Technical note: an outside operator can withdraw the probe out of the operator's hand without effort. This is one way of knowing that the probe is correctly held – without any crispation.

Posterior to the eyeball, a sinuous hypoechoic tubular structure that is usually well outlined by hyperechoic fat (Fig. 24.4) is detected by slight scanning.

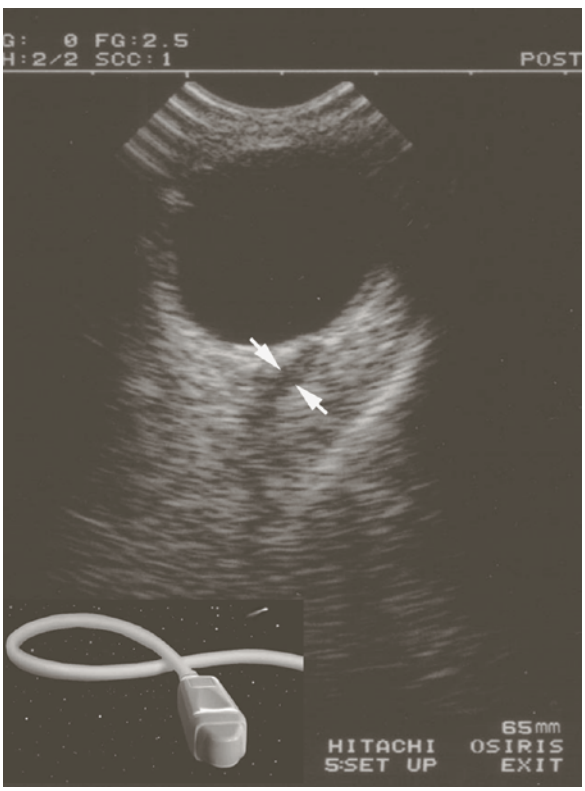

Fig. 24.4 Normal optic nerve. Scan through the eyelid. The optic nerve (*arrows*) has a normal caliper (2.6 mm). Note the sinuous route of the nerve. The pressure of the probe should be almost null in this kind of approach

This application requires some skill. The curves of the nerve must be recognized, in order to avoid confusion with an acoustic shadow, which is not sinuous.

Results

On-site observations confirmed all our theoretical points. In the only work we had time to publish, we compared 25 cases of elevated intracranial pressure proven on CT with 100 critically ill patients (many being ventilated) with proven absence of elevated intracranial pressure. The caliper of the optic nerve on normal subjects was 3.4 mm (range, 2.1–7.0 mm). An enlarged optic nerve was observed in the study group, with a caliper of 5.1 mm (range, 2.8–7.0 mm) (Fig. 24.5). In this study, a cut-off ≥4.5 mm yielded a sensitivity of the test for the diagnosis of brain edema of 80%, and a specificity of 83%. Patients who had a greater value had cerebral edema in 80% of cases. Patients with a lower value had normal brain status in 83% of cases [8].

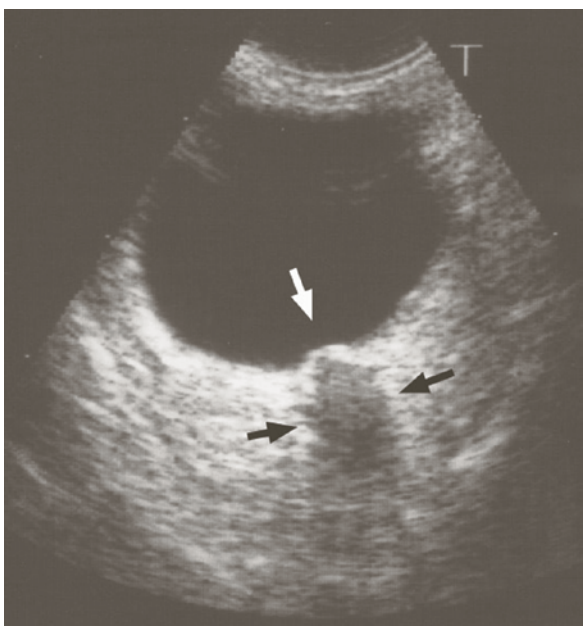

Fig. 24.5 Brain edema. In this scan, the apparent caliper of the optic nerve is markedly enlarged: 5.3 mm (*black arrows*). In addition, the papilla (*white arrow*) bulges in the lumen of the eyeball. There was diffuse brain edema on CT. Diasonic Vingmed unit with a 7.5-MHz probe

A Main Issue

Although not a vital organ, the brain is the most precious and fragile one. Our data are far from the 100% that ultrasound usually provides at the lung area. It is critical to point out these limitations, which we are trying currently to understand and standardize. The number of false negatives, around 20%, is not acceptable. The false-positive cases are also numerous (around 15%), and may be explained by transient episodes of genuine elevated intracranial pressure, as described with hypercapnia or acute hepatic failure [9]. We are trying to refine the method. Does the papilla protrude in the eyeball? Is the end of the optic nerve enlarged, bulging or conversely thinned? Is there a visible splitting of the optic nerve? Are the measurements strictly stable or are there variations for a same operator? Is there a frank asymmetry between the left and the right? One of these items, or others, may increase ultrasound accuracy.

A cardiac probe is totally inappropriate for this application, which requires submillimeter precision.

We are concerned by the possibility that linear high-frequency probes, widely used in the literature, generate acoustic shadows instead of the optic nerve itself (Fig. 24.6). It is true that these uses give good results, with 100% sensitivity and 95% specificity in a study of Blaivas [10]. The cut-off used is 5.5 mm, i.e., much higher than ours, and requires a standardized measurement (usually 3 mm behind the eyeball), because the acoustic shadow regularly increases with depth. Since our observations measure the real optic nerve, direct comparisons are difficult. Meanwhile, more studies have been published. Even the term ONSD (optic nerve sheath diameter) has entered into routine use.

We are concerned when we see colleagues trying to use the endovaginal probes (for the microconvex shape) – their ergonomy seems highly irrelevant for this delicate exploration.

Interest of Ultrasound

Other applications are being investigated; for instance, doing a spinal tap without losing time in order to check whether this procedure is dangerous. Note that severe

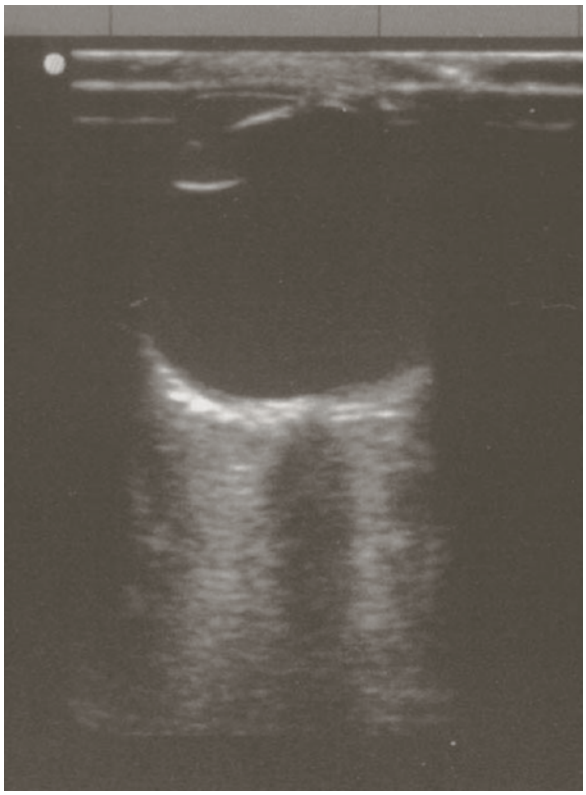

Fig. 24.6 Optic nerve or acoustic shadow? We have no linear probe and have built this image of acoustic shadow as we see it from linear transducers analyses. The "optic nerve" is too straight to be a real optic nerve. Its measurement gradually increases with the depth, obliging to define an standard distance (usually 3 mm) to measure it

meningitis may have various degrees of elevated intracranial pressure, possibly resulting in a too sensitive test. If ultrasound detects minimal brain edema too easily, its benefit may be lost in this particular application. More extensive data will allow us to come to a conclusion.

Practical use: when we receive a comatose patient, we systematically measure the optic nerve. In the absence of strong clinical evidence (of either extreme surgical emergency or ordinary drug poisoning), patients having values below 4.5 mm are monitored at the bedside, and patients with a higher value are referred for emergency CT. This policy prevents us from misdiagnosing rare but dramatic cases of neurosurgical emergencies hidden by alcoholic coma.

Recently, other studies have confirmed the approach we described in 1992 [10, 11].

An Alternative Approach: The Transcranial Doppler

Although long available [12] and possibly of interest in the traumatized patient [13], data on transcranial Doppler (TCD) are not included here. Apart from detecting cerebral circulatory arrest secondary to a caricaturally elevated intracranial pressure, TCD also allows detection in some more moderate cases. Few data are available with brain trauma, mainly diastolic velocity and pulsatility index. Ischemia is a major disorder in brain trauma. The idea is to perfuse the ischemic brain, using mainly early osmotherapy and control of ventilation. We have introduced Doppler only a little throughout this book, believing that a light, simple tool can save countless lives in countless fields. In the precise domain of cranial trauma, we may be committing an injustice. Being open to any criticism in this hot field, we present our comments about the persistence of our choice, and thank the reader for patiently reading below.

1. TCD is very operator-dependent, whereas the skill required for optic nerve detection is clearly lower.
2. TCD is patient-dependent, with 20–30% of patients not having correct windows, whereas feasibility of optic nerve measurement is near to 100%.
3. TCD is not a perfect tool, with accuracy far from 100% (nearer to 80–85%). It has qualitative merits and is considered as a good screening test in the shock room, but its quantitative and monitoring value are not ideal: TCD can be normal in major elevated intracranial pressure [14]. The measurement needs several requirements, taking into account the capnia level, blood pressure, cardiac frequency, which are sources of limitations [15]. Terminassian and other teams estimate that in no case should TCD replace the monitoring of the intracerebral pressure. Note that real monitoring supposes permanent measurement, which is not compatible with the TCD (nor optic nerve measurement), even when repeated several times a day. For a more detailed critical analysis, see Sloan et al [16].
4. TCD is not harmless, unlike optic nerve analysis [17, 18].
5. The rate and severity of road accidents decrease. Trauma centers are increasingly specialized. In such places, we are not opposed to seeing TCD devices. Similarly, in stroke centers, TCD is often performed by neurologists. It is not clear, to our

knowledge, whether TCD use has a major immediate and oriented therapeutic impact here. The diagnosis of vasospasm seems to be a challenge, and the patients receive systematically preventive therapy for a disorder whose therapeutic management is not clearly assessed (with large inter-center variations). Vasospasm and subarachnoid hemorrhage are in fact relevant in specialized centers.

All these issues must be considered in addition to another one, which is not insignificant for the outcome of brain trauma. Carefully designed studies should demonstrate a definitive interest of TCD in the quality of life of the surviving patients. They should demonstrate whether the golden hours are really, or not, the first ones. For many, the edema is easy to treat, but the prognosis is a function of the deep, irreversible brain lesions. For once, we critically require data from really evidence-based medicine.

Bearing all these points in mind, we should not forget that lung ultrasound, especially the limited investigation, allows for accurate control of the volemic status in the critically ill (see Chap. 23). This would be a major point for enlarging the use of osmotherapy, improving patients' prognosis and reducing the need for TCD. Osmotherapy is not easily used now, for fear of causing more harm than good.

Therefore, we wait for the results of studies comparing the optic nerve approach with TCD (in holistic terms). The deal is to equip the world with simple machines. If machines with Doppler are made without detriment to basic functions – which is far from being the case currently – we will clearly accept their use here. For the doctors who are not daily involved in the care of such patients, we would like to balance the attraction of Doppler by sharing a holistic vision – open, if needed, to the DIAFORA alternative.

Chapter 30 explains by which pernicious way Doppler has possibly killed more than saved.

The Brain

A probe applied at a precise location of the temporal bone displays a characteristic image, which ends in a structure interpreted as the contralateral bone (Fig. 24.7). This again proves that ultrasound crosses the bones (or maybe, here, fissures). Midline reflecting brain structures

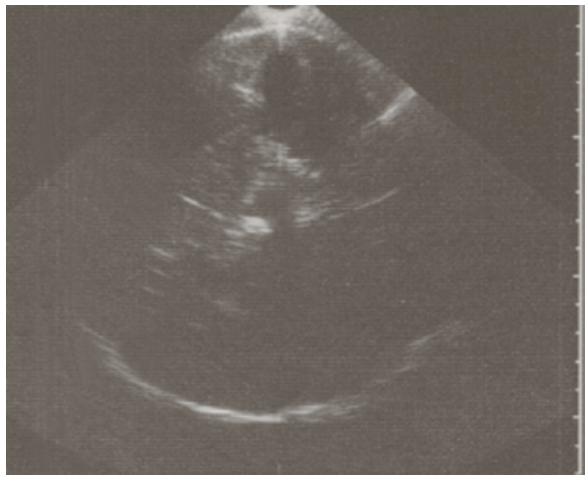

Fig. 24.7 Brain. Transverse scan. The biparietal diameter is 13.5 cm, a usual value in adults. Many details are visible between the two parietal bones

can be described. One aim is to determine whether ultrasound can detect a shift in these images. Long ago, the A-mode, a rudimentary ultrasonic system, was used to determine whether the median structures were shifted, thus indicating surgical emergencies [19]. CT now provides accurate answers, but we would be interested to see whether information can, at the bedside, reliably decrease – or prompt – the need for CT.

The Eyeball

The eyeball – a precious organ – is accessible through the eyelid, with the same precautions that apply for the optic nerve (see above). Ophthalmological occult emergencies in comatose patients can, therefore, be diagnosed (Fig. 24.8).

In case of ocular trauma, an eye injury must be promptly recognized. Ultrasound normally shows an anechoic, perfectly round organ. In terms of spatial resolution, ultrasound is clearly superior to CT, which in addition irradiates the crystalline lens.

Daily concerns may be solved. A retinal hemorrhage would give isoechoic or hyperechoic images anterior to the retina [20]. A retinal detachment yields a kind of flap visible at the posterior pole of the eyeball. Intra-ocular hemorrhage yields a characteristic homogenous echoic pattern with slight dynamic. Regarding the search for ocular candidosis, we await enough cases to conclude.

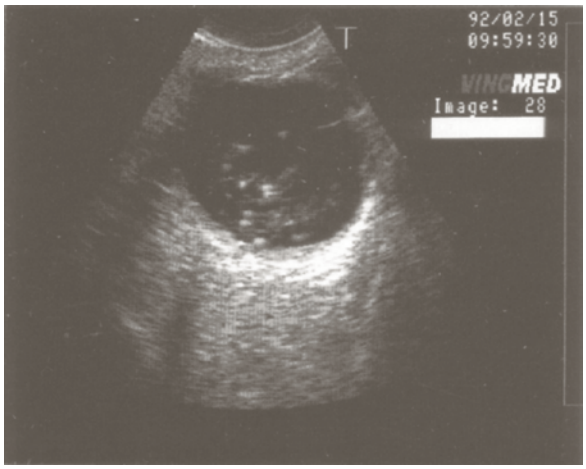

Fig. 24.8 Vitreal hemorrhage. Multiple echoes as in weightlessness in aqueous humor, mobile with the eyeball movements. Diasonic Vingmed unit with a 7.5-MHz probe

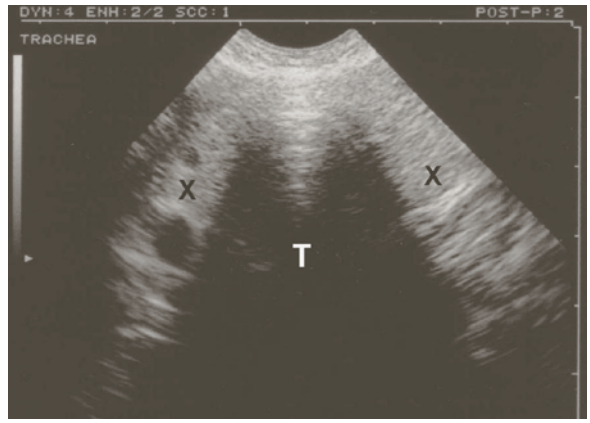

Fig. 24.9 Trachea and thyroid. Transverse anterior cervical scan at the thyroid isthmus. The two thyroid lobes (*X*) and the posterior shadow of the trachea (*T*) are recognized. Since an air barrier is visible immediately posterior to the anterior wall of the trachea, it can be possible to conclude that the anterior wall, at this level, is free

The Face

Parotiditis, a classic complication of mechanical ventilation, should give an enlarged, hypoechoic gland, which should be sought between ear and maxilla (easily using our microconvex probe). We still lack observations on this either rare or misdiagnosed complication.

The Neck

Internal Jugular Veins and Carotid Arteries

These are studied in Chaps. 12, 13, 25, and 28.

Retropharyngeal Space

CT should be preferred in this obscure field. However, hematomas can be documented. A retropharyngeal abscess can be sought [21]. Epiglottitis may be accessible [22].

Trachea

The trachea cannot be missed: an anterior and median cervical structure with posterior air artifacts. Not working at "zero pressure" can be unpleasant to a nonsedated patient. In thin patients, a *tofu* interposition will avoid the purchase of a costly linear probe. The trachea is quickly lost when entering the thorax. Via the anterior or lateral approach, one can study its external configuration (Fig. 24.9). Its anteroposterior and lateral diameters can be measured, at inspiration and expiration. Among a hundred uses, the choice of caliper for the trachea (especially the first rings) can be assessed rapidly before intubation – of interest in children. The fibrocartilaginous tracheal wall is crossed by ultrasound beams. An anterior granuloma will be visible, providing a diagnosis of tracheal stenosis. Of course, fibroscopy is the reference test for tracheal disorders, but the principle remains the same: give the patient a first noninvasive, rapid approach that can alter the usual management, depending on the operator's skill. Within the lumen itself, secretions accumulated above an inflated balloon can be detected, a finding with clinical outcome (Fig. 24.10). Some authors use ultrasound for guiding percutaneous tracheostomy [23]. The intubation tube itself yields a particular signal, with clinical applications for airway management (see Chap. 17). Tracheomalacia may be also detected. Before tracheostomy, the thyroid isthmus (Fig. 24.9), a possible thyroid hypertrophy, an aberrant brachiocephalic artery [24], or the innominate vein are located using ultrasound.

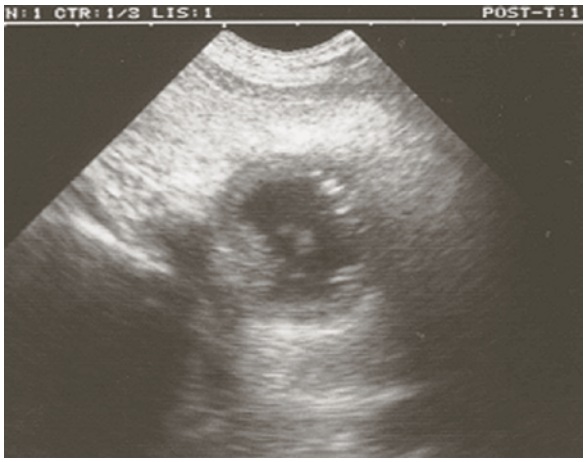

Fig. 24.10 As opposed to Fig. 24.9, this trachea is entirely crossed by the ultrasound beam – thanks to an accumulation of secretions above the inflated balloon. This mandates careful aspiration to avoid aspiration by the lung when deflating this balloon. In addition, the anterior tracheal wall can be accurately measured, here thickened to 4 mm

Cervical Esophagus

This is a strategic space during difficult airway management. With a fast echo possible with the machine beside and no time lost in probe changes nor setting adjustements (i.e., the way we have worked since 1989), a look at the left paratracheal area can, in a few seconds, show the esophagus intubation (Fig. 24.11).

Thyroid

Ultrasound is contributive if an abnormal thyroid gland is described in a patient with suspicion of severe dysthyroidism. In a young female admitted for acute hypercalcemia, fast ultrasound detected a suspect mass evoking a parathyroid tumor. This resulted in prompt surgery, which confirmed the diagnosis.

Cervical Rachis

Finally, the rough integrity of the cervical vertebrae can be assessed via the anterolateral cervical approach (Fig. 24.12). Why not use first-line ultrasound when there is suspicion of cervical rachis fracture?

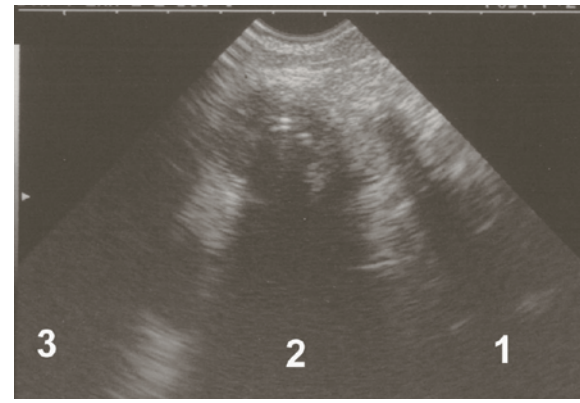

Fig. 24.11 Cervical esophagus. Transversal section of the neck. The trachea is immediately recognized (median structure, roughly 2-cm circumference, followed by acoustic shadow (*2*). To the left, we do not ask to recognize the esophagus in extreme emergency. Yet the tube is immediately recognized, yielding a frank acoustic shadow (*1*). The tube seems strikingly shifted to the left, probably because the esophagus is flexible and the tube is rigid (*3* acoustic shadow due to an imperfect contact between the probe and the skin)

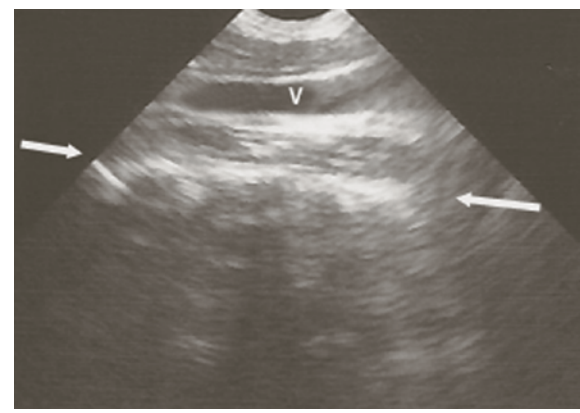

Fig. 24.12 Cervical rachis. longitudinal paramedian scan of the neck. Posterior to the internal jugular vein (*V*) and the muscle, a thick hyperechoic line represents the anterior wall of the cervical rachis, here straight without solution of continuity (*arrows*)

The Nape of the Neck

Suboccipital puncture is sometimes performed in patients with elevated intracranial pressure. Would ultrasound guidance or location be useful in this reputedly risky technique? We are currently investigating the possibilities in this area.

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Soft Tissues and Miscellaneous Areas

25

By "miscellaneous," this chapter considers acute diseases involving muscles, fat, fluids, air, vessels, nerves, spine, etc. Parts of the chapter on the mediastinum in our previous editions are inserted here.

For these structures, our 5-MHz microconvex probe will be sufficient. For analyzing very superficial parts, an inert material (a kind of jellyfish or equivalent – a piece of tofu seems practical) can be inserted between probe and skin, far less expensive than buying a high-frequency linear probe (Fig. 25.1)

Soft Tissue Abscess, Necrotizing Fasciitis, Gangrenous Cellulitis

These problems are more relevant to the emergency room, unless shock develops. The physical examination is often in failure in differentiating these diseases, whose treatement varies from oxygen to surgery [1]. Usually, necrotizing cellulitis yields a diffuse, ill-defined pattern with nonsystematized hypoechoic areas (edema). A disorganization of the muscular fibers indicates myonecrosis, whereas gangrenous cellulitis preserves the muscle. Bacterial gas, when present, can yield punctiform hyperechoic areas. Ultrasound prevents a painful and possibly insensitive clinical search for crepitations.

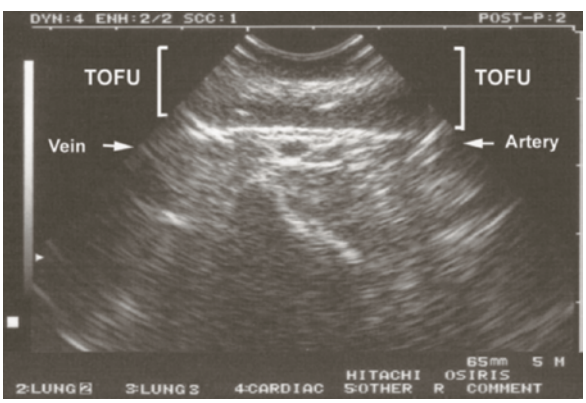

Fig. 25.1 The radial artery. Located 3 mm under the skin, it is perfectly visualized using our 5-MHz microconvex probe, using some tofu in order to get the skin 1 cm away from the probe head

An abscess is usually well-defined, focalized, and hypoechoic (Fig. 25.2). Bacterial gas can again be seen within the collection. For once in this textbook, we take interest in the posterior enhancement, an artifact that allows one to differentiate between a fluid collection and a hematoma that has become solid. To demonstrate the fluid nature of the image by using pressure is harmful, maybe even deleterious (risk of blood insemination), and a needle insertion is the usual way of diagnosis, in the case of clinical hesitation. As for any round image, the question of the vascular mass (pseudoaneurism) will be raised. The clinical context, the absence of auscultation anomaly (thrill) and the absence of dynamic on ultrasound makes a combination yielding certitude in nearly all cases.

Traumatic Rhabdomyolysis

The muscular loges have increased volume, without abscess or hematoma to explain the clinical swelling. A hypoechoic pattern of the muscles with disorganization of the normal muscular architecture has been described [2]. Another advantage of ultrasound is ruling out associated venous thrombosis (and here is a possible place for Doppler if the compression maneuver is harmful).

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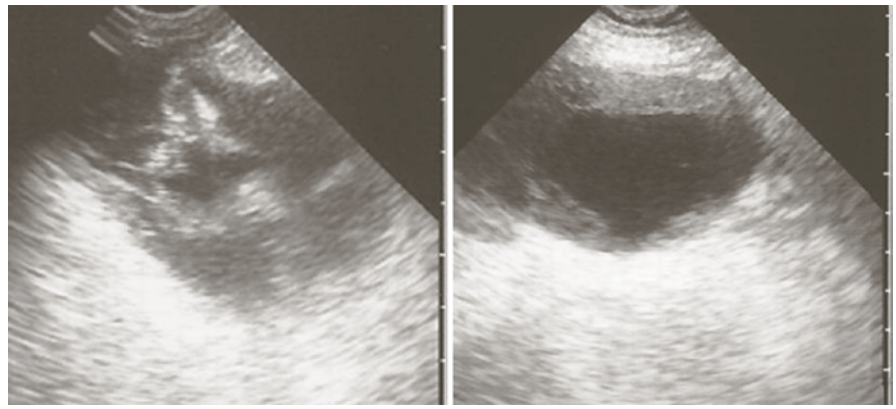

Fig. 25.2 Abscesses. Huge collections in the gluteal area of a traumatized young man (*left*) and the femoral area (*right*). The left collection is heterogeneous, possibly containing bacterial gas. The right collection is homogeneous. Both may be abcesses or hematomas (see Fig. 25.3). Note posterior enhancement. The ultrasound-guided tap has withdrawn pure pus

Malignant Hyperthermia

A heterogeneous and grainy pattern of the muscles, with a hypoechoic pattern of the septa and fascia is described by some [3], not by others [4]. The rarity of this syndrome in our ICU has until now prevented us from making an opinion.

Deep Hematoma

A hematoma gives a well-limited mass that is anechoic at the first stage and quickly becomes echoic and heterogeneous (Fig. 25.3). In case of doubt, ultrasound-guided investigation can give the diagnosis (avoiding pseudoaneurisms, read above).

A hematoma can develop anywhere and give distinctive signs. At the rectus abdominis muscle, its extraperitoneal nature will be recognized since the peritoneal sliding will be preserved, posterior to the mass. In severe forms, it can be the source of compression (bowel, bladder, etc.) [5].

Parietal Emphysema

The comet-tails generated by parietal emphysema were dealt with in Chap. 18. They hide underlying structures and make a hindrance to deeper examination (Figs. 25.4 and 18.14 page 176). On the other side, they are an early sign of deep disorders like esophagal rupture (see page 47), which can sometimes be detected before clinical signs of emphysema (work in progress).

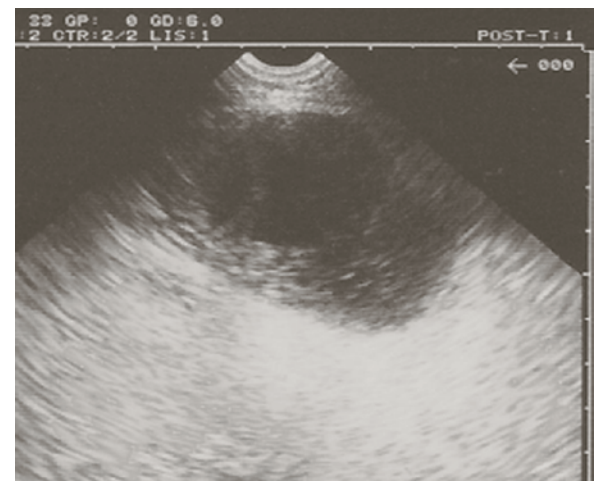

Fig. 25.3 Hematoma. Thigh collection in another traumatized patient. The pattern is not far from that described in Fig. 25.2 but here is a clotted hematoma

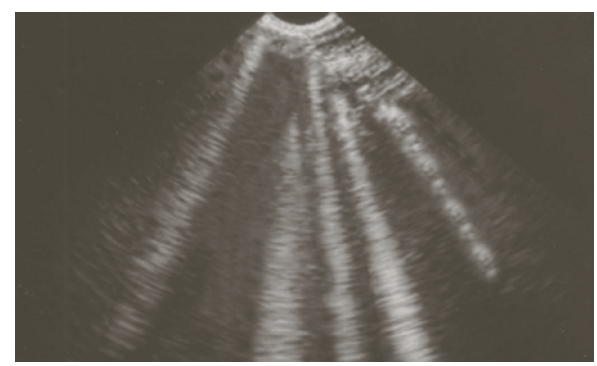

Fig. 25.4 Parietal emphysema. The lung structures in this thoracic view are unrecognizable since they are hidden by numerous comet-tail artifacts. These are W-lines, defined as comet-tail artifacts arising from different levels in the soft tissues (as opposed to E-lines)

Edematous Syndromes

In cases of major hydric retention, the soft tissues are enlarged by edema, with hypoechoic zones dissociating the muscles without disorganization. The analysis of the deeper structures is not hindered, as water is a good conductor for ultrasound beams.

In situations such as nephrotic syndrome with massive hypoalbuminemia, more or less substantial effusions can affect all of the anatomical compartments.

Parietal Vessels

Ultrasound accurately locates the epigastric or internal mammary vessels if a local tap is considered near this area (see Fig. 5.15 page 40). The internal mammary descends just outside the sternal border. In surgical patients (after cardiac surgery), one can detect internal mammary artery false aneurisms. The pattern is usually an egg-shaped, vertical long-axis mass, and its content sometimes shows a blatant whirling flow (Fig. 25.5), in rhythm with systoles. This dynamic pattern is a way to prove the vascular origin of a mass, before any idea of puncturing it, once again without Doppler.

Some doctors like to canulate the radial artery under ultrasound guidance, for instance, for managing cardiac arrest. Although a few millimeters under the skin, the radial artery can be detected using our universal 5-MHz probe, provided a piece of tofu is inserted between the skin and the probe (Fig. 25.1).

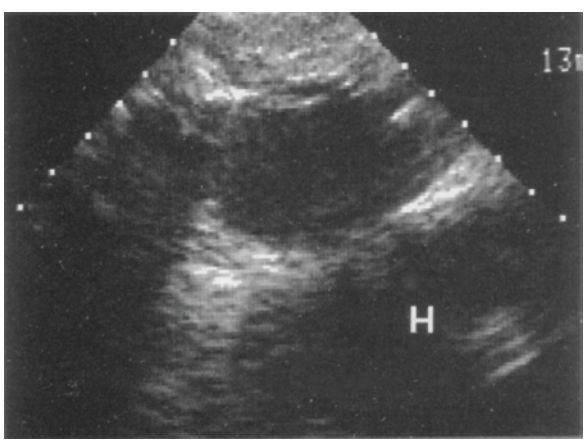

Fig. 25.5 False aneurysm of the left internal mammary artery. Transverse scan of a parasternal intercostal space. Egg-shaped mass with vertical long axis. In real-time, an echoic whirling flow indicated an arterial activity within this mass. *H* heart

Acute Arterial Disorders

Note that arterial occlusion (apart from coronary and brain arteries) is rare in the intensivist's use. To see the carotid arteries is not of major clinical impact in a medical setting. This book does not contain any Doppler figure. Can we push this "paradox" to the artery studies? The aorta and proximal arteries (carotid, subclavian, common femoral, etc.) have a systolic dynamic that logically indicates the absence of occlusion. This systolic dynamic vanishes little by little and is usually no longer visible at the femoral arteries. Applying a microconvex probe with a compression maneuver on such a "motionless" artery will initiate a collapse of the artery. At this moment, systolic waves will be observed when the flow is preserved. In acute arterial ischemia, this "induced dynamic" disappears. This can be recorded in M-mode. Studies are on the way for assessing the value of this simple maneuver, called arterial compression maneuver echography.

For traumatic dissections, please refer to Chap. 28.

Carotid calcifications can easily be detected using our 5-MHz microconvex probe.

Peripheral Arteries and Blood Pressure

Can ultrasound replace the tensiometer? The behavior of the femoral artery, when compressed by the probe against the bone, can give another approach. When arterial pressure is normal, a slight compression does not affect the cross-section. If one insists, the lumen collapses, with systolic expansion despite the probe pressure. When the blood pressure is low, the artery collapses without resistance. On initial whole-body examination, this is quicker than measuring the blood pressure by usual means (to be validated).

Peripheral Nerves

Ultrasound-guided puncture for locoregional anesthesia has had an explosive success in very few years – although this technique was struggling for many years. Once again, this explosion has favored the sale of large laptop units. Our book is not dedicated to this domain, and we refer the reader to authorized sources [6–9]. Meanwhile, see how it is possible to locate a nerve using our 5-MHz microconvex probe (Fig. 12.1 page 90). How about Doppler in this field? Some highly advocate it, others do not use it (local sources). If it is for distinguishing vessels from nerves, this is of least interest for Doppler: a simple compression is enough.

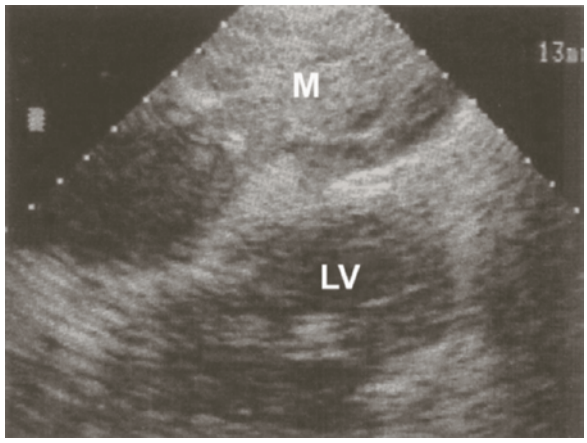

Fig. 25.6 Acute mediastinitis. Substantial collection (*M*) visible by the transsternal route, in a recently operated patient. The collection is echoic and tissue-like. The tap easily withdrew frank pus. Note the heart (*LV*) located more deeply

Mediastinum

Can the mediastinum be analyzed within a general ultrasound approach, i.e., using simple equipment and a trans-thoracic route? Certainly yes, with an effort to sort out perspective, and if one accepts a feasibility rate that is less than 100%. A 5-MHz microconvex probe is mandatory for this use – better than a cardiac probe with flat surface.

A suprasternal approach has been described [10]. A parasternal approach is contributive when the mediastinum is shifted to one side. After cardiac surgery, a not perfectly closed sternotomy provides a window that is modest but sometimes life-saving. The sternum of the neonate is not calcified, creating a large window.

Acute mediastinitis can be diagnosed using several approaches. The transesophageal approach will certainly yield the most suggestive images, but its innocuity should be demonstrated. The external approaches can be parasternal, if the collection extends beyond the sternum, or transsternal if there is some postsurgical disunity. In a patient who had sepsis 1 month after aortic dissection treatment, the transsternal route showed a large, echoic mass of the retrosternal space (Fig. 25.6). An ultrasound-guided puncture of this mass immediately withdrew frank pus. *Staphylococcus* was isolated in a few minutes by the laboratory. Adapted antibiotic therapy was begun before prompt surgery. This visual policy can avoid the blind punctures that are sometimes attempted.

Diving goiters, lymph node enlargments, or mediastinal tumors can be responsible for tracheal compression (see Fig. 12.3 page 90). In a context suggestive of myasthenia, an anterior mediastinal mass will suggest thymoma. The pneumomediastinum yields a complete acoustic barrier, of value if the heart was previously located in this area. Lung sliding outside this area allows one to rule out pneumothorax.

A complete atelectasis can considerably favor the ultrasound analysis of the mediastinal structures using an external approach (see Figs. 13.13 page 107 and 16.10 page 146).

Undernutrition

The nutritional status of a patient is usually monitored using the weighing machine. This requires a demanding maneuver for the paramedical team. Above all, the weight is a summation of inverse trends: in a critically ill patient, the muscles and fat compartments decrease, whereas the water compartment increases. Once more, ultrasound can potentially provide logic-based assistance. A differential analysis of the fat [11], muscle and interstitial compartments can in fact be carried out (Fig. 25.7). Accepting that these variations are the same in any part of the body, only one standardized area should be investigated. An easy-to-access area is, for instance, a

transverse, paraumbilical scan of the rectus abdominis muscle (Fig. 25.7) or, perhaps better, a transverse scan of the crural muscle at mid-thigh (Fig. 25.8). Ultrasound may also detect interstitial edema before clinical evidence, but this precise issue has not yet been investigated.

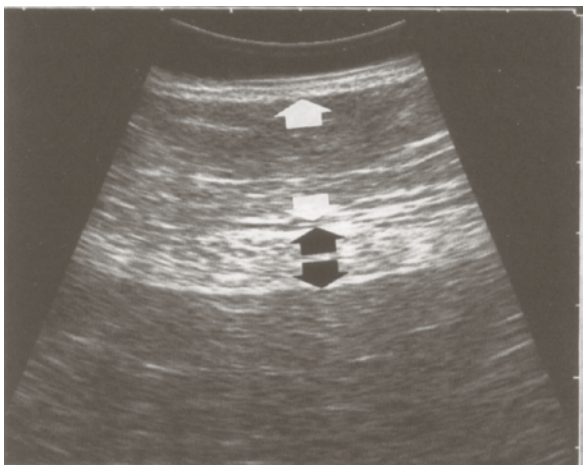

Fig. 25.7 Nutritional status. Transverse scan of the paraumbilical abdominal wall. The *white arrows* sharply delimit the fat compartment (17 mm), the *black arrows* the muscular compartment (9 mm for the muscle). Probe with 7.5-MHz frequency

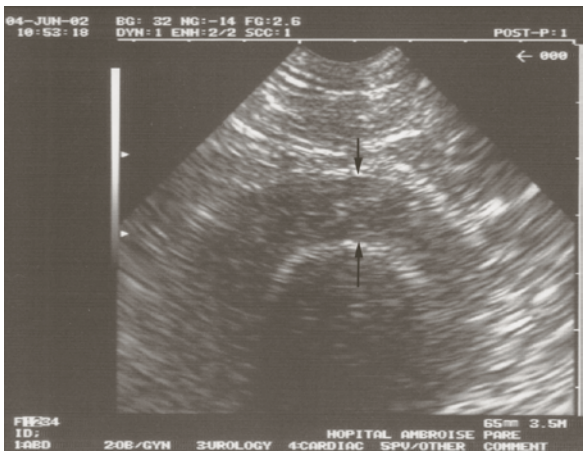

Fig. 25.8 Transverse scan of the thigh. The femur is easy to locate. The crural muscle (thickness here 11 mm) has the advantage of having a regular shape (limiting intra-observer variations) and an easy location – allowing to propose this location as a standard point for checking the nutritional state of patients on admission and during long stay. Microconvex probe with 5-MHz frequency

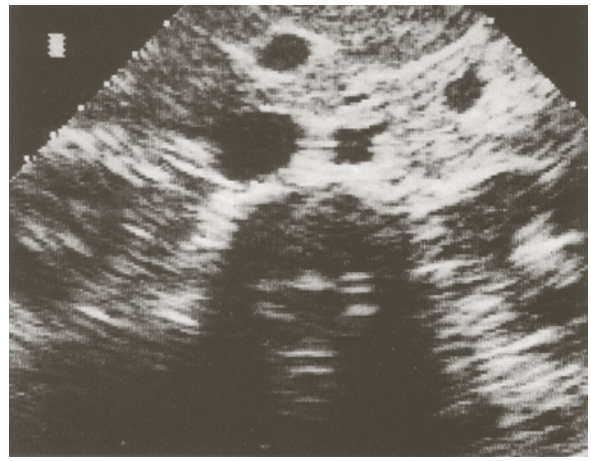

Fig. 25.9 This ghostly vision seemingly observing us, here intended to relax the reader, shows how well ultrasound can perform. In this transverse scan passing through an intervertebral disk, the spinal canal, and the intervertebral foramen are defined, forming the nose and eyes of the creature. Depending on one's imagination, a gorilla in the mist or one of the main characters from the "Star Wars" movies may become visible. This is the only useless figure in this book

Miscellaneous

Multiple disorders such as cysts, arterial aneurysms, lymph node enlargement, osteomas, etc., not related to the acute illness, can be detected in the soft tissues.

Vertebral Disks

The rachis is the posterior limit of the retroperitoneum. It stops the ultrasound beam. However, ultrasound can go through intervertebral disks. It is then possible to analyze unusual structures, such as the content of the spinal canal (Fig. 25.9). A posterior approach is, of course, possible. We have not given this analysis a particular relevance (should meningitis yield a particular pattern?), but Fig. 25.9 is a striking example of some still untapped features of ultrasound.

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Part III

Clinical Applications of Ultrasound

Interventional Ultrasound

26

Interventional ultrasound is mostly used in preplanned procedures, but can be used in extreme emergencies as well. See its place in cardiac arrest in Chap. 29.

The intensive care unit (ICU) is a privileged arena for practicing interventional ultrasound. It allows therapeutic management at the bedside of immovable critically ill patients. It remains, in experienced hands, a safe method [1]. The patient is by definition under high surveillance: early detection of the main complications (hemorrhage or sepsis), *if any*, is guaranteed. Stress-induced complications [2] are usually bypassed in sedated patients. In other words, interventional ultrasound is an opportunity in the critically ill – nearly a philosophy. It is indicated for almost every organ.

Procedures regarding pleural or peritoneal effusions, gallbladder, central veins, etc. are described in the corresponding chapters.

Emergency Life-Saving Insertion of a Short Central Endovenous Catheter

Before dealing with technical data, we reiterate this one use of critical ultrasound, abbreviated as ELSISCEC, seen in Chap. 12. Our system includes the following:

- An ultrasound machine that switches on in 7 s (see Fig. 30.5 page 302)
- A unique probe, always ready with the optimal setting (see Fig. 2.4 page 14)
- A particular catheter, which is 6-cm long and 16 gauge (see Fig. 26.2)

With this, we are able to make immediate subclavian catheterization. This can be indicated in a major hemorrhage when time is of essence. We can even insert it in a sterile manner, using subtle changes of hand that would be a little long to describe (the hand with the needle wears a glove, the other hand holds the probe at a distance – 1 cm).

It is peculiar to see that this simple material, in our areas, can be difficult to find, but critical ultrasound has made us accustomed to surprises; this is here simply one more.

What can be tapped in extreme emergency, simple emergency, or routine?

Immediate Diagnostic Procedures

Pleura, including effusions not visible on radiography in ventilated patients (page 136), pericardium (page 217), peritoneum (page 40), gallbladder (page 66), hepatic abscess (page 57), splenic abscess (page 78), retroperitoneal hematoma (page 88), soft tissue abscess (page 253), and mediastinitis through sternal disunion (page 256).

Immediate Patient Management

Insertion of central venous catheter (traditional or short life-saving): internal jugular, subclavian (page 89)

Right heart catheterization (page 220)

Insertion of suprapubic catheter (page 75)

Radial artery canulation during circulatory failure (page 253)

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Immediate Therapeutic Procedures

Aspiration or drainage of purulent pleurisy (page 136), pericardial tamponade (page 217), abdominal abscesses (liver, spleen, pancreas, or peritoneum). Caval filter insertion (page 265). Blakemore-Linton probe insertion (page 47). Percutaneous nephrostomy (page 75). Percutaneous cholecystostomy (page 67).

Less Urgent Diagnostic or Therapeutic Procedures

A parenchymal biopsy may provide emergency documentation of tuberculous miliary, hepatic metastases. A percutaneous gastrostomy using ultrasound should also be envisaged.

Basic Technique for an Ultrasound-Guided Procedure

For large collections (i.e., projection of 4 cm^2 or more, usually pleural and peritoneal effusions), an ultrasound-guided landmark can be established, followed by the puncture. Once the landmark has been determined, the patient must remain strictly in the same position, the ultrasound unit can be switched-off, the skin disinfected and the needle inserted. This procedure has the advantage of great simplicity and can be done in a few instances without help.

For small targets (deep veins) or large but critical targets (pericardium), the procedure is performed under permanent ultrasound guidance. There are probably several protocols. We describe our technique, carried out by a single operator, with the advantage in our opinion that the maneuvers and encounters between the probe and the needle are coordinated by one brain alone.

The operator installs the sterile operative field. Interventional ultrasound supposes full control of asepsis. A sterile glove is not a serious solution. The probe as well as a long part of the cable should be protected. Nothing was available in the market for years, and we have used for more than 12 years a system dedicated to these applications: combining a sheath dedicated to a video camera and a transparent adhesive dressing (OpSite type), which is not an obstacle for ultrasound beams and closes the opened end of the sheath. This solution, as elegant as efficient, requires less than 2 min to set up (Fig. 26.1).

The procedure can begin. General anesthesia should not be exempt from local anesthesia. Betadine proves to be an effective contact product that does not attack the probe because it is protected by the transparent film. Sterile gel can be used if the operator wishes. The operator holds the probe in one hand, the needle in the other, and proceeds to the tap.

Once the needle is in the target, the probe can be released. It is laid down on the field, ready to be used again if needed.

Targeting

The procedure is planned, time permitting. Where should the probe and needle be applied?

Locating the Probe on the Target

The target is settled comfortably in the sights. A microconvex probe, held like a fountain pen (i.e., firmly *and* softly), makes no tired or uncontrolled movement that may make the target disappear (see Fig. 12.10 page 95). We found it ideal to keep the probe directly above the target. This generates the best probe/skin contact and therefore the best image. It also simplifies the calculation of the needle angulation and insertion.

Relationship Between Probe and Needle

We use simplicity, avoiding servo-control systems, with the needle inserted through complicated devices fixed on the probe. One hand holds the probe, one hand inserts the needle. The advantages are: simple material, flexibility (as the operator is *free* to make slight changes in needle inclination), and simplicity (no heavy disinfecting procedures). Above all, we use the same probe and other equipment as in the 25 previous

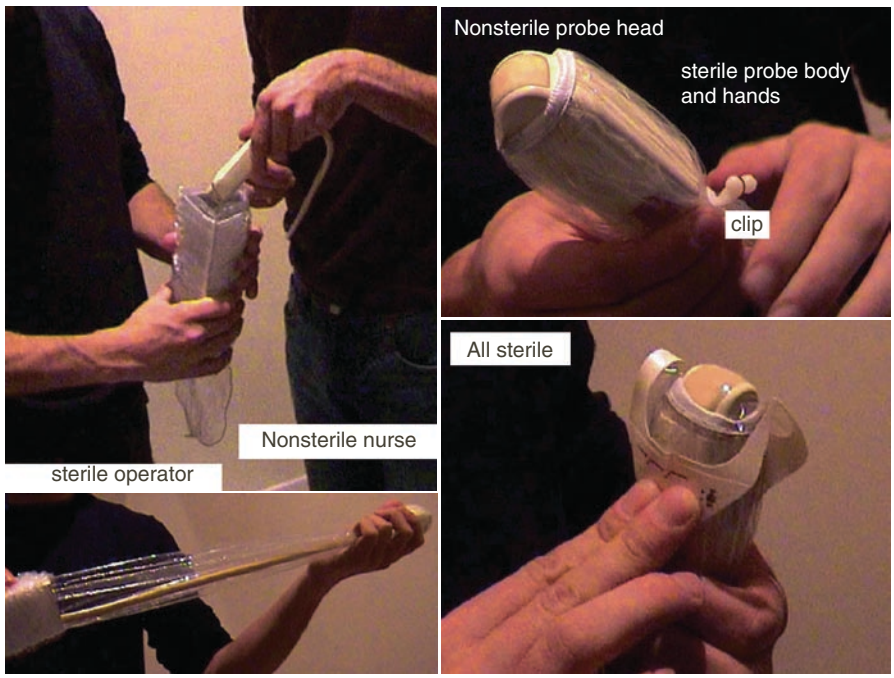

Fig. 26.1 Easy sterile interventional ultrasound. *Top left*: The probe is inserted, by nonsterile hands, into the retractable sheath. *Top right*: The physician takes the probe at the other side, and places the head of the probe at the open end of the sheath, avoiding touching it. *Bottom left*: The physician stretches the sheath. *Bottom right*: A sterile plastic dressing has been applied on the probe head. Everything is now sterile. The ultrasound beam crosses this thickness of plastic with no impairment of the image quality. The usual alcohol-based product for skin disinfection can be used as a coupling product (without probe damage)

chapters. The needle just follows the plane of the probe – more or less parallel to the probe, more or less far – but always in the probe's plane (we consider exclusively longitudinal technique of approach).

Location of the Point of Needle Insertion

We have greatly simplified previous protocols. The distance between the point of needle insertion and the probe head should be equal to the distance between the probe and the target (vertical route). For vascular access and peritoneal tap, the targets are often 2–3 cm from the skin. The same distance between needle and probe border seems a good rule. By using the same distances and angles as often as possible, the user will be familiar with the site where the needle will appear on the screen. With experience, these rigid but practical rules can be made more flexible.

Needle Angulation

An angle of insertion of the needle of 45° yields optimal simplicity (see Fig. 12.10 page 95).

Needle Length

This section can be simplified if one takes care with a long needle. The distance that will be covered by the needle to reach the target can be evaluated on the screen (see Fig. 12.9 page 95). With a needle angulation of 45°, the needle length must be at least equal to 1.4 cm for a probe-target distance of 1 cm.

If the needle does not go straight toward the target, it should be withdrawn as far as possible and inserted again at a corrected angle, in order not to lacerate the tissues.

Penetration of the Needle into the Soft Tissues

The needle penetrates the soft tissues exactly in the section plane of the probe, which is defined by its landmark. Using a longitudinal approach, the needle remains visible on the screen for its entire length (see Fig. 12.9 page 95). This allows one to continuously check that structures to be avoided will not be pierced inadvertently. One should be comfortable holding the needle like a pen, hand firmly applied on the skin, as in Fig. 12.10 page 95. This maneuver provides fine-tuned control of the procedure.

In roughly 20% of cases, the needle is not perfectly visible. This may mean trouble for small targets like deep veins. We see this whether the needle is thin or thick, the gain low or high, the patient thin or overweight, on chronic corticotherapy or not, or whether an anesthetizing product had been locally injected. In these cases, our attitude is simply to check that the needle axis is on the probe-landmark axis and that the probe is well positioned, keeping the target fully on the screen, and following the progression of the needle. The couple formed by the screen (showing the vein) and the probe landmark show the way. Eventually, the tip of the needle is seen when the proximal wall of the vein is reached, and when the needle enters the lumen: the deed is done.

Small maneuvers can help while progressing. The operator can give fine to-and-fro movements to the needle, which can help visualize it.

We are not keen on the numerous solutions of the manufacturers. Some propose grainy needles, which are advocated to be detected more easily. We wonder whether this kind of device will not prompt the formation of venous thromboses (the granulous pattern of the metal should yield a granulous wound of the venous wall). We will accept to buy these costly needles once evidence is shown that this does *not*. Color Doppler help has been described [3], as well as the cabled transmission of an electric source at the end of the probe [4, 5]. Some inject small quantities of air in order to locate the end of the needle. This may rapidly render the area impossible to interpret. Calling on CT in this particular situation is the opposite of our aim. This would result in transportation, cost, and irradiation reaching both the patient and the operator. Our simple and efficient system avoids all these complications. We propose the hypothesis that the multiplication of these systems is a result of suboptimal use of the equipment (linear probes mainly).

Penetration of the Target

When a needle crosses a parenchyma, visualizing it is usually easy (see the case of a subclavian vein, Fig. 12.9, or the pericardium, Fig. 22.18 page 218). When the target is an encapsulated collection whose deep wall is concave toward the probe (bladder, gallbladder), ghost echoes can be generated. These echoes can be unsettling. A moderate gap between the middle and the end of the needle can be seen with certain probes. This problem is highly balanced since we here deal with large targets.

The needle always slightly shifts the proximal wall of the vein, the gallbladder, etc., before piercing it. Some recommend inserting the needle roughly. We never like to be rough. If done, however, this procedure requires careful control of the structures located posterior to the target.

Various Sophisticated Points

In exceptional cases, absolute absence of motion is required for a procedure. If necessary, there is a clear advantage in the sedated patient: disconnecting the machine after good oxygenation. In spontaneously breathing, critically ill patients, such apnea would be hard to obtain.

A sophisticated measurement of the probe-target distance should integrate the pressure that is sometimes made, getting the operator far from the ideal of "zero pressure." This creates a factor based on the patient's adiposity (roughly 1.2–1.4), since the fat tissues are compressed by the probe, which the needle does not make. This factor should be multiplied by the calculated length of the needle.

The syringe may be considered too heavy by some. It is conceivable to disconnect it, provided there is no risk of gas embolism – a point easily demonstrated if the inspiratory dimension of the target (vein) does not decrease (see Chap. 12).

In rare and delicate cases (pericardial tap), a third hand is needed (i.e., a second operator) for simply aspirating the syringe, whereas the needle and the probe are firmly held still by the first operator. The second operator does not need major expertise.

Equipment for Percutaneous Drainage

Still advocating absolute simplicity, we propose a simple kit of equipment and ancillary materials for multipurpose interventional ultrasound. Experience shows that the majority of *emergency* procedures require simple kit. For withdrawing pleural effusions, we find it elegant to use our "universal" 16-gauge, 60-mm-long catheter, which is simply withdrawn at the end of the procedure (Fig. 26.2). Prolongations are welcome since the distal end of the catheter will gain in flexibility. This kit is sufficient for the majority of pleural and peritoneal effusions, and, in most patients, pericardial procedures. In cases where very thick liquid is suspected, a Pleurocath (a thin silicone chest tube) may be preferred.

The numerous and sophisticated equipment and materials used in the radiology department are rarely indicated. We will be brief. The catheter is rigid for avoiding plications in chronic use. Its caliper is adapted to the type of collection. The caliper is expressed either in F (for French), where number and caliper increase in parallel, or in G (for gauge), and here, the smaller the caliper the greater the gauge. It would have been simpler to measure all instruments in millimeters. The catheter ends straight or with a pigtail (Fig. 26.3). It can be multiperforated. It is introduced using the trocar or Seldinger method.

Catheter, guide, and dilatator are sometimes furnished in kits – not the cheapest solution.

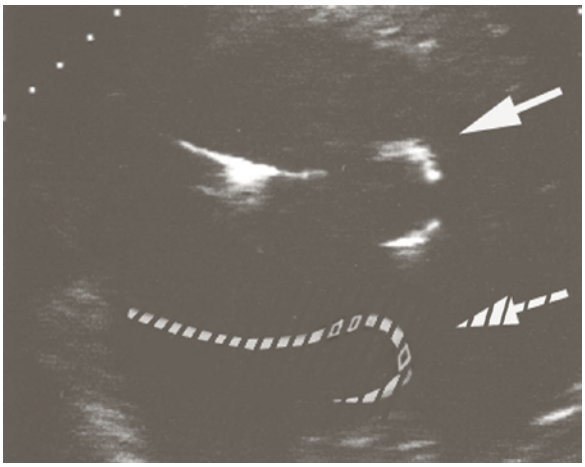

Fig. 26.3 Pigtail catheter. *Upper arrow*: pigtail catheter inserted within the hepatic abscess shown in Fig. 7.3 page 54. The *lower dotted arrow* points to a representation of the whole of the pigtail (which was partly erased by some artifacts) drawn with a dotted pattern

Unusual but Critical Fields for Interventional Ultrasound

The insertion of long devices, such as those used in interventional cardiology, is rare but life-saving. We have the optimal solution for a bedside use, which will, we hope, develop in the future.

We await a major role of bedside endovascular ultrasound in an emergency (BEVUE should not be an esthetic acronym), which should be a way to mechanically fragment massive clots in severe pulmonary embolism.

If physicians consider that a caval filter is clearly indicated (we will not open this discussion) in a patient who cannot be safely moved, or cannot receive irradiation (pregnant woman), it is perfectly possible to insert a caval filter at the bedside, under sonographic assistance, provided local conditions (gas) are correct. One operator inserts the filter while another locates the

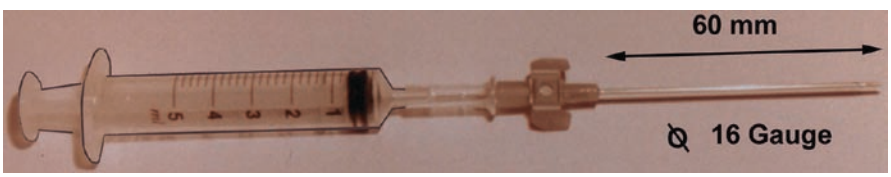

Fig. 26.2 A universal interventional tool. In the same way as we use one probe for the whole body, this simple catheter has the length and the cross-section relevant for, at will, inserting central (or less central) lines, or withdrawing pleural, pericardial or massive peritoneal fluid, i.e., a simple but really universal tool

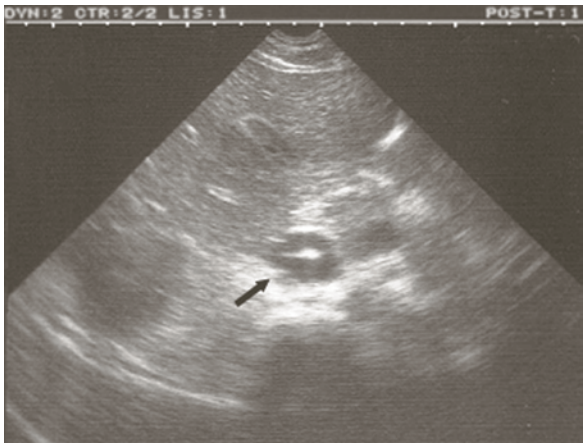

Fig. 26.4 Caval filter, clearly identified within the lumen of the IVC (*arrow*). Epigastric transverse scan. The insertion of the caval filter can be performed at the bedside

main landmarks using ultrasound. The left renal vein (which indicates also the right renal vein) is located (see Fig. 23.5 page 233). Like the pilot-bombardier relation in a B-25, the two operators should be perfectly trained since the roles are permanently inversed (Fig. 26.4).

A liver biopsy by transjugular route is also a potential field.

For these three particular potentials, given the frequency of these situations and the skill required, maybe one experienced and mobile team could satisfy a normal sized city (this is to be assessed).

General Precautions Before Any Puncture

One should take into consideration the following:

1. The nature of the target. Vascular, hydatid, endocrine (pheochromocytoma) masses must be suspected before any idea of puncture. We suspect a vascular nature (false aneurism), without Doppler, using clinical data (history, thrill) and ultrasound criteria:
   - A golden rule in our approach is to be highly cautious with any round-shaped, extraparenchymateous (liver, spleen) mass.
   - An echoic flow, regular with whirling dynamic, is specific to vascular dynamic (see Fig. 25.5 and text, page 255).
   - Slow, nonsystematized particle movements (plankton sign, see Fig. 7.5) can be safely tapped. It signals the absence of vascular connection.
   - In case of doubt, a Doppler study can be done. In these cases, the diagnosis is usually around a possible abscess, and there is usually always time for the DIAFORA (*D*oppler *i*ntermittently *a*sked from *o*utside for *r*are *a*pplications) logistics.
2. The areas crossed:
   - The pleura can be contaminated if it is crossed when an abdominal collection is punctured via the intercostal route. At the middle axillary line, the pleura can reach the tenth rib [6]. Yet these notions are pre-echographic, and ultrasound is an excellent tool for detecting the lower aspect of the pleura.
     - Pleural effusion must not be punctured if there is interposition of the heart, lung, aorta, liver, spleen.
     - The internal mammary (thoracic level) or epigastric (abdominal level) vessels should be avoided. Our 5-MHz probe can detect these vessels precisely (see Fig. 5.15 page 40).
     - When the gallbladder is punctured, a transhepatic approach limits the risk of biliary leakage in the peritoneum (the technique is detailed in Chap. 8).
     - Much could be written about any area. For instance, a groin abscess should be distinguished from a simple inguinal hernia before puncture.
3. Precautions regarding hemostasis, usually impaired in critically ill patients. If the basic rules described above are respected, such troubles are not an obstacle to an ultrasound-guided procedure. The only side effect induced in our experience was a perihepatic hematoma requiring the transfusion of two blood units in one patient, in whom a postprocedure compression was not performed.
4. The right indication. We will not detail this vast domain. Experience plays a large role. Rules can change if using visual medicine. For pleural and peritoneal effusions, an easy puncture policy is always beneficial.

Alternatives to Ultrasound

For those who prefer CT guidance [7], we can imagine that in rare cases ultrasound guidance will not be possible (for instance, an air barrier before a deep

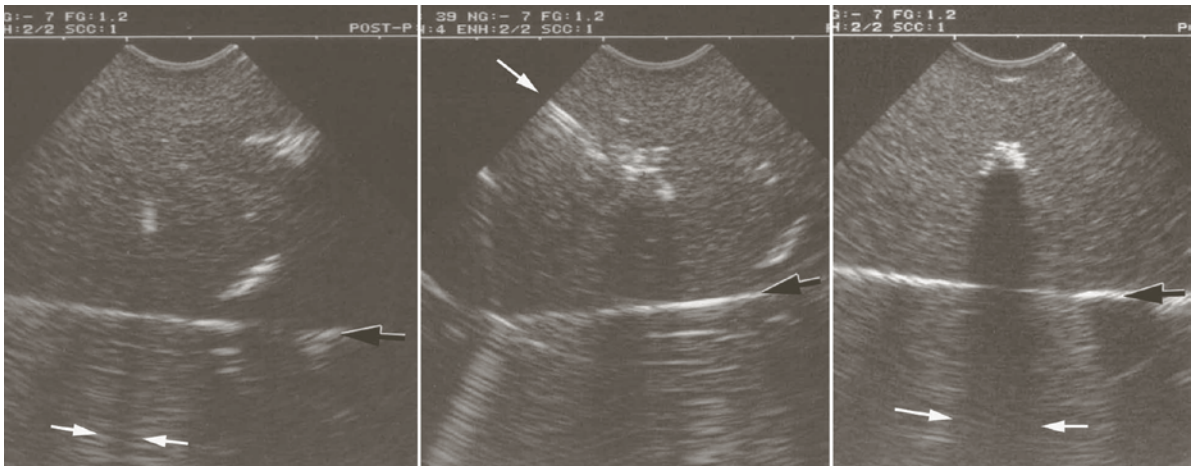

Fig. 26.5 Using a simple piece of tofu, bought for $1, one can observe, to the *left*, the appearance of a metallic wire (note the acoustic shadow *between arrows*). To the *middle*, a needle (*arrow*) aiming at a target created by air injection. To the *right*, the outlook of a nasogastric or chest tube (it easily penetrates the tofu parenchyma), with its large acoustic shadow (*arrows*). Note: these images were easy to produce in vitro. In clinical conditions, the images reproduce the same patterns. The *black arrow* indicates the bottom of the tofu piece, roughly 4 cm thick. Tofu can be conserved for more than 1 month for such use

thoracic abscess). Here, despite the heavy logistics and the high irradiation (for the patient and the operator's hand), CT scan will have a place. The place of ultrasound in this field has been acknowledged for a long time [8].

Ways of Training

For doctors wanting to understand the relationships between the needle and the probe, and train on inert material, we see some options.

1. To buy manufactured silicone phantoms: this is costly (not our option).
2. We have long suggested a piece of compact meat (the best to our knowledge was the French term of "gîte nerveux"). But it was not perfect (the blood puddles, the rapidly putrefying smell, the flies made it somehow repellent).
3. The perfect solution: simply using a piece of tofu (from compacted soya). Easy to find in any market around the world, extremely cheap (a whole team can be trained for one dollar), delicious with some good garnish, tofu perfectly mimics biologic parenchymas (Fig. 26.5). The user can quietly insert needles, see what happens on the screen, refine the angle of penetration, etc. Metallic pieces can even be inserted within the tofu volume, making precise targets for the beginner.

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Ultrasound in the Surgical Intensive Care Unit: Some Peculiarities

27

Our experience comes mostly from the medical ICU but includes a prolonged observation in the surgical ICU. These patients are roughly the same, since a large amount of disorders are common – lung or pleural disorders, thromboembolic disease, infections, etc. Chaps. 1–20 and 22–29 are common to all populations. Some subtle peculiarities can be drawn. Our 5-MHz microconvex probe is suitable for both populations.

General Issues

Acoustic barriers are more numerous in the surgical patient: wounds, dressings, orthopedic material, cervical collar, etc. Most can be overcome if really necessary. In the trauma setting, the low average age is a factor facilitating the examination. The problems of sepsis control are more important than in the medical setting, and vigilance regarding crossed infections must be reinforced (ultrasound units with flat keyboards seem a minimum). Deep collections are more common to the surgical patient.

Postoperative Abdominal Ultrasound

Dressings sometimes cover the entire abdominal wall. Persons responsible for the dressings (surgeons, nurses) should be taught to wisely apply dressings, since critically ill postoperative patients will unavoidably have ultrasound examinations. The probe can be inserted in sterile conditions, and a sterile contact product can be used. The sterile protection of the probe should conduct the ultrasound beam without interference [1]. Fine transparent adhesive dressings, such as OpSite, offer the advantage of being transparent to ultrasound. Some thick dressings with thick network may seem impenetrable by ultrasound, but the beams occasionally are not stopped, and basic answers to clinical questions can be obtained (free blood).

Apart from the anomalies described in previous chapters, ultrasound will search for infected postoperative collections [2]. For some authors, ultrasound sensitivity is high and specificity is low [3]. Noninfected collections, usually anechoic, are possible in this setting: serous, lymph, urine, bile, or digestive liquids. The increase in volume of a collection is one criterion for reoperation in postoperative peritonitis [4]. We simplify the approach by liberal interventional diagnostic ultrasound (see Figs. 25.2 and 25.3 page 254). At the expense of useless taps (but not deleterious if basic rules are respected), septic or hemorrhagic postoperative complications are promptly detected.

As to the therapeutic part, a percutaneous drainage can be preferred to classical surgery, when the locations are not too complex and when the route is not hindered by bowel obstacles for instance [5]. The diagnostic tap helps in assessing the viscosity of the fluid, which helps for choosing the pertinent material. We withdraw the maximum of pathologic fluid using fine material when the viscosity seems in agreement (help of the induced sinusoid sign, see page 35 and 36), before envisaging the percutaneous insertion of more traditional tubes (large pigtail materials) required for thick fluids [6].

From our experience, acute acalculous cholecystitis is probably particular to the surgical ICU. On the other hand, popular disorders, such as the familiar subphrenic abscess, are rarely seen. Forgotten foreign bodies can be detected. A compress generates a large image with a matrix-like pattern and a massive acoustic shadow. A metallic instrument has a strikingly straight shape, with typical sinuous posterior artifacts: S-lines.

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Hematomas are rather frequent. They are first anechoic, then rapidly become echo-rich, yielding heterogeneous, solid images. They can be observed in the retroperitoneum, the pelvis, and the muscles of the abdominal wall.

Postoperative Thoracic Ultrasound

Hemothorax, pneumothorax, tamponade, phrenic paralysis, pneumomediastinum, some false aneurysms (see Fig. 25.5 page 255), and mediastinitis are accessible with ultrasound. After long and complex operations, postoperative patients have often posterior atelectases, which are easy to detect at the PLAPS-point.

In the postoperative period of thoracic surgery, the intensivist must promptly determine if the content of the hemithorax is fluid or air, if the mediastinal shift is controlled. Ultrasound immediately provides the answer.

A periaortic collection can be detected and even tapped with ultrasound guidance. Sepsis of the prosthesis will thus sometimes be diagnosed. In this severe setting, the current habit is, however, to perform CT.

Here again, appropriate information to the team limits the extent of the dressings.

Thromboembolic Disorders

Upper Extremity Veins

A frequent problem in the emergency setting is the difficulty of inserting a central venous catheter. Postoperative patients have usually to be managed, hypovolemia has often be corrected. Therefore, inserting venous lines may be less difficult than in the medical ICU.

In our experience, the frequency of internal jugular venous thrombosis seems high in severely ill surgical ICU patients. Maybe this experience was biased by a frequent use of Swan-Ganz catheters.

Lower Extremity Veins

In trauma patients, dressings, surgical devices, and postcontusion changes can decrease the potential of ultrasound. Deep venous thrombosis seems frequent in the surgical ICU, perhaps because local trauma is a major cause of venous thrombosis. Compression ultrasound can be painful, and Doppler may have a small interest here.

Specialized Surgical ICUs: Neurosurgical and Cardiac ICUs

In such ICUs, Doppler equipment will possibly be useful.

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Critical Ultrasound Outside the Intensive Care Unit

28

The intensive care unit (medical, surgical, pediatric, etc.) is the first and most important step for developing critical ultrasound, but there are countless settings where the intensivist's experience can be extrapolated.

Ultrasound for Flying Doctors

In an airplane, room is a true concern, and hand-held units are a providence here. We had the privilege to drive the first medical experience of pre-hospital ultrasound – from a medical helicopter in a mission over Morocco, Mauritania, Mali, and Senegal – and are glad to see that this principal paper initiated a wide use in pre-hospital ultrasound [1]. In our pilot study, the physicians directly answered vital clinical questions on-site. A focus on life-saving problems occuring in trauma (pneumothorax, hemothorax, hemopericardium, abdominal bleeding) provided the answer to 90.6% of the questions. The local conditions (sun of the desert, vibrations, interference in the helicopter) in no way affected the ultrasound examination.

So, without mistake, the first pre-hospital ultrasound diagnosis of pneumothorax was made in the Mauritanian desert, in January 1996, using a portable machine (Figs. 28.1 and 28.2). We now use the 1.9-kg compact machine described in Chap. 2 for our flying missions, and would feel really lost without it. By the way, we have designed an ultrasound report dedicated to medical transportation (Table 28.1).

In some countries with a low-density population (Australia), physicians willingly use the air route, and may feel reinforced by this clinical tool.

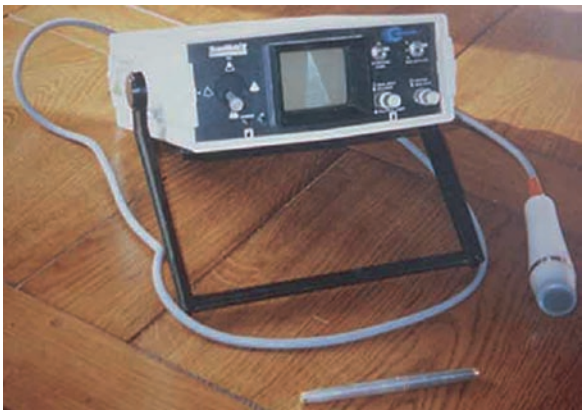

Fig. 28.1 The antique Dymax TM-18. This is the ultrasound unit that we took in 1995 for the Paris-Dakar rally. This machine, with five buttons, no space for storing images, only one probe and a battery, i.e., full autonomy, prefigurating the modern "stethoscope." The pen in the foreground indicates the size of the machine

Fig. 28.2 A première? January 10, 1996, Saharian desert in Mauritania. Pneumothorax in a biker of the Granada-Dakar rally. Maybe the first pre-hospital diagnosis of a life-threatening lung disorder. The concepts we defined and wrote in 1992 (critical ultrasound, lung ultrasound, and point-of-care ultrasound) are concentrated in this simple figure

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Table 28.1 Ultrasound Lump Test Initiating Medical Airway Transportation protocol

Name:		
Date:		
Setting:		
Indication: checking for the absence of occult disorders, which may influence safety of the air medical transportation		
Operator:	Ultrasound unit: Tringa S-50, 5-MHz probe	
Technique: two- dimensional technique only	Various parameters (ventilated patient, etc.)	
Lungs		
- Screening for pneumothorax (2 s × 2)	ABSENT	PRESENT[a]
- Screening for hemothorax (10 s × 2)	ABSENT	PRESENT[a]
- Screening for one lung intubation (5 s)	ABSENT	PRESENT[a]
- Screening for interstitial disorder (6 s × 2)	ABSENT	PRESENT[a]
Heart		
- Screening for pericarditis (10 s)	ABSENT	PRESENT[a]
- 2D impairment of LV contractility (10 s)	ABSENT	PRESENT[a]
Abdomen		
- Screening for pneumoperitoneum (5 s)	ABSENT	PRESENT[a]
- Screening for hemoperitoneum (30 s)	ABSENT	PRESENT[a]
- Screening for mesenteric ischemia (30 s)	ABSENT	PRESENT[a]
- Screening for distended bladder (5 s)	ABSENT	PRESENT[a]
Deep central veins		
- Screening for a venous thrombosis including strategic area or having instable pattern:		
- Internal jugular axes (6 s × 2)	ABSENT	PRESENT[a]
- Iliofemoral axes (15 s × 2)	ABSENT	PRESENT[a]
Head		
- Screening for optic nerve changes indicating intracranial hypertension (7 s × 2)	ABSENT	PRESENT[a]
Miscellaneous elements seen during this examination that will not affect the safety of the transportation, but may be of clinical relevance:		

Average timing, using 15 changes of site: possible in 240 s by trained users

[a]If the answer is "PRESENT" in one or some of these items, the safety of the transportation should be questioned

Physician-Attended Ambulances

What was possible in a small helicopter is even easier in an ambulance. Should one be destitute in the full arid desert of Mauritania or highly medicalized in a road tunnel in the heart of Paris, one may feel the need for the diagnosis of a life-threatening condition. The traditional quandary of "scoop and run" versus "play and stay" can be elegantly smashed when visual medicine is used on site.

Our experience with pre-hospital medicine has been followed in the ambulances by exciting papers [2]. All the content of this book can be achieved without any adaptation in such a setting. We are concerned to see some attempts at developing sophisticated cardiac echo (with Doppler) for this use. Especially if not integrating the lung, it would not be our way of use. After reading of Chaps. 20 and 23, we hope that these attempts will be adapted.

Critical Ultrasound in Shaky Settings

Turbulence (air, road, sea, space, battlefield, etc.) can be a source of difficulties. One relevant issue is the monitoring of a pneumothorax. We describe the van Dravik protocol (with his authorization): before the transportation, we search for an anterior b-line. This is a frequent event at the minor fissura. We carefully mark its location. During the transportation, in spite of vibrations, detecting this b-line is much easier than subtle lung sliding. We regularly take the blood pressure, saturation, cardiac frequency, van Dravik protocol, and the trip goes on safely.

Ultrasound in the Emergency Room

Developing ultrasound in the emergency room is of major interest. We do not deal here with the critically ill patient, who has been promptly managed in a private circuit of the ER, is rapidly sent in the ICU, and benefits from the 27 previous chapters. We deal with all the other patients, since a main problem of the emergency team is centered on the necessity to decrease the recurrent accumulation. We are not keen on the word *triage* as typically used. Ultrasound provides a diagnosis, not a rough triage indication. An impressive number of situations (renal colic, rib fracture, withdrawal of foreign body, even spinal tap, and a hundred others) can be quickly diagnosed or ruled out. Excellent textbooks are now available in this setting.

In the ER, the laptop units were a commercial solution to a scientific problem, which was to just think different. There was enough room for the 1982 technology units, such as the ADR-4000 (40-cm wide), and even more for the 1992 technologies (our machine, 29-cm wide). We invite the readers to use the instrument featured in Fig. 30.2 page 298 for measuring the width of the units currently invading their ERs, and above all to consult Fig. 30.4 page 300 about the image resolution, which shows how subtly the community lost 25 years of progress. See more details in Chap. 30.

Maybe in an ER with less urgent and less life-threatening problems Doppler would be a little more interesting. Yet when studying each situation one by one, we always have an alternative, and still consider that its utility can be balanced. We remind the reader about the DIAFORA concept,[1] indicating that we are not closed to Doppler, for moderate emergencies. When we ask our emergency colleagues why they need Doppler, the answers are multiple but, interestingly, different from one doctor to another. Some want to diagnose deep venous thrombosis (Chap. 13 showed that it is not mandatory). Some want to know the cardiac output (these are usually patients for the critical care physician, and Chap. 23 showed a simple alternative). Some want to assess abscesses before puncture, when they fear confusion with pseudo-aneurisms. In this case, the clinical data (history, thrill) and the moderate degree of emergency allow the doctor to avoid inserting a needle in these kinds of structures (see our note about round masses in Chap. 26 page 266), and ask for the classical Doppler analysis done by specialists.

Some would like to distinguish testicular torsion from orchiepididimytis. We develop this point a little (Fig. 28.3). First, in order to locate its relevance, we must consider that the frequency of testicular torsion is low. It should be interesting to study the accuracy of combining simple but insufficient clinical tools (age, temperature) with ultrasound signs, simple (testis size) or more subtle (epididymal structure). Knowing that Doppler is not perfect (yielding false-negatives), it should be interesting to quantify the real relevance of Doppler. The DIAFORA approach can be used during

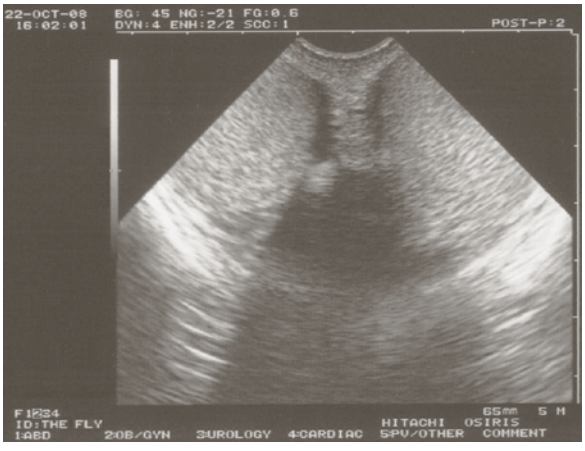

Fig. 28.3 This kind of fly with these voluminous bulging eyes is often seen wandering in the ER, but rarely reaches the door of the ICU – a domain not developed in this book. It is, in fact, an ultrasound image of healthy male fertility organs

[1]Doppler intermittently asked from outside in rare applications

open hours. The aim is to see a minimal rate of useless exploratory surgery. Meanwhile, lives are saved daily using simple ultrasound. This example illustrates a principle used with the BLUE protocol: the clinical approach is mandatory but insufficient. Combining it with accurate ultrasound data makes a winning couple.

There are multiple examples where the DIAFORA approach will solve not very urgent or not very life-threatening problems, but we cannot deal with them in this volume.

The surgeon called at the ER may consider ultrasound a beneficial tool [3]. Thousands of articles show that this option is reasonable. Acute appendicitis [4], intestinal obstruction and pneumoperitoneum are some openings among many.

The place for non-ICU emergency ultrasound will not be limited to the ER alone.

Ultrasound in the Trauma Room

This extensive field will be briefly described, since Chaps. 5–24 contain the necessary information.

When we wrote our 1992 edition, car accidents created severe lesions, CT was an adventure for these patients. Facing countless minutes for image acquisition, many patients never came back from the CT department. The year 1982 (ADR-4000) was a golden opportunity for critical ultrasound to develop – a quiescent revolution for a complete autonomy. Countless stars in the sky are trails of lives that could have been easily saved from this time (or perhaps even before).

Now, the situation is changing, since each small city has some ultrarapid CT units, the doctors have just to push the button and have a whole body analysis in 10 s, which provides a complete study of the deep organs, the skeleton (cervical spine), a functional study by iodine injection that shows vascular ruptures or parenchymal lesions at the liver, spleen, kidneys, etc. It is, therefore, natural to highlight CT scan as the first tool in trauma – now [5,6].

We will not underline again CT's drawbacks. CT is still reserved for the most stable patients, and to be fair, we know some remote areas in the far world that are not yet equipped with hypermodern CTs. We hope that the development of pre-hospital ultrasound will allow more patients to come alive to the hospital. Let us also consider that CT access may become restrained in the future for limiting irradiation – making ultrasound of major interest in focal trauma [7].

Lung

On site, ultrasound detects disorders requiring immediate management: hemothorax, pneumothorax, one lung intubation. Lung contusion [8] yields lung rockets and alveolar consolidation – better than radiography, which is only 63% sensitive [9].

The second principle of lung ultrasound (the sky-earth axis) will be borne in mind if the patient is not strictly supine but, for example, completely imprisoned in an upside down, crashed automobile.

Mediastinum

Aortic rupture can be suspected or detected in patients with favorable morphotype.

Tracheal rupture usually occurs near the carena. The value of standard CT is still obscure. Ultrasound will show parietal emphysema, pneumothorax, abolished lung sliding, or lung pulse. Main bronchus rupture can yield atelectasis. The pneumomediastinum is to our knowledge a subtle diagnosis.

A hemopericardium should be sought routinely in a traumatized patient. There is no need for an acronym for this.

Diaphragm

The diaphragm is almost always assessed using longitudinal scans, an indisputable advantage of ultrasound when compared with the transversal slides of CT (see Figs. 4.1, 15.4, 15.6, 16.2, 16.4, and 16.11). As usual, radiography lacks specificity. Ultrasound, here again, plays a role [10], with emphasis on indirect signs: ectopic locations of subphrenic organs, spleen (liver more rarely), GI tract, and abolished lung sliding in spontaneous ventilation.

Abdomen

Detection of peritoneal blood is a basic step familiar for many [11]. Yet fluid in the peritoneal cavity can be urine, bile, or digestive fluids (easy to diagnose,

see Chap. 26). Signs of pneumoperitoneum mean rupture of a hollow organ. The parenchymal analysis (liver, spleen) should not delay management, but yields characteristic signs: heterogeneous (usually hypoechoic) images of contusion (Fig. 28.4), hyperechoic lines of fracture (Fig. 28.5), biconvex external images of subcapsular hematoma. A pancreatic trauma mimics acute pancreatitis. The diagnosis of vascular rupture (renal artery) is better approached by Doppler, CT, or angiography.

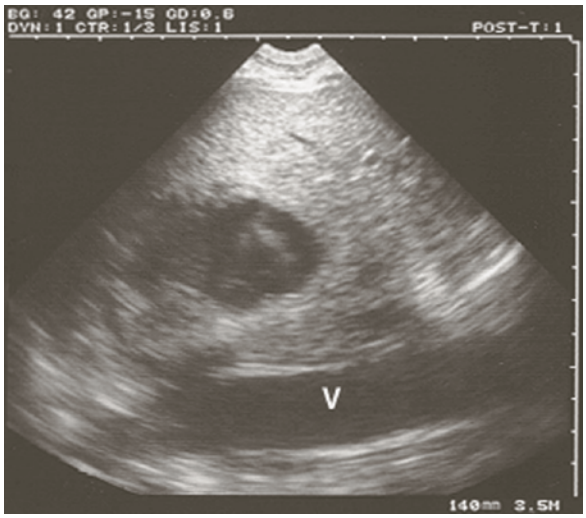

Fig. 28.4 Liver contusion. Heterogeneous ragged image within the liver parenchyma in a young woman with abdominal trauma. *V* inferior caval vein

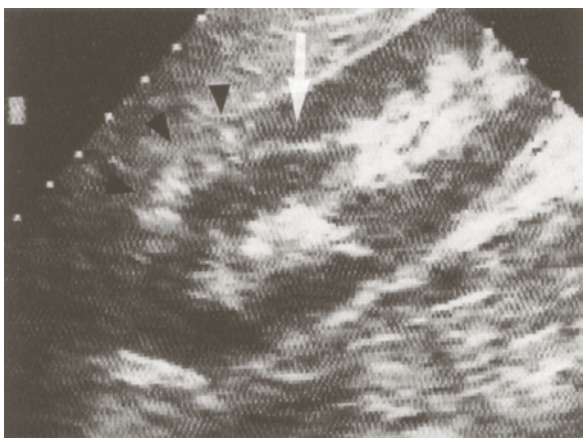

Fig. 28.5 Kidney fracture. The clear line (*white arrow*) indicates a virtual space at the level of the fracture. The *black arrowheads* delineate the hematoma of the renal space. Trauma in 45-year-old male

Head and Neck

Chapter 24 showed how optic nerve analysis informs about a possible brain edema, how eyeball integrity can be checked, how signs of frank cervical vertebra rupture are accessible to ultrasound from C1 to C7.

Carotid artery dissection makes us penetrate into a complex field, as opposed to most applications seen previously. The diagnosis usually refers to Doppler. Enlarged caliper, segmentary ectasis, offset stenosis, radish-tail tapered occlusion, double lumen, intimal flap, anomalies of velocities and pulsatility index with flow inversions when compared with the contralateral artery are searched for [12], yet heavy concerns are present. The skill required is high. Fine analysis is compromised by the cervical collar, or worse, when withdrawn, by the usual agitation of the patient. Heparin therapy can be double-edged in these traumatized patients. Eventually, it is often admitted that a Doppler study of the carotid artery makes no sense if not integrated into the clinical context – a tacit acknowledgement of the weakness of arterial Doppler. In fields such as lung ultrasound, on the contrary, the signs can be interpreted independently from the clinical setting (an effusion is an effusion, etc.), indicating its high degree of standardization. We would like to see, in this delicate context, the same conclusions that were made in the areas of the veins, the hemodynamic, and many others regarding the real utility of Doppler. In this spirit, we currently investigate a simple two-dimensional analysis.

Ultrasound Surrounding the Operating Room

If it succeeds in penetrating into the prestigious operating room, ultrasound can initiate a small revolution. For this, waiting for the laptop era was a waste of time (ceilings are high in operating rooms): the 1992 technology was perfect.

Imagine the orthopedic world, where the surgeons depend so much on the radiologic technicians, and the students receive so much irradiation.

The anesthesiologist would have been able since 1992 (or 1982) to immediately insert central venous catheters with nearly zero error, and control the massive fluid losses of some abdominal interventions,

among other examples. TEE is useful when there is no access to the thorax. Lung ultrasound will find many applications (even used by the surgeon, or any person able to apply a probe on a chest) for making a limited investigation considering volemia – especially in settings where the thorax has been opened (one more limitation of TEE, since the pleural variations are unavailable). See again Chap. 23.

Recognizing high-risk surgical patients is a sharp task. The cardiac function and the BNP are useful, but how about a fast lung ultrasound scanning for identifying these high-risk patients? Some papers are beginning to deal with carotid artery intimal wall analysis (private talk with Tim Mäcken).

Bone Ultrasound

This may be the occasion for creating a whole discipline. Those willing to invest in it (there are 206 bones, more or less) will have a bright future. Basic knowledge allows one to define two kinds of locations.

1. Long bones, where the diagnosis is really simple – femoral diaphysis, tibia, fibula, humerus, radius, cubitus, fingers, ribs, etc. (Fig. 28.6). In this area, minute ruptures (even 1 mm) are detected using soft scanning. This potential is being used at last [13].

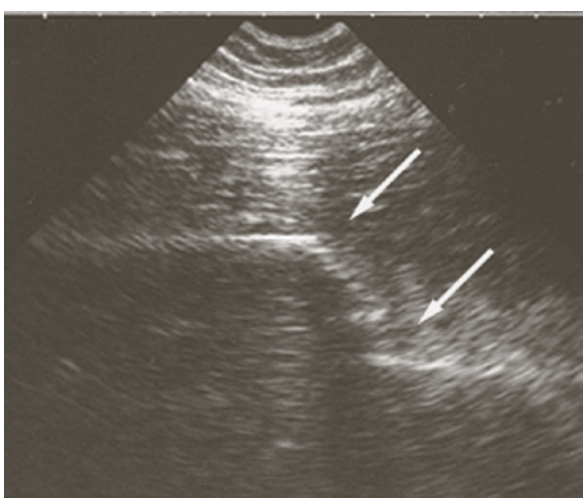

Fig. 28.6 Femoral fracture. This displaced fracture of the diaphysis cannot be missed. The proximal and distal segments are 20 mm distant, without overriding (*arrows*)

2. Bones with more complex anatomy (head of the femur, pelvis, carpe, etc.), definitely needing advanced expertise.

Maybe a new type of specialist will arise, able to diagnose or rule out in seconds familiar situations. Let us consider, from the most vital (odontoid) to the most functional (scaphoid), the possibility of immediately documenting a cranial dish-pan fracture, a displacement of the cervical rachis (see Fig. 24.12 page 251).

Other Usual Medical Disciplines

Ultrasound is welcome everywhere. We calculated that about half of the clinical disciplines would be interested.

We await an investment by physicians who deal with critical situations, especially with the lungs, and from the pediatricians first.

The cardiologists will immediately detect interstitial syndrome.

The pulmonologists have an extremely wide field for daily use.

In thoracic surgery, many concerns can be controlled. A pulmonectomy gives abolished lung sliding and the A-line sign, without any lung point. A swirl sign can be visible when the cavity is filled, little by little, with fluid. After a pulmonectomy, the intrathoracic pressures must be balanced, between the residual air and the contralateral lung. The "gold standard" (mediastinal location on bedside radiography) may be replaced by ultrasound.

Internal medicine may gain time (i.e., costs mainly) with this discipline.

The family doctors may immediately detect whether a child has a pneumonia or sinusitis. In adults, physicians can detect aortic aneurism, among a hundred applications.

Ultrasound of the World

We should consider a striking feature of ultrasound. The same approach, valuable for sophisticated ICUs of wealthy countries (or spaceships) will perfectly suit all these disadvantaged regions of the world, where a

simple radiographic unit is a luxury. In this setting, *the same ultrasound semiotics will be used,* with a low-cost unsophisticated unit acting as a terminal to make therapeutic decisions.

All doctors employed in remote, austere medicine or with mass casualties, and in other areas will discover an impressive potential.

We must congratulate the WINFOCUS and its founders, Luca Neri and Enrico Storti, Mike Blaivas as prominent members, and so many names that this book would suddenly become too heavy. Many of them are, in fact, imbedded in the main text. In the wide field of critical medicine, WINFOCUS has lifted our spirit from 1992 in considering ultrasound as a simple tool for visual medicine through all parts of the world.

Our next edition will report our experience of early detection of lung anomalies in children, in settings with scant resources.

Ultrasound in Space

While many people have to face a difficult life on earth, others are destined to make long interplanetar journeys (initiating other difficulties). A hand-held ultrasound unit is a unique opportunity to diagnose a potential acute disorder that can be managed on-site, typically pneumothorax [14].

Futuristic Trends

A therapeutic use of ultrasound has been proposed since the 1960s [15]. Studies have pointed out the potential role of therapeutic ultrasound for strokes [16]. High-intensity, focused ultrasound may be used for the kidney, liver, pancreas, breast, bones, lung, etc.

Ultrasound for Vets

Our 19 years of research has proved useful in the human being, and is fully extrapolable to animals – let us say mammalians for sure. Usually, some morphine is used and many tears flow when a critical disorder occurs in our beloved pets, without space for sophisticated diagnosis. Imagine the benefit of ultrasound to these pets, who cannot express themselves. Note that veterinarians were not the last to have understood the (commercial) interest for ultrasound (for knowing pregnancy states). Ironically, since 2000, we use in our aeronautic missions a hand-held machine from the veterinary world, contributing to saving human lives from time to time.

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Analytic Study of Severe and/or Frequent Situations in the Critically Ill

29

Our small, compact ultrasound unit (with the 5-MHz microconvex probe) allows for whole-body exploration. How does it work in practice?

Ultrasound Exploration of Acute Respiratory Failure

This is included in this new edition and debated in Chaps. 13 and 20.

Ultrasound Exploration of Acute Circulatory Failure

This is also included in this new edition and debated in Chap. 23.

Management of an Extremely Severe Shock (Imminent Cardiac Arrest)

Most was developed in Chap. 23. We extend our limited investigation in a practical use.

It is correct, from an academic point of view, to distinguish the mechanism of a shock from its etiology. Critical ultrasound – a kind of visual approach – allows a different thought process. In an extremely time-dependent patient, we find it interesting to take all elements into account, as they come, i.e., mechanism *or* etiology, but with a certain logic. Finding either signs of hypovolemia (small heart) or a major source of hypovolemia (hemoperitoneum), both go in the same direction: immediate fluid therapy. Our sequential echographic screening assessing mechanism *or* origin of a shock of indistinct cause (SESAM*O*OSIC – a long abbreviation that we shortened in the SESAME protocol) or our personal examination regarding shock using adapted sonography indicating origin *or* nature (yes, PERSUASIO*O*N, for those who prefer tortuous acronyms) allows pragmatic management of any kind of shock.

The SESAME protocol is used in extreme circulatory instability, a setting where academic considerations can be double-edged. Mostly devoted to young doctors, but currently used by older ones and the author, it made a compromise by combining the situations that were the most frequent, the most easy to diagnose using ultrasound, and the most accessible to immediate management[1].

The SESAME protocol invites one to follow a certain order of examination when facing an imminent cardiac arrest, assuming that all settings are considered together (home, trauma, ward, ICU, this resulting in a thin textbook), and that we have really no clue for orientation. The principle is simple: if the situation is critical, the signs are caricatural. The only exception is the miasma sign, indicating that, when pulmonary embolism is massive, venous thrombosis is discrete. We suggest this order (Figs. 29.1 and 29.2):

1. The first check should be at the BLUE points. Lung sliding immediately rules out pneumothorax. An A-profile is consistent with hypovolemia, and above all allows immediate fluid therapy in this context

[1]The usual errors in diagnosis, yielding rapid death in the night of admission and painful self-questions, were frequent before the era of visual medicine, and usually turned around a few possibilities, mainly obstruction (embolism, tamponade), hypovolemia (bleeding, from any source) and more rarely pneumothorax.

D. A. Lichtenstein, *Whole Body Ultrasonography in the Critically Ill,*
DOI: 10.1007/978-3-642-05328-3_29, © Springer-Verlag Berlin Heidelberg 2010

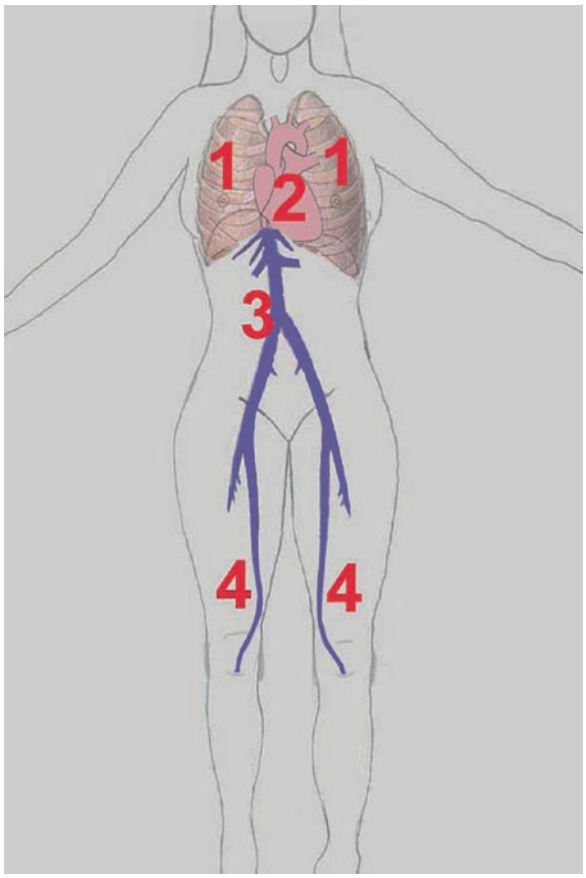

Fig. 29.1 The SESAME protocol. A logical order suggested for assessing an extreme circulatory failure. For the sake of efficiency, this fast protocol mingles the signs of the mechanism and the signs of the cause of the shock. *1* BLUE-point checking for clearance for fluid therapy (and absence of pneumothorax). *2* Simple cardiac sonography, which shows (if the heart is visible) pericardial cavity, left heart contractility, and right heart volume. *3* Fast search for major fluid in the peritoneum. *4* The protocol now searches for deep venous thrombosis. These four steps have pointed on the diagnoses of, respectively, hypovolemia, pneumothorax, pericardial tamponade, cardiogenic shock, hemoperitoneum (hence hypovolemic shock), and pulmonary embolism... in less than 1 min. The SESAME approach is a really fast protocol

[1]. The detection of the B-profile should refrain from immediate fluid therapy (apart from particular situations).

2. The second check is for the heart. If the heart is visible, left ventricle hypercontractility prompts again for fluid therapy, hypocontractility for inotropics (associated with a B-profile, this makes consider cardiogenic shock).
3. A substantial pericardial effusion in this context means pericardial tamponade (not following this speculation will create more harm than good – a rapid visualization of collapsed right chambers dramatically shifts this speculation toward a reality).
4. A right heart dilatation prompts a search for venous thrombosis first (whereas already asking the nurse to prepare fibrinolytic therapy).
5. No available cardiac window is a possibility. Less than 15 s are sufficient for concluding this. Insisting should be deleterious. We immediately leave the heart, giving up (temporarily) the intention to search for a mechanism, and now search for a cause: substantial peritoneal fluid. Such a finding again prompts for fluid therapy, but is redundant: the nurse was already preparing fluid therapy, in accordance to the lung data. We try to see the abdominal aorta (an aortic aneurism in such a context means acute hypovolemia). See sophisticated note below.
6. The venous scanning is done before the search for peritoneal fluid if an enlarged right ventricle with an A-profile is seen meanwhile. Our fast protocol uses the butterfly technique (see page 106) and includes common femoral points and V-points (at the Hunter area) if there is no hole, and jugular internal vein plus iliac vein if there is a local hole (from recent catheterization), following the CLOT protocol (see the section on pulmonary embolism, which deals with the CLOT protocol). We advise the reader not to spend too much energy in searching for a floating thrombosis in the inferior caval vein of this highly critically ill patient: for sure, this vein will be free – now.
7. If the first probe scanning has shown disseminated lung rockets, we do not begin with fluid therapy, estimating that the problem is not related to a low preload. If there is no clinical orientation, we extend the analysis to the lung, beginning with the PLAPS point. A massive alveolar consolidation (which can be visible also at the anterior wall), a massive pleural effusion indicates likely hypoxic shock, ordering massive oxygenation before all, followed by prompt chest tube insertion if required. Fluid therapy is sometimes required (a suddenly white lung means that liters of fluid have invaded the lungs – liters suddenly leaving the volemic compartment).

Time for this exploration – in the best conditions – should be, using our fast system (one smart machine, only one probe, our contact product, etc.) less than 1 min (the minimal time is 35 s). If not contributive, this protocol can be enlarged.

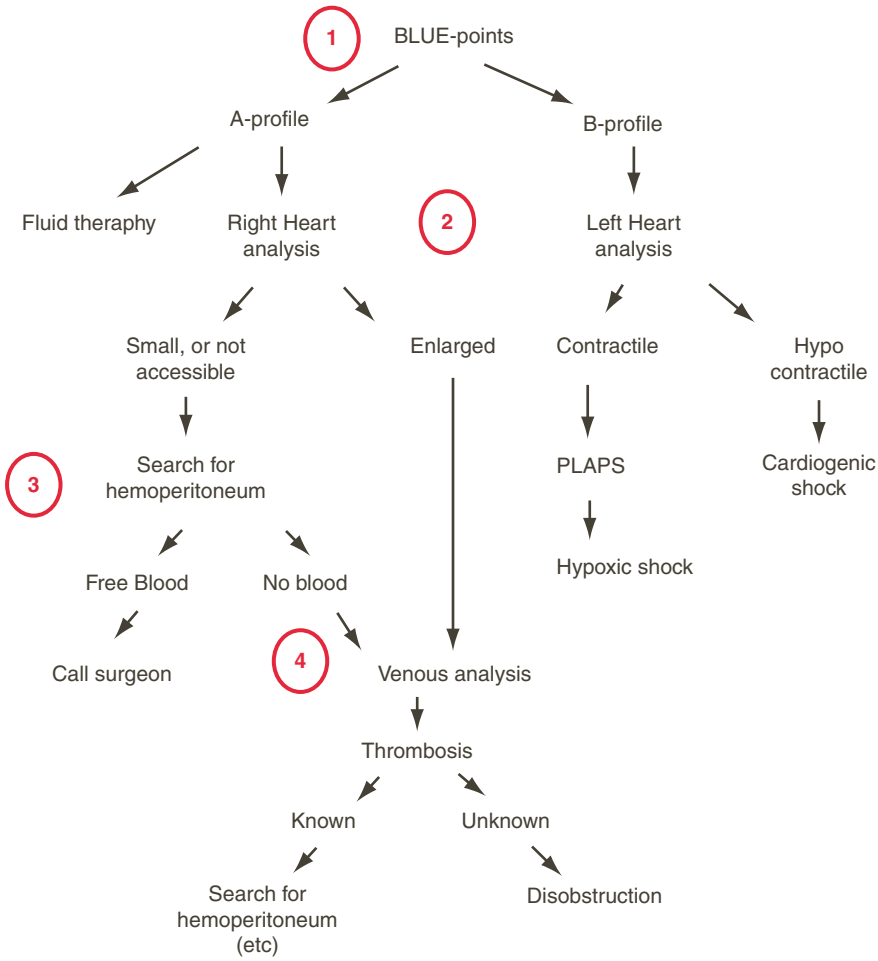

Fig. 29.2 Decision tree – development of the SESAME protocol in a kind of decision tree

We can also search for the mechanism of shock (for simplifying, we do not evoke dissociative shock). We remind the reader that shock was initially considered in Chap. 23.

Cardiogenic Shock

The usual presentation is a left ventricle hypocontractility and a B-profile.

Hypovolemic Shock

It shows a small and hypercontractile left ventricle, an A-profile at the lungs, and flattened veins. The SESAME protocol will associate a site of fluid (major bleeding, or multiple sites of serous fluid, or digestive sequestration of fluids).

Vasoplegic Shock

Anaphylactic shock usually raises no diagnostic problem. It associates lung A-profile, hypercontractile LV, and full veins.

Septic Shock

Depending on the stage, the heart can be hypo- or hypercontractile. Depending on the stage and the cause (lung source), the lung has various presentations, from the nude profile to the B- (preventing fluid therapy), B′-, C-, A/B-, PLAPS profiles.

Obstructive Shock

This classification is a bit artificial for an ultrasound user, since two opposed conditions are put together. Right ventricle collapsed by substantial pericardial effusion makes no major difficulty for diagnosing pericardial tamponade. Right ventricle enlarged plus normal lung surface (A-profile) argue for pulmonary embolism. The relevance of "blind" fibrinolysis in imminent cardiac arrest should be enriched with the information obtained at the lung area.

Side note: What about the ABCDE management?

We do not follow the ABCDE management, because the airway management is a step solved without the aid of ultrasound in the huge majority of cases. Breathing and circulation are really major targets, where ultrasound has a front-line role (BLUE protocol, limited investigation). The brain (with a B, not a D) can wait a few minutes. The E for exposure seems to be here only for closing a shiny "acronym." Our view is that we have no time for subtle acronym management. Please see our comments on page 305.

Sophisticated note:

Searching for peritoneal bleeding before venous thrombosis is not fully logical, because it does not change the immediate management ordered by the lung profile. Yet the abdomen is on the way, and peritoneal bleeding responsible for critical shock is supposed to be substantial. Mostly, finding a venous thrombosis associated with a peritoneal effusion should prompt some reflexion. Maybe this patient was already on heparin therapy (for a documented embolism), and is bleeding from an overdose or a preexisting lesion. No protocol can be 100% logical.

Ultrasound in Cardiac Arrest

Cardiac arrest is a major threat to life. The best medicine is to detect prearrest states and to respect some terminal situations. Facing a cardiac arrest, our role is fast recognition of reversible causes, as underlined by ACLS recommendations. However, the role of ultrasound is not yet specified within these recommendations.

Using simple critical ultrasound during cardiac arrest should become routine in the future. The patient will benefit from prompt life-saving diagnoses: hypovolemia, pneumothorax, pericardial tamponade, pulmonary embolism. Ultrasound can play only a modest or no role in the other causes: myocardial infarction (unfortunately the main cause), hypoxia (no need for ultrasound for administrating oxygen in a cardiac arrest), hypothermia, and toxins.

Carrying out an ultrasound examination during resuscitation of a cardiac arrest was not in most minds when we wrote about it in our 1992 edition. The simple emergency cardiac sonography that we used during this period is now solidly popularized under the names of RACE, FEER, FATE, FOCUS showing that the community took interest in this concept.

Cardiac arrest is not a favorable setting for well-designed studies with accurate "gold standards." There is little room for evidence-based medicine. No evidence of ultrasound usefulness during CPR is available, yet strong signals are perceptible [2]. For want of randomized series, we cannot but rely on anecdotal evidence. We must try to catch information without definite proof, with a major but not too rigid critical mind. Note that even without ultrasound, the management of cardiac arrest is somehow operator-dependent – with new modality propositions constantly appearing, which can increase the confusion.

Simple emergency cardiac sonography will not be useful to the physician who perfectly controls the management of cardiac arrest. It is rather devoted to the young intensivists facing difficult cases and wishing to do their best. We have lost a lot of time trying to explain that the use of ultrasound does not mean a loss of time – but many doctors had in mind these cumbersome machines that needed to be carried out, switched-on with endless minutes of start-up, multiple probes with time for choosing one, making the setting, etc. Such a use would, it is true, definitely lose any chance of saving a patient in cardiac arrest. Paradoxically, in a setting where each second counts, this is time to use fast echo – i.e., having the unit that switches-on in 7 s, the *suitable* probe already set up (a problem that is simply solved by using one probe for the whole body), and no complicated modes that may distract the user. For cardiac arrest, a 5-MHz microconvex probe is perfect for heart, lung, vessels and belly management. Our coupling product allows one to save precious seconds. The protocol developed by Breitkreutz et al. [3] takes greatly into account each second of management.

When cardiac output is interrupted, the blood becomes visible in the heart chambers (Fig. 29.3).

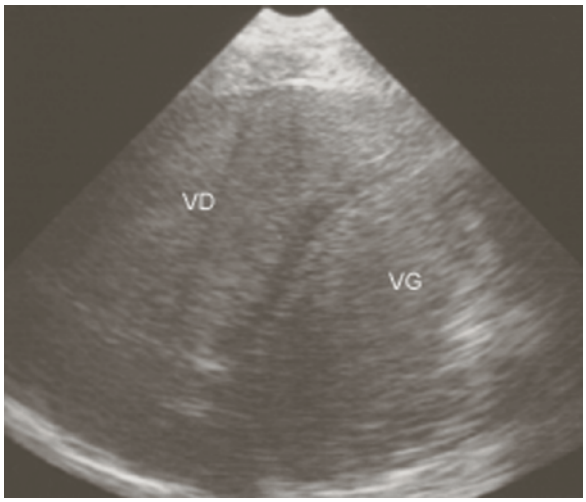

Fig. 29.3 Cardiac sludge. In this subcostal view, all chambers have echoic homogeneous content. This sludge pattern is the immediate result of cardiac arrest (hypoxic asystolia). The chambers will become normally anechoic after recovery of a spontaneous cardiac activity (*VD* right ventricle, *VG* left ventricle)

The user must focus on fast recognition of reversible causes or complications:

- Pericardial tamponade. Even if the cause is rare, the ease of detection is a major raison d'être of critical ultrasound.
- Tension pneumothorax with gas tamponade, a rare but reversible cause. Less than 5 s per lung is sufficient to rule it out.
- Hypovolemia (lung A-profile associated with massive free fluid in the peritoneal and pleural cavity).
- Identifying a cardiac dynamic in a patient with clinical cardiac arrest, i.e., missing pulse. A persistent activity recorded on EKG defines electromechanical dissociation (EMD), or, more modern, pulseless electric activity (PEA). PEA remains a severe accident [3]. Ultrasound can distinguish a standstill heart, which characterizes true-PEA (half of cases), from a persistance of myocardial activity, called pseudo-PEA (the other half). Swinging heart and kissing walls are cases of pseudo-PEA. Half of the cases of pseudo-PEA can benefit from return of spontaneous circulation.
- Confirm an asystole: standstill heart, including true-PEA, of severe prognosis, as shown in the large series of Blaivas et al. [4].
- Recognize some causes of arythmia: high degree auriculoventricular block. Auricle systole not linked with ventricle systole is characteristic. Ventricular fibrillation may mimic asystole on EKG and give on ultrasound a shivering myocardium. In ventricular tachycardia, observations seem to show barely detectable ventricular contractions. Torsade de pointe seems to give more marked contractions. Clearly, many other potential signs exist, being complementary to the EKG or quicker.
- As a typical "subtle" sign, left bundle block yields septal contraction anomaly.
- One-lung intubation (the lung pulse) or esophageal intubation.

Interventional ultrasound allows immediate draining of a tamponade or a pneumothorax. It allows for fast central venous access: simply checking for a favorable venous caliper or ultrasound-guided procedure. This is no time for traditional catheterism, this is time for our ELSISCEC system, with the 60-mm-long catheter, described on page 97 of Chap. 12 and page 265 of Chap. 26. This multipurpose equipment should obviously be on-site on the ultrasound cart (one more reason for having a cart, one more reason among many for not finding major interest in the laptop philosophy). For nonskilled users, the femoral route is the best since the massage can be maintained (remember that the arterial pulse is difficult to detect). For non-experimental users, less than 15 s are sufficient for the internal jugular or subclavian access.

If an EES probe must be inserted, ultrasound has a double advantage: immediate venous access and guiding the probe within the cardiac cavities.

Once cardiac activity is restored, the same information (pneumothorax, hemothorax, tamponade, venous access, etc.) should be searched for in a more quiet atmosphere.

As seen, everything turns around the concept of being *fast* – a word that we do not like to spoil. Academic readers will wonder if this use of ultrasound will decrease mortality and neurologic sequela of this drama. We keep the question open. One point is not insignificant: our profession is made up of a lot of technicalities, but also some part of emotion. Managing a cardiac arrest using *visual* assistance allows the physician to see that everything is done for this patient. This enables us to endure our stressful profession with optimal efficiency, year by year. This is good for the doctor, and is consequently good for the many other patients he or she will manage. Critical ultrasound keeps physicians active.

Technical note: Some like to benefit from a radial artery during resuscitation, in order to distinguish shock without pulse from PEA [5]. For them, since we find it deleterious to change the probe (cardiac probe for linear probe), our extremely simple solution, allowing us to keep the same microconvex probe, was presented on page 255, Chap. 25.

Septic Shock

This section is short because previous pages of this book have dealt with this disorder. In septic shock, immediate adapted therapy results in a decreased death rate [6–8]. Critical ultrasound shows the sepsis site at the bedside [infected pleural effusion, peritoneal collection, rupture of hollow organ with pneumoperitoneum, acute cholecystitis, biliary or urinary obstacle, deep abscess (liver, spleen, kidney, pancreas, or even lung), bacterial pericarditis, endocardial vegetation in most instances, mediastinal collections, severe maxillary sinusitis, soft tissue abscesses, etc. Nearly all of these findings can benefit from ultrasound-guided diagnostic tap (empyema, peritonitis, etc.) with maximal safety using this visual control. The sample is promptly sent to the laboratory. This authorizes immediate and adapted (not probabilist) therapy [9] while calling the surgeon if required. The use of simple ultrasound, either at the hemodynamic and diagnostic step, should change the usual management of septic shock.

Pulmonary Embolism: A Crossroad

Pulmonary embolism is a guest star of this book, having the honor of being featured in Chaps. 13, 15, 16, 17, 20, 22, and 23. It will here benefit from a synthesis.

For this daily concern, obvious here, tricky there, the abundance of protocols indicates that any simplification is required. The usual tests can generate misleading results [10]. D-dimers raise increasing reluctance. Helical CT, the gold standard, is not perfect [11]. Any help should be studied with interest, especially if noninvasive.

We provide a reminder the ultrasound signs:

Venous thrombosis – found in roughly 80% of cases when using the appropriate tool at the appropriate sites.

Pleural effusion, alveolar consolidation, typically C-lines – a sign of limited interest in the critically ill.

The A-profile, i.e., a majority of anterolateral A-lines – a sign of normality, highly suggestive in a patient with respiratory failure.

Dilated right ventricle. The relevance of this sign is moderate in acute respiratory distress but major in acute circulatory failure. The BLUE protocol has demonstrated that a patient with acute respiratory failure and an A-profile (the usual presentation of pulmonary embolism) has no left heart failure – since there is no sign of pulmonary edema, and has usually the right heart failure common to embolism, pneumonia, COPD, etc. The place of cardiac echography can therefore be simplified, allowing democratization of this part of medicine.

A dislodged thrombus directly visible in a branch of the pulmonary artery makes the diagnosis. Our simple approach can achieve it in certain cases (see Fig. 22.15 page 217), or traditional echocardiography, or transesophageal echography [12]. The most direct way should probably be endovascular ultrasound [13], which could probably be done at the bedside. Note that pulmonary embolism is rare. Pulmonary embolism without venous thrombosis is five-times rarer. We wonder whether such an approach could not be developed by ambulatory teams (similarly for bedside caval filter insertion, see Chap. 26 page 265).

We do not pay major attention to posterior lesions (PLAPS). Although frequent (52% in the BLUE protocol), they completely lack specificity with most other causes of respiratory failure. Since infarctions have no time to develop, we think these lesions are mostly due to small atelectases, secondary to alteration in surfactant and reflex bronchospasm [14].

All in all, ultrasound allows, *most of the time*, the intensivist to avoid transportation of unstable patients to the CT room, or conventional angiography. Or worse, to initiate blind heparintherapy or blind thrombolysis in this shocked patient without major proof. Finding here evidence of embolism, or there differential diagnoses (pneumonia, pulmonary edema, abdominal disorders with thoracic pain, etc.), our simple approach should find interest to the intensivist.

We open the discussion here about one potential of critical ultrasound: the possibility to classify any suspicion of pulmonary embolism seen in the ER into four categories:

1. Severe state plus visible venous thrombosis: extreme risk for sudden death
2. Severe state without visible venous thrombosis: major risk for sudden death
3. Good tolerance with venous thrombosis: risk for sudden death
4. *Good tolerance without visible venous thrombosis*

This last situation is interesting because the management can be adapted.

Case of the Nonsevere Patient with a Weak Suspicion of Pulmonary Embolism and Negative Venous Ultrasound

For once in this book, we deal with a noncritical situation. It regards the case of a young woman, e.g., with isolated basithoracic pain, seen in the ER.

We deal here of this situation because traditional managements can do more harm than good. The fear of the doctor to see such patients suddenly die is justified. Yet the (laudable) energy invested in this diagnosis – in the particular setting described here – implies night aggressive helical CT (without premedication), possibly pulmonary angiography, blind night heparintherapy, or blind thrombolysis, plus the remote consequences of irradiation. The price to pay for this behavior is a certain morbidity [15–17].

The Grotowski law speculates that a few seconds before sudden death occurs from a massive pulmonary embolism, there is *always* a voluminous, floating, highly unstable deep venous thrombosis – easy to detect using simple ultrasound at the iliocaval areas, present since an indetermined period, in a patient with no or little thoracic complaint. De la Pallice was said to be still alive 5 min before his death (in the year 1525). Usually, 5 min before death, people are in extremely critical shock. For drama such as massive embolism, De La Pallice was possibly right: massive pulmonary embolism should be anticipated.

Here, the venous network is supposedly free (i.e., really free, see Chap. 13). We must define the patient as having a reasonable safety margin, i.e., not with chronic respiratory disease, not with acute major dyspnea, nor foreseeable respiratory fatigue. The Grotowski law (do not search for this name on the internet) is based on the speculation that using simple ultrasound, such patients can be located far below the morbidity line. The balance between benefits and risks can be completely modified using ultrasound. What is reasonable in one situation is no longer in another.

Those who would exploit the Grotowski law to its limits would simply assume that a patient as defined above can have a pulmonary embolism anyway – since a *small* venous thrombosis was possibly missed. Such patients are assumed to present *moderate* chest pain, with *moderate* discomfort, i.e., time for quietly scheduling usual investigations – or more pragmatically, the old scintigraphy, which will be relevant precisely in a patient without lung disorders (nude BLUE profile). It can here be done during open hours, is far less irradiating that helical CT and is therefore more elegant. Meanwhile, a frequent situation can happen: fever appearing, or positive hemocultures, and distinct worsening of the respiratory conditions indicating blazing ARDS. In such an evolution (not infrequent), sending the patient to helical CT is really at risk, there is no longer time for the diagnosis of embolism. The use of critical ultrasound will give a new future to scintigraphy.

In other words, we consider that the distinction made by the BLUE protocol between severe and nonsevere pulmonary embolism has a relevance in patient management. Subtle alveolar signs may be found in nonsevere pulmonary embolism [18]. In the experience of the BLUE protocol, they usually indicate infectious processes.

Another frequent situation is the patient in the ICU who presents a possibility of acquired embolism.

Case of the Critically Ill Patient with Previous Major Lung Disorders (ARDS): the CLOT Protocol

This is the case of the ARDS patient after several days of mechanical ventilation, several venous line insertions, etc. The CLOT protocol proposes a new, reasonable approach to the diagnosis of pulmonary embolism in such patients. The diagnosis is sometimes suggested by sudden clinical worsening after some improvement, but the challenge is major at first view. A right ventricle which has undergone intensive training (e.g., several days of ARDS) has, little by little, adapted to this increased downstream pressure

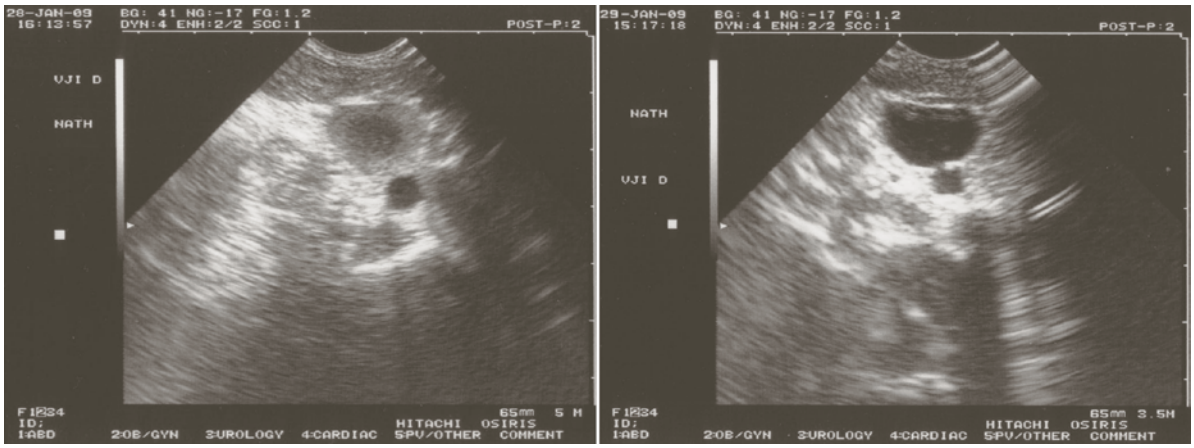

Fig. 29.4 The CLOT protocol. Transverse scan of the neck of a young woman with ARDS. *Left:* A massive internal jugular thrombosis is visible. Real-time showed movements inside this thrombosis and any compression was carefully avoided: this scan was diagnostic (i.e., gold standard, in our opinion). *Right:* The same patient, same view, 24 h later. We are not sure whether a physiologic fibrinolysis can dissolve such an occlusive thrombosis in this short time. We can only speculate that the massive clot of the left image is somewhere else

by hypertrophying, therefore making the conditions for not enlarging in the case of embolism (personal opinion). Therefore, a thickened right ventricle, just slightly enlarged, is not a major contribution. D-dimers are virtually never negative in ARDS. Referrals to CT are usually not envisageable. Even lung ultrasound is poorly contributive, virtually never showing an A-profile. Usually, B-, B′-, or C-profiles are seen. Venous thromboses are frequent [19]. The *CLOT protocol* was evoked in Chap. 13. The CLOT (catheter-linked occult thromboses) protocol uses the Grotowki law, and is defined by daily applying the probe onto skin areas that show holes from recent or present catheterizations. The dressing of a catheter is only a slight hindrance, when using our microconvex probe, since information is usually obtained, at least for downstream examination. One or more of the six usual sites (subclavian, jugular, femoral) are checked, taking less than 1 min (for the six sites). The CLOT protocol is routine or goal-directed in case of acute impairment. A positive CLOT protocol is defined by the sudden disparition within 24 h of a thrombosis previously detected. Assuming that a physiological thrombolysis requires several days for dissolving a thrombosis, the CLOT protocol makes the assumption that the thrombosis has not been dissolved but has embolized. Finding a deep thrombosis during a CLOT protocol, the physician is free to treat it or not. Facing a positive CLOT protocol, this physician should consider that the diagnosis of pulmonary embolism is highly suggested – not to say more. Figure 29.4 summarizes the CLOT protocol.

All in all, our ultrasound-enhanced clinical management uses, one more time, the principle of simplicity.

ARDS

ARDS is in full crisis currently (which definitions, which real frequency of each face, which therapies, which outcome...?) and this is maybe an opportunity for the patient to benefit from a bedside lung ultrasound in emergency. The physiopathologic basis of lung ultrasound in ARDS was dealt with in Chap. 20 page 192.

We briefly review the ultrasound arguments for ARDS (versus hemodynamic pulmonary edema), facing a patient with white radiography: anterior location of alveolar consolidation (C-profile), abolished lung sliding (B′-profile), unilateral anterior lung rockets (A/B-profile), or absence of anterior lung rockets (A-profile). The B-profile, found is 97% of cases of hemodynamic pulmonary edema, is seen in only 14% of cases of acutely dyspneic patients coming for pneumonia initiating ARDS [20]. Lung sliding is frequently abolished (between 33% and 40% of cases).

Ultrasound facilitates an understanding and evaluation of the disease. Each of the main disorders (alveolar consolidations, interstitial changes, pleural effusions, and pneumothorax) benefits from a qualitative and quantitative approach, as detailed in Chaps. 14–18. Diffuse B3-lines are correlated with ground-glass areas [21], a notion of interest for those intensivists who adapt the management according to this pattern (study in progress).

Ultrasound allows bacteriological diagnosis, when a microorganism is isolated from a thoracentesis.

Ultrasound allows the monitoring of each component of the disease.

- Pneumothorax is immediately managed.
- Pleural effusion can be withdrawn at will.
- The consolidation volume shrinks under recruitment therapies. We do not enter in the debate whether alveolar recruitement is good or bad (in terms of generating acute right heart failure, septal interference, impairment of the right coronary circulation, etc.). Those who want to recruit can benefit from this bedside visual guidance. Ways of avoiding overdistension using lung ultrasound are under study.
- The amplitude of lung sliding can be measured (see the section "Evaluation of Lung Expansion," page 159).
- It will soon be possible to specify which patient should benefit from the prone position. Anticipating many rejections, and lost time (years), we confide the principle of our study in progress for free, for the benefit of the patients. If diffuse interstitial syndrome is not associated to substantial posterior alveolar consolidation, this heavy maneuver may not be beneficial. Lobar patients (assuming A-profile plus PLAPS) may benefit from it. In a prone patient, ultrasound remains feasible, the patient benefits from the "prone points" (see Fig.14.6 page 122). A trans-scapular lung approach is fully possible (Fig. 29.5).

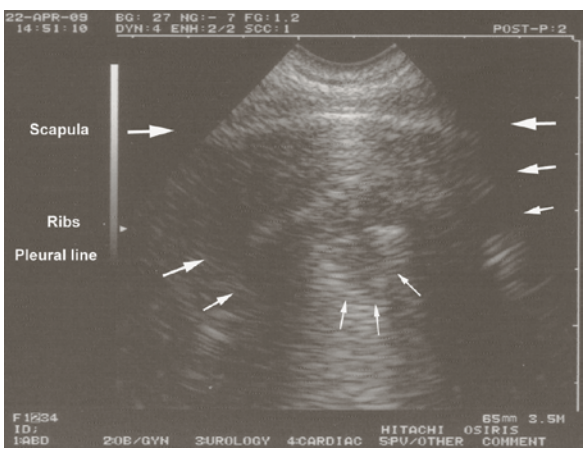

Fig. 29.5 Two dogmas. This single figure simultaneously encompasses two dogmas, which stipulate that air as well as bone are insuperable obstacles to ultrasound. At the top of the image, the scapula is indicated by the *large upper arrows*. The *intermediate arrows* indicate the ribs. The *lower, smaller arrows* indicate the pleural line. Arising from the pleural line, an alveolar consolidation, with a shred sign, is perfectly identified (*vertical arrows*). Even measurements can be done: this piece of consolidation is 12-mm thick (or the consolidation index is roughly 1). ARDS in a 35-year-old patient with pneumonia, in the prone position

The whole of these simple interventions may optimize patient's survival or quicker discharge from the ICU.

Fever in the ICU: The Fever Protocol

Fever or occult manifestations of sepsis (circulatory, hepatic or renal failure, fluid retention, muscular shrinking, etc.) is the usual daily situation in the ICU. Low cardiac output, fall of diuresis, anuria, increase in creatinemia, cholestasis, occlusion, edema of lower or upper extremity are some other conditions awaiting the patient. All have a common point: a major place for simple 2D ultrasound.

There is no acronym in "Fever protocol," just a daily situation. Those who need acronyms may call our protocol the FICUS (fever in the intensive care unit sonography) protocol. The 286 previous pages have shown how to rapidly find a cause of fever.

One can once again use the bulldozer method, i.e., scan from head to feet.

- Anecdotical: optic nerve (fever due to intracerebral infectious process).
- Daily: maxillary sinusitis.
- Daily: internal jugular, subclavian, or iliac venous thrombosis. This is the CLOT protocol, used here not because of pulmonary embolism but in the investigation of fever.
- On occasion: extension to the arm veins (Fig. 29.6).
- Daily: lung, especially the PLAPS point (the anterior analysis is here of lesser relevance). The lung and pleural space are the most familiar sites of infection in the critically ill [22].

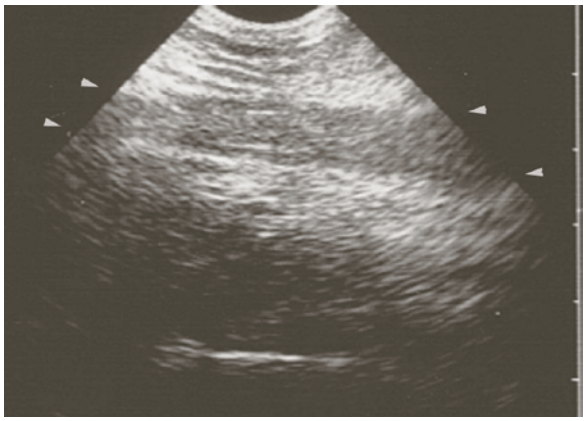

Fig. 29.6 Venous humeral thrombosis. Complete thrombosis in an ICU patient with unexplained fever (*arrowheads*). The diagnosis is: tubular structure, echoic pattern, uncompressible image, satellite artery (not visible here) continuity with the same tubular structure, anechoic, compressible. For once, a longitudinal scan at the arm. Note that a 5-MHz microconvex probe has been used. In patients who are too slender, for teams who have no vascular probe, some cheap *tofu* will create adequate acoustic interposition

- Anecdotical: endocarditis.
- Classical but infrequent: cholecystitis.
- Infrequent but immediate to document: GI-tract complication, peritoneal effusion, pneumoperitoneum.

One familiar itinerary begins from the right upper quadrant for a sudden pain, which shows a normal liver parenchyma, a normal gallbladder, and dilated hepatic veins. This initiates a search for dilated right ventricle, which invites one to move to the sites of catheterization for detecting a remaining venous thrombosis. The sudden pain was simply an acute cardiac liver, and should be simply relieved by prompt heparin therapy.

Anuria was a situation dealt with in a whole section in our previous edition (since dealing with decreased cardiac output). It simply needs a routine search for probe obstruction, and, if negative, routine investigation of a shock.

Other causes of fever, such as bedsores, are superficial and today are not a matter for ultrasound.

A routine exploration can draw up an "ultrasound photograph" that, like a regular physical examination, detects new emerging alterations. The CLOT protocol is a typical application of this concept.

Other Contributions of Routine Ultrasound in a Long-Stay Intensive Care Unit Patient

Apologizing for the use of multiple abbreviations (in the aim of fast communication), we saw the role of the BLUE protocol (dyspnea), the FALLS protocol (circulatory failure), the CLOT protocol (embolism), the SESAME protocol (imminent cardiac arrest), and the FEVER protocol (fever). Countless other situations can be revealed using simple ultrasound: sudden pneumothorax or pulmonary edema under mechanical ventilation, urinary obstacle, denutrition, etc.

Labeling all these uses, in the name of the SLAM (see page 304) in one locution, would make a simpler medicine. How about the "ULTRASOUND protocol"?

Difficult Airway Management, Difficult Weaning of Ventilated Patients

This was considered in Chaps. 14–20. Esophageal intubation is a clinical diagnosis, which can be confirmed in a few seconds (see Chap. 24 page 251). In one-lung intubation, a lung pulse is immediately visible [23], the left cupola is still whereas the right cupola has exagerated amplitude. This potential of ultrasound is slightly expanding [24]. Ultrasound can again help before or during tracheostomy [25,26].

For weaning, ultrasound can detect a number of unfavorable conditions:

- Diffuse interstitial changes (fluid overload or inflammatory changes) – usually radio-occult.
- Substantial pleural effusion – often radio-occult.
- Alveolar consolidations, radio-occult if hidden by the diaphragm.
- Pneumothorax – possibly radio-occult.
- Phrenic dyskinesis (radio-occult).
- Venous thrombosis (of any territory), a source of small but iterative emboli.
- Substantial peritoneal effusion, creating abdominal hyperpressure, and hampering phrenic excursion.
- Maxillary sinusitis, a possible source of pneumonia.
- Vocal cord edema, laryngeal edema are sources of post-extubation dramas (stridor). Stridor can complicate from 2% to 15% of extubations [27]. The cuff-leak test has good negative predictive value but poor

positive predictive value The ultrasound air-column width measurement should identify high-risk patients.

Exploration of a Thoracic Pain

Pain is assumed to be intense since the patient is managed by the intensivist.

One main cause is acute coronary syndrome, a challenge for ultrasound, needing great expertise. Fortunately, there are other tools, mainly the EKG, which is usually performed in such settings.

Apart from this, the majority of disorders yielding thoracic pain give characteristic signs, described in Chaps. 13–21. Great vessels (pulmonary embolism, aortic dissection, aortic aneurism, aortic trauma), other vital tubes (tracheal rupture, esophageal rupture), heart envelope (pericarditis), lung (pneumonia), pleural space (pneumothorax, pleurisy), chest wall (rib fracture).

Defining the Cause of an Abdominal Disorder

Nearly all major painful abdominal syndromes give ultrasound signs. Ultrasound gives more information than plain radiography and is often able to replace CT for indicating surgery. The user is free to use any order; this is a methodic one.

The Wall

A parietal hematoma or abscess can simulate intra-abdominal emergencies.

The Peritoneum

Analysis of gut sliding and the peritoneal cavity can detect pneumoperitoneum, peritonitis, or hemoperitoneum.

The Bowel

Many items are accessible:

Peristalsis (mesenteric infarction?)
Wall thickening (pseudomembraneous colitis?)
Loop caliper (occlusion?)
Intraparietal gas (bullous pneumatosis?)
Intrahepatic gas (mesenteric infarction?)
Gastric repletion (acute gastric dilatation?)
Fluid contents (sequestration with hypovolemia)

Other Hollow Organs

Cholecystitis, angiocholitis, obstacle of the upper urinary tract and bladder distension are possible diagnoses.

Plain Organs

Liver and spleen abscesses are usually rapidly diagnosed. Acute pancreatitis gives signs in the best cases.

Vessels

Ruptured abdominal aortic aneurism is a priority diagnosis.

Mesenteric venous thrombosis can sometimes be easy to detect.

Retroperitoneum

Retroperitoneal hematoma is a basic diagnosis but requires some expertise.

Thoracic Disorders with Abdominal Expression

Pneumothorax, pleural effusions, pneumonia, and some cases of myocardial infarction can, clinically, confuse with surgical abdominal emergencies.

Exploration of Acute Deglobulization

In acute anemia with signs of shock, ultrasound has rapid access to all possible sites of hemorrhage.

Have in mind that in a polytraumatized patient, the sites can have modest volume but their number can generate hemorragic shock. Hemothorax, hemoperitoneum, hemopericardium, capsular hematoma (liver, spleen, kidneys), retroperitoneal hematoma, soft tissue collection (femoral fracture), and even GI-tract hemorrhage with gastric or bowel inundation is quickly recognized. The following step, if needed, is confirming the nature of the effusion using a safe diagnostic tap.

A normal ultrasound scan brings to mind other causes for a drop in hemoglobin (hemodilution, hemolysis, etc.).

In GI-tract hemorrhage, ultrasound is not mandatory for management, but the reader can just imagine the following benefits:

Early diagnosis of hypovolemic shock (Chap. 23).

Early diagnosis of GI-tract hemorrhage, before any exteriorized bleeding (Chap. 6).

Immediate insertion of a venous line (possibly central) in a severely hypovolemic patient (Chap. 12).

Diagnosis of esophageal varices, cirrhosis, indirect signs of gastroduodenal ulcer (Chap. 6).

Guidance for inserting a Blakemore probe (Chap. 6).

Early detection of complications stemming from the Blakemore probe: esophageal rupture, with left pleural effusion (Chap. 15), left pneumothorax (Chap. 18).

Detection of an abdominal aortic aneurysm (Chap. 11), with leakage in the GI-tract, a rare finding with immediate therapeutic consequence.

Detection of enolic dilated cardiomyopathy (Chap. 22), a possible association, which can result in a poor adaptation to acute hypovolemia.

Monitoring gastric content (Chap. 6).

Pain Management

Ultrasound plays an immense role in pain management.

First, it allows to confirm immediate diagnoses. Years ago, the patient came in the ER twisting from visceral pain, had to wait for examination by the first doctor, then the surgeon, then the radiologist, who concluded that there was too much gas for ultrasound test and required a CT, then of the CT team, where finally a perforation was diagnosed. During this observation period, morphine was forbidden. These times are past. The sono-intensivist immediately diagnoses the pneumoperitoneum, asks the nurse for morphine and calls the surgeon for a prompt laparotomy.

Second, any procedure, when it is ultrasound-assisted (venous access, thoracenthesis, etc.) is done properly, and this contibutes to the patient's comfort.

Last, ultrasound-assisted nerve blockade is an exploding advance (see page 256). We will try to demonstrate no emotion when observing that it was maybe subsequent to the laptop market, and could have been achieved long ago, independently from this technical detail.

(This basic paragraph was written after a talk with Dr. Aurilio, where we realized that this part was maybe one of the most important.)

Pregnancy and Acute Ailments

We will end with this difficult situation. The possibility of pregnancy in a critically ill female is raised in Chap. 9. Once we know that the patient, admitted for instance for lung injury, is pregnant, this is the very time to carefully read the ultrasound user's manual. This noninvasive method should be considered now or never as yielding a decisive answer, and no longer an approximate screening test requiring confirmatory tests.

The list of complications that can be directly managed with ultrasound analysis alone is edifying.

This young patient can develop pneumonia (aspirative or nosocomial), which is recognized, quantified, and watched over under therapy. Repeated ill-defined radiographs are avoided.

Pleural effusion is directly drained. There is no need for diagnostic radiographs or even CT, nor a need for follow-up X-ray after thoracentesis. Some of the complications (e.g., pneumothorax after blind thoracentesis) that result in other irradiating imaging modalitites are also decreased.

If intubation is necessary, one-lung intubation is ruled out.

Iatrogenic pneumothorax can be drained and followed-up without the traditional procedures (repeated radiographs, even CT).

A subclavian catheter is safely inserted, avoiding follow-up X-rays and the numerous radiographs for the various possible complications.

The correct position of a gastric tube is checked.

Abdominal complications, such as hollow organ perforation, peritonitis, etc., bring the patient to the operating room directly, thus avoiding the uninformative plain abdominal radiographs as well as irradiating CT.

Venous thromboses, acute dyspnea due to pulmonary embolism directly benefit from heparin, reducing the need for venography or helical CT.

The search for maxillary sinusitis no longer needs CT.

The particular case of pregnancy demonstrates that ultrasound can open the way to a genuine visually based medicine.

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Free Considerations

30

A man with a hammer in the hand finds a lot of objects which need to be hammered

Mark Twain

If time permits, the reader can glance through this chapter, in which we have inserted free thoughts about our vision for critical ultrasound in relation to recent developments (distinguishing scientific from commercial outlooks), how to explain some misconceptions that were (and still are) so widespread in this discipline, and how to position ultrasound in the clinical approach. We take advantage of this chapter to present the SLAM.

Critical Ultrasound, Not a Simple Copy-Paste from the Radiologic Culture

We are glad to have had the opportunity to enrich the discovery of Dénier and all the founders of ultrasound [1,2], for defining, since 1992, the field of critical ultrasound [3]. This definition considered fields adapted to the critically ill (lung first, optic nerve, etc.), procedures specific to the critically ill (venous line insertion, etc.), the approach of classical fields devoted to the critically ill (simple emergency cardiac sonography), and use 24/7 (24 h a day, 7 days a week) on-site, ideally by the managing physician, among others. Our approach was not a simple copy-paste of the radiologic culture, with some applications (aortic aneurism, biliary tract disorders, etc.) just transferred from the radiology department to the emergency room. In this field, our main adaptation was to define a simple unit and simple rules as the right way, as far as we could, without any compromise for patient safety.

At the very time we sent the manuscript of this textbook to the publisher, some academicians – to a high degree – still do not believe in critical ultrasound. This is may be because they have kept the traditional vision of a complicated discipline – not to be entrusted into any but a select number of hands. We are so much accustomed to a nearly "zero fault" in patient management that it is hard to see that critical care, intensive care, or emergency medicine, are described as difficult professions, with some fatalism regarding the cases that were "too difficult."

Critical Ultrasound: A Late Take-off – An Explanation?

Critical ultrasound was like a silent volcano, silent for decades, which began to rumble in early 1990 and now explodes in showers of lava. Like the wave that eventually shapes the cliff, we have showed over the years to those who wanted to listen how to wake up this sleeping giant.

The prehistorical period ranged from the 1950s (the birth) to 1982. The pioneers who created medical ultrasound were internists like Dénier [1] or surgeons like Wild [2]. Since the tool provided images, this immature method was promptly put into the hands of the experts of medical imaging. They could use their skill for creating a sophisticated discipline, immune to the noninitiated, but they had some deficiencies with the critically ill. Whereas cardiologists and obstetricians immediately

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self-appropriated the method, the doctors involved in intensive care or emergency medicine did not immediately use the potential of ultrasound, mainly noncardiac. Meanwhile, ultrasound came of age with the advent of real-time imaging (1974, Henry and Griffith), but this was a discrete revolution that was not, once again, noticed by the critical care physicians – nor by the academicians whose work is to acknowledge the real innovations in medicine and biology.

This initiated a *blackout* period (1982–1989), which was strange because excellent mobile machines were present but not used. We have no explanation regarding this period. See comments below, in the section about lung ultrasound.

Another weird period ranged from 1989 to 2001. We have had the opportunity to work since 1989 in a prestigious ICU (François Jardin), equipped with ultrasound, the first to our knowledge [4]. These logistics allowed us to define the field of critical ultrasound [3]. The intensivists were able to see its utility on a daily basis, but little happened at the academic level. Intensive care (especially medical) is a prestigious discipline, and maybe these elites had mastered their duty and did not feel the need to be better than excellent. We created a rather strong contrast when we used general ultrasound (an unusual image in 1989, fully inappropriate in this profession), and were pointing out that the most important application to develop was for the lung. This double approach possibly initiated some hesitation in the community, unfortunately for a rapid development of critical ultrasound. We had to make a critical choice, devoting 100% of our time for submitting papers as top priority on the lesser known, i.e., lung ultrasound, instead of promoting known fields (blood in the peritoneum) or simple critical ultrasound. The period of these endless submissions took years and years.

The *commercial period* (from 2002 to the present) was initiated by the laptop market, which quickly imposed low-height but large machines in the emergency departments. In the search for an acknowledgement of their hard work, the emergency physicians saw there a unique opportunity for improving their conditions, favoring an explosive success. This was a good thing in one way. Once ultrasound was in the hands of the appropriate population, the content of our 1992 textbook (free blood in the abdomen, optic nerve, venous access, etc.) was published in countless papers.

Common Places and Misconceptions About Ultrasound

In no other field of medicine have we seen so many dogmas.

The Operator Dependency

In many minds, the performance of critical ultrasound depends on the operator's skill. On one side, those who do not use critical ultrasound, often from academic institutions, argue ad nauseam that it is a highly operator-dependent discipline, of limited interest when compared with CT, etc. On the other hand, those who use it cannot do without it any longer. The former ones just confuse critical ultrasound with traditional ultrasound, which *is* difficult (echocardiography-Doppler, obstetrics).

Critical ultrasound is not a new discipline, but is used throughout the intensivist's management, from head to toe. The combination of critical ultrasound with a redefined critical care profession should create, indeed, a new discipline – ultrasound-enhanced critical care, a profession done by sono-intensivists, to give them a name. This combination results, paradoxically, in a lighter profession: ultrasound can simplify the basic knowledge required for critical care.

If some academic passivities had not slowed down this process, each of us would now have had 25 years of practice, i.e., *now* for sure competent teams. Just imagine, in the times when auscultation was not part of the clinical routine, physicians called for specialists in auscultation for detecting rales. Ultrasound is nothing more than a stethoscope, slightly heavier than Laënnec's invention.

Echo in the Critically Ill: Only the Heart?

Many minds restrict ultrasound in the critically ill to the heart, and only the heart. The traditional word is "Echo," an abbreviation of advanced echocardiography-Doppler. This method is of great interest, and we fully understand that those who invested energy in this tool use it intensively. We published in 1992 a simple vision to approaching the heart [3]. This made, in fact,

inroads with the traditional echocardiographic culture of the cardiologists, then with the traditional culture of the intensivists based on TEE, and then with the traditional culture of the intensivists based on TTE.

The Cardiologist's Outlook

They obviously have a different culture, and were not trained for answering questions regarding critically ill patients. For many years, "echo" in the critically ill was a copy-paste of this culture. Cardiologists need standardized views, like policemen require strict front and profile identification views. Yet anyone is able to recognize a familiar face by any incidence, even not strictly frontal.

The TEE Intensivist's Outlook

The readers may feel surprised to have in their hands a textbook on critical ultrasound that does not deal with transesophageal echocardiography (TEE). We appreciate TEE, a powerful technique providing high-quality imaging. Directing the reader to excellent textbooks that highlight its potential, we recall drawbacks of the technique, however. The high cost makes TEE irrelevant for most care settings in the world. This cost includes that of the probe, which is scheduled for a limited number of examinations. The technique is heavy, needing full installation, long disinfection, etc. The blind introduction of rigid material in the esophagus is a risk for the esophagus, the stomach, the trachea, making TEE semi-invasive [5, 6]. The learning curve is not insignificant. Acquiring transesophageal technique blocks the way to whole-body ultrasound, condemning the user to study the heart and only the heart. One more drawback, in our view, is the absence of certitude that TEE is the "gold standard" for hemodynamic assessment – since it cannot be compared with any current gold standard.

The TTE Intensivist's Outlook

The image quality of TTE is inferior to that of TEE, but remains acceptable [7]. The examination is more democratic (cost, risk, etc.). The problem is now reduced to the interest of cardiac Doppler in the critically ill. The analysis of the flows provides a physiologic approach of high interest. Yet this use will give an answer to this sole question: did the patient receive enough fluid? This question is basic, but first it makes maybe 1% of the potential of ultrasound in the critically ill; second, there is no gold standard for assessing this use, whereas the FALLS protocol makes a different approach for the tolerance of fluid therapy (see Chap. 23).

Our Simple Cardiac Visual Approach

The simple visual approach to the heart that we published in 1992, when added to other data, provided sufficient information for initiating therapeutic plans. When the Doppler information is lacking, but replaced by the lung information (which provides the *direct* marker), in addition to superior vena cava information by the external approach, and a few others, the overall amount of information in terms of urgent therapeutic change is possibly the same, with added simplicity and rapidity. If the two approaches disagree, we are obliged to ask which is the wrong method – and no tool will currently answer this question.

Some believe in the heart (with no lung), we believe in the lung (with some heart). We will pay full attention to the TEE, once a gold standard will specify the exact place of each tool.

An analogy will clarify our vision. Emergency cardiac sonography is a simple discipline. The organ is the same, but the eye of the user (cardiologist, intensivist) is different. A grand piano can be used for classical music (the cardiologic way) or popular music, as we do. Popular music is less *academic* than classical, but obeys extremely rigorous rules regarding harmony, rhythm and layout, far from meaning "low-scale" music. The rules are just different. Those who consider popular music as a precise discipline will be interested by critical ultrasound, which follows the same logic: an instrument that makes a different music, not requiring the rigid training and scores of traditional classical music. A different but nice music, if we dare.

Lung Ultrasound: Two Words That Don't Go Together Well?

Air was the traditional hindrance for ultrasound. With the lung, we face two consecutive historical mistakes. The first one, not to have developed lung ultrasound at

the outset, was a mistake, but we do not blame anyone. The experts had maybe something different to think of, and maybe just forgot the lung. As to the second one, i.e., slowing down the publication of papers, proving that this first error could be repaired was a more severe one. Many, many years were lost in the face of an efficient rejection policy.

We have tried to find explanations for the late development of lung ultrasound. A common explanation to any novelty is frequent: if the thing was possible, it would have been developed long ago. This being said, the detractors had found the solution and could return to their daily task, reassured. We have another explanation. Since ultrasound provided an *image*, it was confided to the experts in *imaging*. They had very quickly in their hands, nearly at the same time (the year 1973), CT technology – and they did not feel any interest in developing the ultrasound tool – which supposed direct contact with patients of any origin, day or night. The radiologists do not have the same concerns as the intensivists, and are more tuned into deep structural changes (cancer stage, lymph nodes, etc.). So to speak, they have buried ultrasound alive! The medical community passed suddenly from the radiographic era (since 1895) to the CT era (since 1973). Our merit was just to use our long nights in the ICU for developing fields that were already described but simply not used (search for free blood, etc.), and countless untouched areas (optic nerve) from 1989 to 1992. Since no book of this period (1989) dealt with the matter, we had in our own book all the latitude needed to define the field and limits of critical ultrasound.

Our first studies were hard to publish, maybe because each application, if considered separately, had something anecdotal, with efficient alternatives (CT, X-ray). "Why complicate things?" was maybe the concern of the reviewers.

Publishing our findings was a trench warfare, with countless rejections. We fully respect our reviewers, but many teams in the world can thank them. Each rejection showed its consequences years later. We are glad to have the microphone now, although unfortunately too late for preventing the sale of machines that were less adapted to this exercice than our unit, the development of a thinking based on traditional use and some leadership. Despite this handicap, teams successfully published on lung ultrasound as a tool for the critically ill [8–18]. We have the pleasure to see an increasing family that contributes to spreading this discipline far and wide. Some, more efficient than us, took profit in the rigor of our reviewers, contributing to the cake being shared as multiple portions. We are glad for this. Too many papers as few hands is not good.

Interesting work was done in the pulmonologist area [19–22]. Yet we found rather a radiologic, sophisticated approach, making wide use of Doppler, linear probes and a population of not critically ill patients – i.e., not exactly our target.

Doppler: Really Mandatory in Critical Ultrasound?

Doppler is an interesting technique. It is part of the radiologic and cardiologic culture. Its incorporation to the critically ill without adaptation is again making a passive copy-paste maneuver, keeping the discipline complicated and costly.

Throughout this whole book (as well as the three previous editions since 1992), we have taken time to explain the spirit of a simple discipline. The incorporation of Doppler is interesting in many parts of medicine. In public (not private) hospitals, where there are critically ill patients, simple alternatives exist.

The cost was the main drawback for a long time. Out of reach for hospital budgets, the units were not bought, keeping critical care doctors blind to their benefits. The conviction that Doppler was mandatory has therefore *costed lives.* Countless patients died for absence of a simple visual diagnosis. Meanwhile, buying our 1982 technology was a simple formality – a cheap revolution.

Doppler's use adds buttons, i.e., complexity and risks for cross-infections.

Doppler does not mean *good* Doppler. Those who really need Doppler should know that its quality can be very different from one machine to another. In traditional machines swarming in the ERs, users are advised to check if the adequate quality is present (from non-academic but highly respectable sources).

Doppler's harmlessness is not established [23–25].

Inserting color Doppler images would have increased the cost of this textbook. The few color images were inserted in order to make a textbook that was not too gray in tone.

All along this book, alternative ways were used for optimizing a simple machine for venous patency, hemodynamic assessment, and brain assessment (Chaps 13,

23, and 24). To show the direction of the flow is of little interest for us (we guess arterial flow is centrifugal). To determine whether a vessel is a vein or an artery is the least of Doppler interest (see Chap. 12). To show a venous thrombosis is visual and/or dynamic (see Chaps. 12 and 13). For diagnosing the origin of an acute dyspnea, demonstrating a mitral regurgitation is of interest, but lung ultrasound is able to make the first step: detecting pulmonary edema. To monitor the cardiac output can be of interest, but we still speculate that our approach, including direct lung markers, does the same work as sophisticated approaches for managing fluid therapy, as seen in Chap. 23 (until solid gold standards invalidate our method). To assess renal perfusion may be of interest, but the practical value of this potential is not fully validated, and we have equivalent tools (see the philosophy of our limited investigation in Chap. 23). To show an arterial obstruction may be interesting, but first, this is a rare occurence in the intensivist's work, and second, we have developed a way of doing without Doppler (see Chap. 25). To see an impairment of cerebral perfusion may be redundant with the detection of an enlarged optic nerve (see Chap. 24). Even ultrasound-guided nerve blockade may not require Doppler (see Chap. 25). A mitral valvular destruction requiring immediate surgery in the night is a rare situation – where often other tools can be suggestive (simple auscultation, simple visualization of the mitral valve).

This rarity of situations really requiring urgent Doppler without an alternative is central to our vision. Again, for these few cases, there is the possibility of traditional management (our DIAFORA concept). This includes even transportation of the patient to a specialized department, if needed. The DIAFORA concept shows how we have advanced since 1989, and allows the purchase of a low-cost machine for the majority of daily tasks (see page 15 of Chap. 2). Once its full potential is exploited, we promise that we will be open to Doppler. Christian Doppler, from Salzburg, made his finding around 1852, has his street in Serries, a small city east of Paris, and we guess that coming back among us, he would be surprised to hear that his family name is probably the most often pronounced in daily talks in all critical care disciplines. While maintaining high respect for Doppler's works, we consider that the concerns mentioned above are substantial enough to invite users to think twice. We will reconsider this rigid position if new machines equipped with Doppler make us happy with our other requirements (size, flat keyboard, cost, etc.).

The Gel, Really Necessary?

The traditional image of ultrasound is rather sticky. A kind of sauce, surrounded by amounts of crumpled wipes, infiltrates everywhere – on the probe, the doctor's tie, etc. Sometimes, we see the gloomy spectacle of a sedated patient who received an abdominal or cardiac examination and was simply not wiped. The correct description is "a mess." People accept this landscape, in view of the utility of ultrasound, but would possibly like an alternative.

We even think that this image has possibly succeeded, for a minute part, in generating a limited acceptance by the community (Fig. 30.1).

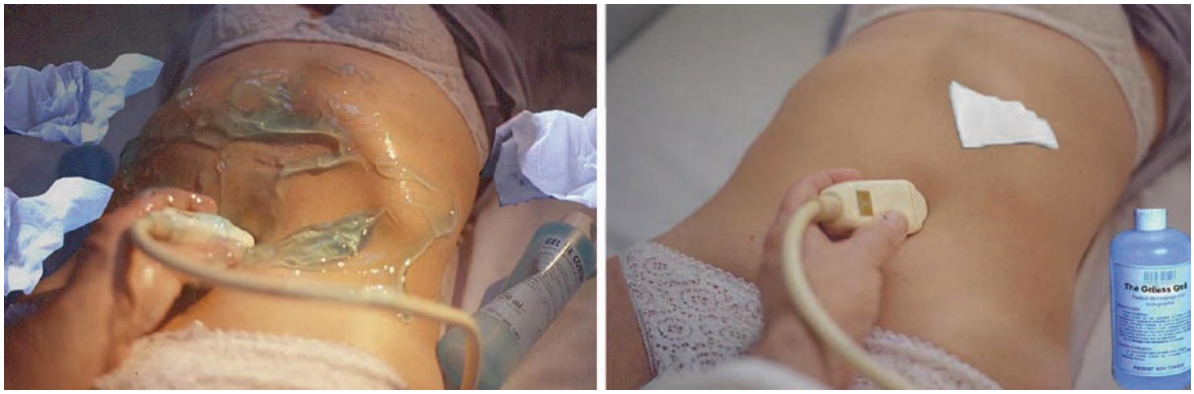

Fig. 30.1 Use of The Gelless Gel on the *right*. To the *left*, this sticky image, done thanks to the stoicism of Joëlle, is not our vision of ultrasound. Not only does it make a psychological barrier to widespread use but it also makes the chest wall slippery (an issue during rescusitation), is a blessing for microbes, and would make fast protocols (such as the BLUE protocol) longer

This is *no longer* our vision of ultrasound. In our daily world, there is no gel, no wipe, no sticky skin, no endless hours of (imperfectly) cleaning the skin (see Chap. 2).

One Probe for All Territories

Only one probe is sufficient in the intensivist's use, as outlined throughout this book: our microconvex, 1- to 17-cm range one. All the others are good for each corresponding specialist, none of them being suitable for the main organ: the lung.

See our detailed comments above.

We are afraid by the perspective that one day the manufacturers may propose a *liver* probe and a *splenic* probe. They could easily convince us that the performances of ultrasound will be enhanced. We advise interested colleagues to refer to dedicated doctors when buying a probe.

The Revolution in Critical Ultrasound: Possible Thanks to the Laptop Technology?

We do not share this concept, and dedicate a whole section on this subject.

Was Miniaturization a Step Forward?

Several doctors think that modern machines are small, and strongly believe that it was the factor which initiated the revolution in the emergency rooms. We would be happy to share this enthusiasm by finding the qualities of preexisting materials in this market. To make our work as scientific as possible, we took simple but objective tools (a ruler, a chronometer, a bacteriologic swab, simple comparisons in costs, and simple thoughts). This is a difficult section of the book. We describe our seven requirements, which are in our 1992 technology, and would like to see these lines inspire the manufacturers of the future machines.

1. Size of the machine

In a hospital setting, space is lacking around the critically ill. Moving from bed to bed, from ICU to ER, etc., is a challenge. Each saved centimeter is a victory. The small height of the laptop machines was a good idea. Current laptop machines have a lateral width of 40–44 cm. This is smaller than more cumbersome machines, but we go on using our 29-cm-wide equipment designed in 1992 (and still manufactured) because we strongly believe that it is important for sneaking the unit between a patient and a ventilator. Our machine is higher (27 cm) than traditional machines (6 cm), which is not a problem since our ceilings are high enough. The winning dimension is the width. A simple measuring device (Fig. 30.2) demonstrates why we did not need to wait for the laptop revolution for introducing our philosophy into ICUs, ERs, and ORs, throughout the world, suggesting a *scientific* revolution. In this spirit, the 1982 machines were excellent, especially the respected ADR-4000, with its 42-cm width and its wheels. Basically, it allowed our patients to benefit from critical ultrasound in extreme priority and allowed us to define the potential of critical ultrasound. Now, 29 cm is better than 42 cm. For those who work in tiny places, where ceilings are actually low (airplanes, etc.), hand-held machines are interesting. We use a 1.9-kg machine, since we consider 6 kg a little heavy for so-called hand-held machines.

Fig. 30.2 A tool for scientific assessment of the laptop revolution. This folding ruler, easily affordable in any hardware shop, allows one to assess the place of laptop machines, fixed or not on carts. Widths as large as 44, 48, 52, and 68 cm, currently measured in typical machines found now in ERs, are larger than the 29-cm (33-cm if cart included) width of our 1992 unit

Size of the machine with the cart

Laptop machines have carts with lateral devices, which are useful because they allow to put the various probes somewhere (the top cannot be used). With these devices, we obtain an overall width of 48–56 cm (not considering the lower part of the cart, even larger). Convinced that the small size of a machine devoted to critical ultrasound is important, we still use our 1992 system, because we exploit the top (see Fig. 2.3 page 14) and the cart fits our 29-cm-wide unit, making a 33-cm total. Its center of gravity is at the bottom, which

is ideal and allows keeping the 33 cm from the top to the bottom. So, 33-33-33 cm are dream measurements for a mobile ultrasound machine, opening the door to bedside visual medicine.

For those who think that a laptop unit can be used without the cart in a hospital:

a. The absence of cart makes the hand-held unit an easy prey, at a predators' mercy. This means additional costs for remunerating the caretaker, who will have to work 24/7, or else machines may prompty vanish (a kind of honor, in one way). Daily practice shows that these machines should remain solidly fixed onto carts (in our talks, we use a more biblical word). Let's take again our ruler. These machines pass from 44 to 56, up to 70 cm. With 70 cm, it remains possible to go between a patient and a ventilator, but a 33-cm machine makes it twice as easy. Traditional echocardiographic machines are 60 cm wide (Fig. 30.3).
b. We sometimes see machines without a cart, simply laid down on the bed – this implies very demanding disinfection maneuvers (if done). In addition, such machines can fall – even if they have been designed for falling.
c. In the hospital, the cart is very practical. A physician using a laptop machine without a cart, and called in an emergency, would be condemned to take the unit in one hand, the contact product in another, some probes at the neck, the procedural material between the teeth, the disinfectant product between the knees, and be obliged to jump through the corridors. Highly trained doctors may arrive quickly on-site, but the image would not be very elegant for the spectators, nor for the patient. With the cart (that makes hand-held technology not so small), the whole material is transported using one hand.

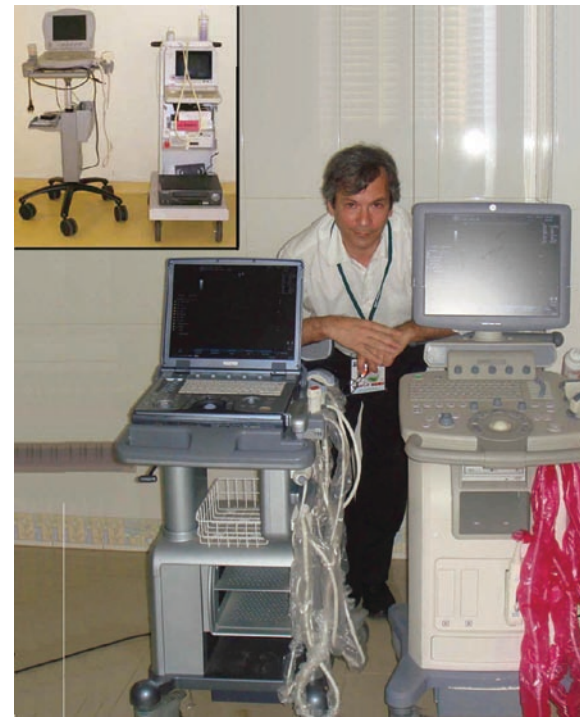

Fig. 30.3 The fourth dimension. Mumbai, November 2008. The machine on the *left* (dark screen) is a laptop model (6 cm high). The machine on the *right*, which has a similar width, could be heavily transported for workshops, whereas the smaller laptop one is a blessing for the warehousemen, maybe its main interest. Note that this manufacturer has at least decided to make a narrow cart for the laptop machine (according to our advice), making now the laptop machine's overall dimension not larger than the traditional one. One step in the right direction. In terms of efficient volume, there is no advantage of one machine over another for being moved to a critically ill patient. Wheels make the machine free to go easily between various obstacles. This third dimension opens the route to the fourth dimension: imagination.

2. Image quality

One main result of the recent revolution was to suppress the excellent *cathode ray tube monitor*. The plasma quality of the initial machines in 2000 initiated a 20-year step backward in the history of ultrasound (Fig. 30.4). Now, LCD screens improve the image quality little by little. We think that in some years time they will be as good as our 1992 reference. Like vinyl music or fixed phones, which give a better acoustic quality than digital music or cellphones, the cathode ray tube of our unit gives top quality. We learned that some manufacturers said to new users (in the 2000s) that we "would get accustomed [to this new imaging quality]..." The authors did not.

We use again the term "harmony" (see Chap. 2), since the concept of a cathode ray tube monitor results in a small size (in width) with, in addition, an available top, avoiding lateral devices which take up unnecessary space.

3. Disinfection issues

Numerous buttons, cursors, hand levels, etc. of traditional laptop machines are interesting for making multiple settings, by experts in ultrasound. Yet these prominent nooks and crannies are a godsend for microbes, which can freely proliferate, sheltered from harm – unless the user carefully cleans each button. We go on using our *flat*

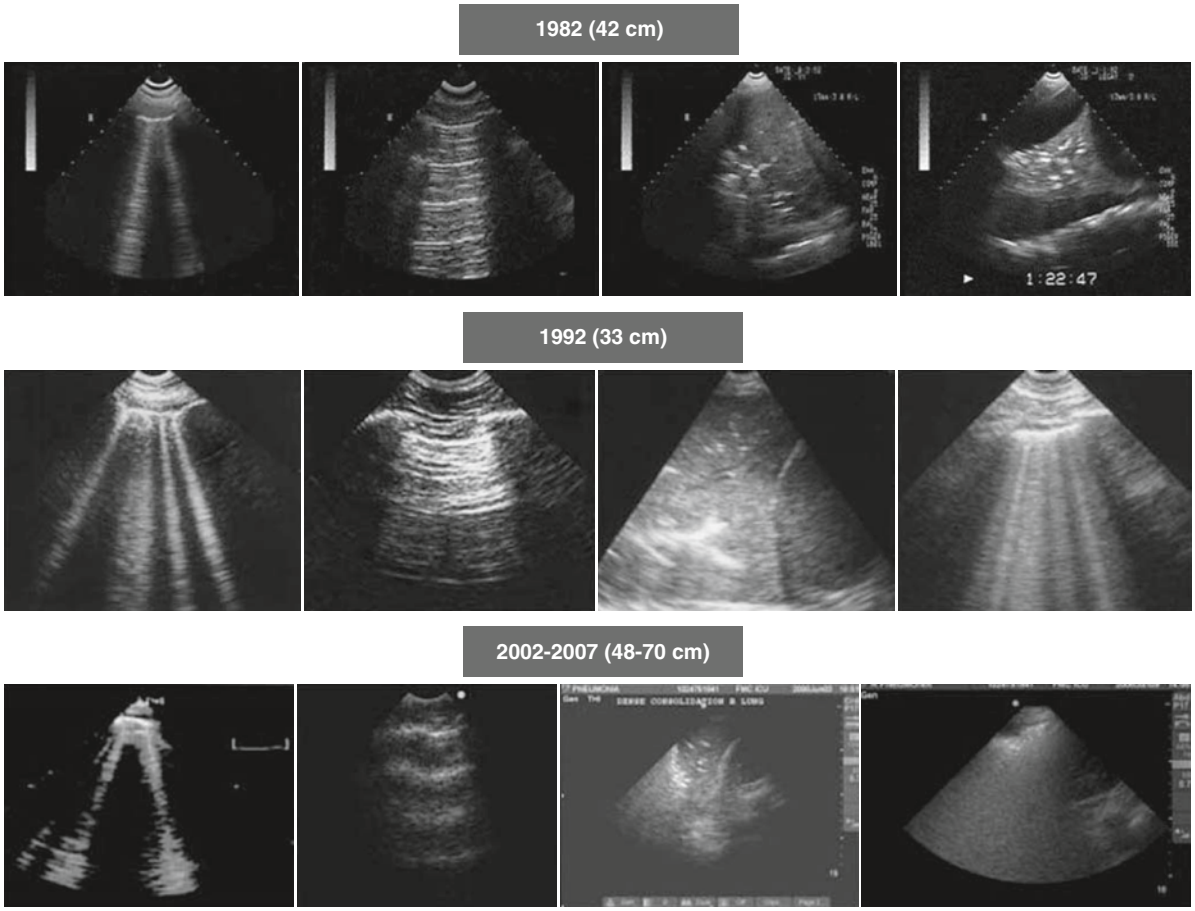

Fig. 30.4 This image shows how the recent laptop technology has resulted in a 27-year jump backward for ultrasound (*in parentheses,* the width of the unit with the cart). *Top*: ADR-4000, 1982

keyboard, which we can clean in a few seconds, since 1992. The concept of a unique probe has a basic outcome on the access to efficient cleaning, since dense forests of cables and probes are again a blessing for microbes. We deeply hope that manufacturers of laptops will at last use flat machines, but all the previous machines which were bought before should, therefore, all be sent to the garbage: an unprecedented waste.

4. Start-up time
Machines devoted to critical ultrasound have start-up times of usually 2½ min. This is short. Yet shorter is better in time-dependent patients. Since each second counts, we go on using our system, which has been starting-up in *7 s* since 1992. The start-up time of the traditional machines shortens little by little. We estimate that in some years, technical progresses will make them able to reach our speed. We would like to see a smart exploitation system eventually choosen.

5. The relevance of a smart cart
Critical points about the cart were written above (under "Size").

6. Access to the ideal probe for critical ultrasound
We detailed the choice of the probe in Chap. 2. The new market uses the traditional probes, i.e., for the cardiologist, radiologist, angeiologist and gynecologist, and this is good because each of them finds a familiar environment. Yet it is ironic that this new market, devoted to critical care without mistake, did not care to use the *intensivist's* (not the less important discipline) probe, the most suitable for the *lung* (not the least useful organ).

The probe of the intensivist is not the phased-array probe, the abdominal probe, or the linear probe, etc. The *microconvex* probe is providential, since it was not done on purpose (it was intended, without mistake, for transfontanellar use initially). We keep using this universal 5-MHz probe , employing 1992 technology, as it

is perfect for access to any part of the whole body. No time is lost for changing the probe, cleaning it, buying several different probes. Maybe thanks to our reiterated remarks, microconvex probes can be found on some laptop machines. Unfortunately, they cover only an 8- to 10-cm depth, not our 17 cm, i.e., not suitable for really universal use.

Note that since the lung was not considered, many variations can be seen, orchestrated rather haphazardly. Therefore, some cardiac probes are better than others for the lung, some linear probes are shorter than others. For linear probes, we reiterate that, for studying biological organisms, like the human being, this is a weird concept. We are not linear. Linear probes are a relic of the industrial (premedical) era of ultrasound. Even if we were *snakes*, such probes would be suitable for the longitudinal scans, but the user would find difficulties for transversal ones. So the user is restricted to some areas more linear than others (long-axis of the internal jugular vein for instance). Once the probe is applied, small angulations are not possible. Large linear probes need more effort for compression (which is not focused), not our way to do it. The following vessels are hardly or not accessible to vascular probes: the subclavian vein, the innominate vein, the superior caval vein, the inferior caval vein, the iliac veins; the popliteal vein in supine patients; the calf veins in their short-axis, especially by anterior approach in supine, critically ill patients; the whole aorta, especially at the thorax. In other words, more than half of the network. We consider that vascular probes are not suitable for vascular assessment, especially in the critically ill.

Our perception is that these tools were accepted by the same experts who thought that the lung was immune to ultrasound. These probes may be labeled "vascular," but one can feel free to criticize this label.

7. Simple conception

Laptop machines purport to be complete ultrasound equipment, and this is a good point because experienced users can use Doppler, harmonics, or other modes for suppressing the artifacts. However, these machines were developed using traditional concepts. Did anyone see the setting "Lung" in the modes? The addition of the lung upsets the priorities of critical ultrasound: sophisticated modes become of lesser relevance.

We do not find Doppler mandatory in the critically ill, even at the hemodynamic area (see Chap. 23).

Traditional machines usually display the real-time image on the top and M-mode on the bottom. This is excellent for the heart, but this is a typical misconception regarding lung ultrasound. When both images are aligned, but with a slight lag, this is even worse: see our comments in Chap. 18 page 164, and Figs. 14.10 and 18.1 pages 126, 165). If we compare ultrasound to music, one can utter a wrong note.

Sophisticated machines with too many buttons are not adapted to use by nonexperts on time-dependent patients. In the crowd of the buttons, the inadvertent use of some can create unexpected actions, such as sudden disappearance of the image. The only solution for the user is to promptly find the correct page in the (thick) user's guide, while the team carries on the rescusitation.

Among countless details, imagination must work for the cable length. Smart cables do not trail. Trailing exposes a double danger. First, microbes on the floor can transfer onto the cable. Second, this can create an appalling vision: a wheel suddenly blocked by the cable, provoking the immediate tipping-over of the machine (at best on the doctor's foot, which would at least result in decreasing the shock to the machine). This has already happened, of course in very stressful settings, when the machine is being quickly moved.

Simple concepts yield low costs. Traditional laptop machines are less expensive than traditional echocardiographic machines. We think that the cost is a critical point: each saved Euro (Dollar, Rupee, etc.) makes a machine more easily bought, i.e., more lives saved. Our gray-scale machine is cost-effective, at, since 1992, the cost of one *modest automobile*.

A Small Thought: for Free

In our previous editions, we wrote: "The unit must be as small as possible. The idea of making any effort for moving the unit should in no case be a physical or psychological obstacle." This sounds a little obsolete now. The volume of our ADR-4000 unit (see Fig. 2.2 page 13) was 40,000 cc. Such a volume could be dispatched in a 200 × 200 × 1-cm volume (with minor arrangements). Building ambulances with an additional length of *1 cm* could have made space for point-of-care ultrasound a reality since *1982*. Countless patients did not arrive alive at the operating theater because minds were not ready for this simple idea of ultrasound devoted to the critically ill.

Concluding Remarks About the Equipment

Some Japanese manufacturers still build machines in our spirit: small size, compact keyboard, cathode ray tube monitor, gray-scale technology, low cost. Using a ruler, we proved that our 1992 unit – and even our respected ADR-4000 from 1982 – was smaller than most laptop machines, without or with a cart. So what are the advantages of these machines? We have analyzed one by one the seven requirements defined in Chap. 2. At the time when these lines were written, one popular brand has two or three of our criteria, while another popular one has simply *none* of them. By trying by any means to write a balanced section, we found some advantages. Laptop machines are a godsend for the storekeepers of the congress workshops, because they can move them easily from their trucks. Commercials tell us that their machines can fall down to the floor without (immediate) damage. This can be interesting in wartime, yet we are hopefully not for long in this setting. And we are not accustomed to let our beloved unit fall down.

We admit that any machine is able to do some ultrasound, more or less, with various degrees of difficulty. We have just a thought for a discipline which could have been developed since the year 1982, in a simple way, and we stoically wait for improvements to come from the laptop market. As soon as this market will fulfill our seven requirements, and provide any advantage, we will immediately throw our beloved machine to the trash compactor.

For years, our vision for ultrasound is a clean, small, compact, simple one. It contains no nooks or crannies, no multiple probes with cables lying like creepers, no endless minutes waiting, no low-quality images (Fig. 30.4). There is no gel, meaning also that the vision of probes with the dried gel of the previous night (with various biologic elements, hair, etc. stuck on it) is also absent in our world.

To end this section with optimism, we consider that the critical care community has acquired its first experience using machines which succeeded in giving the illusion of being small. We lost an opportunity of discovering a simple discipline. The potential of ultrasound could not fully appear with this first attempt. With time, we bet that one machine per department will appear insufficient. When the purchase of a second machine will be a priority, the community will have the choice of buying the same machine, or to think twice and consider our point of view. They will then really discover ultrasound.

The PUMA: Our Answer to the Traditional Market

Since 1992, we have developed the concept of the *p*olyvalent *u*ltrasound and *m*anagement *a*pparatus (PUMA), just exploiting the third dimension. This dimension – the height – is a strength that is unexploited when we see the 100,000 cc of empty space below the current machines fixed on large carts. Searching for maximal efficiency, each cubic centimeter of free space is occupied, and we explain why we take the PUMA for each patient. The technology of the wheel is a strong point, fully exploited.

PUMA is our answer to the current market (Fig. 30.5).

PUMA is *not* an ultrasound unit.

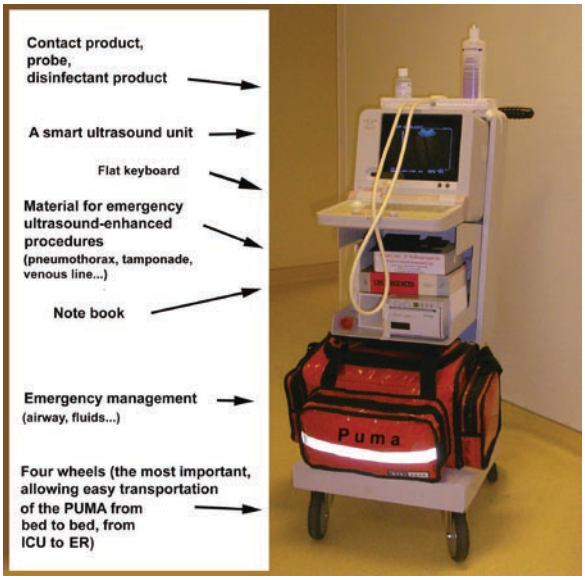

Fig. 30.5 The polyvalent ultrasound and management apparatus (PUMA) concept. This figure just shows that ultrasound is only a part of the patient management. The PUMA system allows infinite procedures in the critically ill. It does not yet make coffee (which may be considered, devoted to relaxing the team once the diagnosis promptly made and the patient stabilized), but this wink just indicates what is critical ultrasound; a visual medicine that makes everything quicker and simpler

PUMA *includes* an ultrasound unit. This nuance indicates the importance of the third dimension. Basic emergency therapeutic materials are (metaphorically) "in the lobby" (25-cm high), material for interventional procedures of extreme emergency "on the 1st floor" (10 cm), a refresher textbook "on the 2nd floor" (5 cm, of help for the youngest of us). "On the 3rd floor," the reprograph and video-tape recorder are set up (15 cm). "On the 4th floor," you find an incorporated ultrasound machine (27 cm high), coming at the correct height for bedside use. With PUMA, immediate diagnoses are done, followed by immediate extreme emergency procedures (tension pneumothorax, etc.).

On top of our ultrasound unit (i.e., "the 5th floor"), the probe is surrounded by our coupling agent and desinfection product, solidly inserted on adapted stands, avoiding falls when the cart is mobilized (see Fig. 2.3 page 14). These falls are a loss of time: time for picking objects up, time for disinfecting them, or if not, time for nursing patients from nosocomial infections coming from the dirt grasped from the ground.

Critical Ultrasound: A Tool Enhancing the Clinical Examination

Critical ultrasound will not replace the physical examination. The BLUE protocol is the best example of integration of these two weapons. We can, however, redefine priorities according to the usefulness of a given physical sign, and above all the allocated time for searching for it. The incorporation of critical ultrasound allows to hierarchize elements of this basic discipline in time-dependent patients. This new hierarchization, made sign by sign, should deserve a whole book.

The stethoscope is the respected symbol of medicine. Hung around the neck in a hospital corridor, it makes you look like a doctor. Is critical ultrasound a clinical tool, a modern stethoscope? Half of the answer is given if one considers that an examination performed at the bedside is clinical (*clinos*, the bed). The other half is achieved if one looks into the etymology of this word, which, also coming from the Greek, was coined by the French physician Laënnec in the early 1800s [26]: a means of looking (*scopein*, to observe) through the lung (*stethos*, the chest wall).

Sir John Forbes wrote a preface for the English translation of Laënnec's book of auscultation, in 1821. He thought that the role of the stethoscope would be minor in medicine. Maybe he was not so wrong. We have used the stethoscope thousands of times, and still find auscultation a difficult tool for immediate life-saving decisions. It is for us a help, but rarely the decision-maker tool, in fact. We rarely heard a splitting of the protodiastolic heart sound in the crowded, noizy emergency room, for assessing left heart failure. Signs of inspection and palpation are possibly more relevant. The difficulty of the physical examination is rarely assessed scientifically [27].

The SESAME protocol (Chap. 29 page 279) defines a situation where speed is life (imminence of cardiac arrest). Note that a minimal clinical examination has been undertaken for making this diagnosis (patient's habitus, coma, cutaneous signs of shock). In this setting, just after this step, some diagnoses should be done by ultrasound. We give less than 1 min using this life-saving protocol. If negative, we search, time permitting, for swollen abdomen, blue unilateral leg, focused pain... All these signs are easy to detect *and* of clinical value. Several other signs make the physical examination a difficult exercise: detecting small pleural effusions, pulmonary edema without crackles, urinary obstacle in obese patients.

Featuring at the height of difficulty should be the increase in precordial dullness in pericardial tamponade. Some basic diseases have no clinical sign: interstitial syndrome, where ultrasound plays a major role (see the BLUE protocol). Once accustomed to the level of information allowed by a fast whole-body ultrasound examination, the physician can become aware of his or her limitations regarding the physical examination, sign by sign.

One tool has already threatened the use of the clinical examination: CT. Like the GPS or internet, CT exempts physicians from thinking [28], with foreseeable consequences on mental performance. Ultrasound is a didactic tool, allowing to enhance one's physical examination – a unique opportunity to get self-improvement, since it shows diagnoses in real-time. The physician who did not clinically detect the effusion can pay more attention to discrete signs such as this pleuretic murmur. This will make doctors armed in the clinical examination with precious help when the unit is suddenly not available (used by others, in breakdown, etc.).

We could show hundreds of examples but this would make this book too heavy.

One can detect a parietal contraction, take the probe and confirm peritonitis without imposing a painful rectal examination. An area that is painful to palpation (or echopalpation) will reveal the cause: abscess, or cholecystitis. One way of diagnosing hepatic abscess for a long time was the percussion of the liver. This maneuver has no longer a raison d'être if a liver abscess has been identified, and the patient able to compare will be grateful to you!

Apart from its intrinsic utility, the physical examination is a strong moment for the patient, when conscious. This direct contact with the hands of your doctor has major psychological impact. Ultrasound was a unique opportunity for the radiologists to get closer to the patients.

Note, for academicians reluctant to use ultrasound, that the scientific assessment of the physical examination should yield nice surprises. It would oblige the community to classify these signs, from those which are really excellent to others that do not work so well [29]. The high specificity of the physical examination when compared with radiography for diagnoses of pleural effusions or alveolar consolidations has already been proven [30].

The SLAM

The *s*ection for the *l*imitation of *a*cronyms in *m*edicine (SLAM) was born on April 1st, 2008 (an appropriate day for creating an acronym against acronyms). Two criteria allow classification. First, are they really innovations or simply a copy-paste of a previously available method that was done by certain doctors (radiologists) for the use of other doctors (emergency physician)? Second, are they a source of possible confusion, i.e., using words that we use daily in a discipline where communication must be fast?

Acronyms are sets of initials pronounced without spelling, like words. This is good for creating medullar reflexes, until a critical amount occurs – and creates confusion. The SLAM would like to see a reasonable number of them. Some readers have searched in vain in this book for a familiar acronym, nearly a synonym of critical ultrasound for many, but which would not have obtained an average note. We fully respect the spirit in which these developments were done, but also want to show our respect for those teams that did not lose time finding shiny acronyms for popularizing life-saving procedures – just using terms such as "ultrasound," "sonographic search for free blood," etc. The SLAM has been created as an answer to the power of words which throughout the history of mankind have shown double-edged consequences.

In the 200 pages of our 1992 textbook, each line was important for defining critical ultrasound, no matter who was holding the probe (radiologist, physician). The aim was to define *what* was possible using this probe. In 1992, which textbook dealt with visual venous access in the critically ill? The idea of adapting the signs of peritoneal fluid for the search of free blood took *12 lines*; this was sufficient space for this life-saving application. The SLAM is concerned to imagine that some doctors needed an acronym for realizing that ultrasound was this irreversible step forward. The SLAM regrets the number of avoidable deaths occurring between our first findings (1989) and now, simply because we did not find it so important to develop acronyms. Acronyms are a kind of marketing, i.e., an art where the outside makes one forget what is inside.

It is not difficult to create flashy acronyms.

We could have called our search for free blood the "*a*ssessment of *b*lood *u*sing *s*onography in an *e*mergency". But this is not all.

The *q*uality *u*ltrasound to *i*mprove *c*urrent *k*nowledge protocol (submitted) aims at refining the traditional signs of the search for free peritoneal blood, using more than a copy-paste that was initially devoted to sonographers (i.e., technicians with 3-year postgraduate). Such protocols require very standardized views (i.e., not real life) and use ascites (not hemorrhage) for training. We disdain the traditional five sites, making instead a liberal scan of the belly. The QUICK protocol is an original approach, since it includes new signs (induced sinusoid sign, and bat wing sign), which are not to our knowledge in the traditional protocols.

*S*imple *u*ltrasound *d*evoid *o*f *c*omplicated *u*tensils is a game of strategy. On one side, there is a complex critically ill patient; on the other, there is an extremely simple machine (with only one probe, fast switch-on, no Doppler, etc.). One must make the winning combination, for an immediate life-saving use.

Conversely, lung ultrasound in the critically ill (in the sky or on earth, with or without diamonds), simple emergency cardiac sonography, our limited investigation considering hemodynamic therapy (including the concept of the fluid administration limited by lung

sonography), the ultrasound search for free blood, whole-body ultrasound in a few words, and all those applications using our simple critical ultrasound design (a long distance weapon indeed), all these uses did not benefit from an acronym, for a symbolic reason: if the use of an acronym is to save a few seconds, the use of ultrasound allows the saving of *hours* (when compared with tradition management, using CT, etc.). The wish for saving time using an acronym in the ultrasound world comes from a questionable intent.

We are currently working on a protocol designed for ultrasound distinction between a foot corn and a coryza, that will be labeled an "*a*lgorithm of *b*edside *s*creening *u*ltrasound to the *r*ight *d*ecision. It may possibly be relevant. Maybe the SLAM will give an average note for it.

The SLAM is keen in some acronyms. The WINFOCUS is a rather elegant one, describing an original activity, not sounding confusing. The KISS, from Kathleen Garcia, holds a nice place since it summarizes our approach: *k*eep *i*t *s*imple *s*onography. The best acronym for a long time will probably be VOMIT (the *v*ictims *o*f *m*odern *i*maging *t*echnologies), a concept that should be interested by critical ultrasound, precisely. We deeply hope that acronyms are not designed for creating more or less artificial territories. We apologize in advance for close colleagues who could feel the work of SLAM not considerate of their hard contribution. They should understand its approach, which aims at opening a door on the fact that critical ultrasound, defined long ago, did not benefit from marketing effects. Should the miracle therapy for the cancer (if ever invented) *not be developed* for lack of a flashy acronym?

SLAM simply does not favor *a*cronyms *a*t *a*ny *p*rice (AAAP[1]).

Is the ABCDE-management an example of AAAP? "A" for airway is basic. "B" for breathing initiates a progression. "C" for circulation is an excellent sequel. A-B-C is nice, but we wonder if the "D" was necessary. We see rather another "B," for brain, without major damage to the concept. ABCBE (with E for "etc." rather than exposure) would have done a similar job for the very young doctors who need to understand that in a cardiac arrest, the search for abolition of osteotendineous reflexes is not a priority if the airways are obstructed? These doctors are maybe young, but also not pupils, after those 8 years of high degree studies which are among the hardest.

Sometimes, acronyms can fight. Are the FATE, FEER, and FOCUS racing? Maybe the RACE will arrive first? Some protocols used by close friends began by the abdomen, and little by little invade the lungs. We worry about a possible whole-body *vampirization*. Before the acronyms become too long, we would love to relearn words such as "whole-body ultrasound," or simply "ultrasound."

One day or another (but we bet it already happened), some doctors will ask protocols traditionnally devoted to traumatized patients when applying them in not traumatized patients.

We would like to see this BOA (battle of acronyms) eventually dying by eating its tail.

So, why a BLUE protocol? This work was the conclusion of 20 publications which, brick by brick, rejection after rejection (the editorial boards were prudent), took 18 years – whereas a simple copy-paste of the simplest application (fluid in the peritoneum) was to many minds a complete revolution. We had to take a critical decision: submitting the really interesting matter, or disseminating less innovative applications. Instead of trying to take any leadership (now solidly done here and there throughout the world), we aimed at sharing the way we managed acutely dyspneic patients in a few minutes. The BLUE protocol is our nice answer to the revolution of free blood detection. This label fulfilled the two conditions required from SLAM: innovative work, not a confusing term (can be used without ambiguity in a doctor's talk in fast emergency settings) and mostly… it is not an acronym: it reminds first that the patient is cyanotic, second that the venous network is associated with the lung analysis.

As regards lung ultrasound in neonates, we firmly hope to make use of no acronym [31]. Should they be necessary for saving lives of neonates? What is barely tolerable for adults cannot be accepted here. As a symbol of serenity, ultrasound of the neonate lung will benefit from the no-acronym protocol.

And How About US?

Here, we leave the acronyms, which intend to create words, for the small world of abbreviations (ab.). The ab. that worries us mostly is certainly "US."

[1](say "triple-A-P" for more rapidity)

Ultrasound is the most critical word we have to use. As opposed to computerized tomography, or again United States, which are groups of words, *ultrasound* is one word. The use of an ab. is therefore not logical. It does not decrease the word count in an article. Ultrasound has ten letters, maybe a heavenly symbol. Ultrasound is time-saving for immediate care of critically ill patients. We can devote 2 s to type it in full letters (versus 0.6 s for "US," i.e., a final investment of only 1.4 s). The ab. US is confusing since ultrasound has increasing political outcomes. If US decide to involve US, does it really mean that the use of US will improve the global health level of the US? This makes a bed for fatal confusions – what SLAM wants to avoid. In the end, we admit that our attraction for this pacific method of visual medicine implies, as a kind of *homage*, to write its name in full. Ultrasound offers so much to us, we can make this small effort. "US" is not entirely respectful.

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We also thank Xavier Leverve for his advice regarding a flexible behavior toward the manufacturers – although we did not fully succeed in following this advice.

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A Way to Learn Critical Ultrasound

31

The initial training of the intensivist can be limited to one single application; for instance, lung sliding. Once trained, he or she knows that the unit can be used each time the question of pneumothorax is raised (i.e., every day), with an immediate binary answer: no pneumothorax versus possible pneumothorax. Once familiar, the second application is studied (we suggest B-lines), and so on for an indeterminate period. Using this approach, the intensivist will, little by little, modify his or her way or working, with always the possibility of going backward in case of difficulty. We do not suddenly become sonographers (in the same way that we do not suddenly become intensivists). Ultrasound mastery has certainly a beginning but no end, as this author learns every day.

We have had to chose between defining critical ultrasound (full-time work) or training colleagues, and have devoted ourselves to the defining work (not figuring out it would be so long). We, nonetheless, created a training center (called CEURF) in order to modestly spread our vision of simplicity. CEURF (say "surf") was born from the absence of an adapted training structure, when some courageous collagues had to register for traditional ultrasound diplomas, where they learned about the thyroid, etc., but nothing about the acute lung (etc.).

CEURF focuses on personalized training, which is slow but solid. Our experiences have shown promising results. A 30-min session every week for 18 months covering the whole body has given a 18.5/20 accuracy [1]. Obviously, obtaining the value of 17.5/20 takes less time. A training for the limited BLUE protocol, focusing only on an anterior analysis of lung sliding (yes/no) and lung rockets (yes/no) gives, after short sessions making a total of 90 min, an average accuracy of 19/20. A training focused on the lung part of the BLUE protocol has given, after roughly seven sessions of 1 h, an accuracy of 19.5/20.

There are now countless training centers, often teaching well-established fields. CEURF has kept its seven original features.

1. CEURF focuses training on the points yielding *immediate therapeutic management* (no space for describing steatosic liver, etc.).
2. The bedside step is done within the ICU – not using wealthy but uninformative models (yet see below). Lung and venous diseases are usually present.
3. The quality is controlled regarding the number of attendees: no more than two at the bedside, during a whole morning. This warrants for personalized training.
4. CEURF is not limited to importing a traditional model of the radiologic culture (gallbladder gallstones, use of Doppler, multiple probes, etc.). It creates an *adapted approach* – using an adapted unit, one adapted probe, adapted fields (mesenteric infarction, pneumoperitoneum, optic nerve, emergency cardiac sonography, etc.). The *lung* is the key point of this approach, with respiratory and hemodynamic uses.
5. The principle of one lecturer can be double-edged. The drawback is that only one opinion is present (the one of simplicity anyway). The advantage is the homogeneity of the course, and the integration of 19 years of practice into a user-friendly discipline.
6. Simplicity is the key word of CEURF. Using a specific approach, simplicity works without any compromise to the patient's care.
7. Attendees are then invited to a remote refresher didactic day, scheduled to allow them to check their understanding after a period of practicing on their own (6–12 months). This is also an opportunity for questions, comments, and suggestions.

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Like the bat of our logo, which is as big as the last phalange of our thumb but gives birth to *one* baby each *year* (Which so small species does this?), we try to propagate quality (Fig. 31.1). The trained colleagues are subsequently able to spread the method.

We give a simple clue to our attendees for making self-improvement.

1st step: Once the attendee knows how to search for lung sliding, he or she must wait for a patient with confirmed pneumothorax, take ultrasound, and mandatorily find a stratosphere sign. If there is no stratosphere sign, there is a problem: was the probe correctly at the BLUE points? Was the radiograph reversed by mistake? Is it the correct patient? Was the M-mode abusively used? And so on. After as many as possible examinations on known patients, the next step is aimed.

Fig. 31.1 The logo of our training center, the Cercle des Echographistes d'Urgence et de Réanimation Francophones (could be roughly translated as "Circle of Emergency Ultrasound for Rescusitation in French-Speaking Countries"); abbreviated as CEURF (pronounced "surf"). The benefits of this nonprofit association are used for spreading simple critical ultrasound development throughout the world. This makes us independent of manufacturers and the goodwill of academicians. The bat is the only mammal that uses ultrasound, since 55-million years. Apart from the popular dolphin (known for being rather smart), one bird also uses ultrasound: the gray-rumped swift (the French word is *Martinet*), a really rare bird, which can fly while sleeping among others, and was awarded bird of the year in 2003. For comparison, the bull has no ultrasound equipment for distinguishing the toreador from the cape – a godsend for the toreador and the joyful crowd. Some people fear the bat, a nice and useful animal in the vast majority of cases. In contrast, the snake, which has killed many human beings, has been choosen as the symbol of medicine. For more details on this animal, which looks like no other, see www.ceurf.net. CEURF trains English-speaking colleagues, but has kept its native label. Small groups profit from a bedside training. The critically ill patient, meanwhile, profits from comprehensive ultrasound examinations, providing an ethical dimension to CEURF

2nd step: This step is searching for the stratosphere sign in a patient with an acute problem, make immediately the traditional management (CT, etc., time permitting), and thereby build self-confidence little by little in this way (but not yet taking any therapeutic decision based on sonography).

3rd step: This step, done after this sequence, is: facing a patient in a critical state (with no time for confirmation) with clinical suspicion of pneumothorax, demonstrating a lung sliding, and *not* inserting a chest tube but driving the thought process in another direction, etc. This softly initiates a life where the "traditional" losses (for difficult diagnosis) will gradually decrease, yielding to ultrasound-enhanced critical care: a new discipline.

Training among colleagues in the same ICU is probably the best. Even if not many are trained per year, they transmit a solid knowledge in their next institution. If it had began in 1982, we should have 25 years behind us. Integrating ultrasound use into university medical studies would be the most efficient way to prepare future intensivists.

Wild Ultrasound

They can also perform what we call *wild ultrasound*. The solitude of a night shift in the hospital is the appropriate setting for the development of wild ultrasound. Facing a patient with uncontrolled worsening, and perfectly aware of his limited knowledge, a physician would be temptated to use the ultrasound machine (possibly one of the countless laptop machines currently invading our corridors), barely remembering the one or two lectures heard on this topic, and trying to do his best for controlling the situation, also trying not to be the sorcerer's apprentice. This is wild ultrasound. We wager that the number of situations saved with ultrasound will exceed the number of cases where the ultrasound unit should not have been switched on. Anyway, the deontology obliges any physician to use any means in case of extreme emergencies if no choice. We believe the intensivists and emergency physicians would do a respectable job, not tarnish the method [2,3] and use ultrasound with humility, not condescension.

The Approach in Our Workshops: How to Make Our Healthy Model a Mine of Acute Diseases, How to Avoid Bothering Our Lab Animals

We see with some concern that laboratory animals, pigs mainly, are used for simulation of lung diseases. We have imagined solutions for decreasing this trend.

Also, costly simulators are developing here and there. We will show this also is maybe of relative interest.

In our workshops, we have usually a young, normal slender model. We imagine he just comes from a 13-h airplane travel (economy class) from a wild area full of infectious diseases. He has major tobacco habits and an allergy to airplane insecticides. Highly stressed during the flight by the prohibition of smoking, he took sleeping pills. The cabin crew found him comatose, woke him up. He vomited, coughed a lot, then complained of sudden dyspnea and chest pain. We see him at the ER, severely dyspneic, near to encephalopathy. In the rooms behind, drunkards generate a large amount of noise, which prevents a serene auscultation. Our patient could have *all possible diseases:* pulmonary embolism, pneumonia (from the wild country or from aspiration), but also pulmonary edema complicating acute coronary syndrome, not to forget pneumothorax, or again severe asthma.

1. We make a stage-1 examination, showing how to locate the upper and lower BLUE points. We demonstrate the bat sign and the interest of longitudinal scans.
2. We demonstrate lung sliding, seashore sign, and A-lines (expected in this model) at the right lung.
3. We check for left lung sliding, but apply our probe obliquely, *on the rib*, making (ab)use of the M-lines, and demonstrating a motionless pattern with horizontal repetition artifacts, generating a stratosphere sign. This can look like a pneumothorax, but without a bat sign. This is simply a transversal technique that tooled a rib on purpose. We benefit from this by explaining why we never use transversal or oblique scans, and those details which would make ultrasound a difficult science.
4. Coming back to a correct technique, we demonstrate an A-profile (bilateral normal pattern). The A-profile invites to search for venous thrombosis. Using some black magic and the *Hypargonos* maneuver, so to speak, we apply a probe that has discretely been inverted at the internal jugular area, with a pressure sufficient for making the vein vanish. The screen displays the artery, and, apparently outside, a tubular tissue-like structure: the body of the thyroid gland, used as a model of occlusive jugular internal venous thrombosis. The diagnosis of pulmonary embolism is done (specificity 99%).
5. Coming back to a correct technique, we search for B-lines (often the lateral last intercostal space above diaphragm in healthy people). If no B-line at all is visible, we search for GB-lines in the abdomen, sometimes visible at the jejunal areas (and ask the attendees to imagine that these artifacts arise from the pleural line). We then search for Z-lines, usually always found, and point out the five basic differences. We ask the attendees to imagine three B-lines (i.e., lung rockets) per scan, and diffuse lung rockets at the four anterior BLUE points, making the diagnosis of hemodynamic pulmonary edema (specificity 95%).
6. We then illustrate a nude profile, making a rapid venous ultrasound scan at the V-point (this portion near the knee, reputed to be difficult to compress, a symbol in our vision of simple ultrasound), showing in 3 s a normal collapsibility – extrapolate to the rest of the venous system for saving time. The BLUE protocol asks us to come back to the lung, searching for PLAPS.
7. With some more black magic (and the *Hypargonos* maneuver), we show at the left lateral wall a frank pneumonia at the lingula: tissue-like image touching the wall, often with air bronchograms, and the shred line. Below is a normally aerated lung. The diagnosis of lingular pneumonia is done. Facing this A-profile plus PLAPS, we conclude a pneumonia (specificity 96%). This is, of course, the simple spleen with an inversed probe.
8. Coming back to a correct technique, we analyze the PLAPS point, and demonstrate a nude profile (normal lung surface, normal venous system). This young man shows the profile of acute asthma, with a 97% specificity.

It is, at the time given, difficult to simulate on-site pleural effusion, but we can show what pattern could be given by a pyothorax, or again a hydropneumothorax (shaking our contact bottle), and even a pneumothorax by simulating the lung point using the tongue point (the correct French term would be something like

the *langue point*). For those who are not tired and want to go beyond the BLUE protocol, we can again simulate a peanut aspiration, by demonstrating abolished right-lung sliding with standstill cupola and the lung pulse, whereas left-lung sliding and cupola work correctly (we just use a previously agreed command with the model to make him discretely halt breathing).

Now is the raison d'être of the BLUE points: we imagine that we work with a handheld machine with a battery near to its end. This technical problem demonstrates the strength of the BLUE points, which tell exactly where to apply the probe. If we clinically suspect an incipient left hemothorax, but have a battery with only 10 s of power, we apply the probe at the left PLAPS point, switch on the unit and are at the correct place for making immediate assessment. The unit then runs out of power and switches off, but we can manage the patient: immediate surgery, or simple surveillance.

All in all, we are able to demonstrate, in our usual, healthy models, and step by step: pneumothorax, pulmonary embolism, pulmonary edema, pneumonia, acute asthma, empyema, foreign body with complete atelectasis. This is acquired just using some imagination, i.e., for free, avoiding costly simulators, or bothering lab animals.

A more important detail is that we prove there is no magic in it all, just (intentional) bad technique, which is easy to avoid. Our main message is: *do it yourself*, to avoid any kind of manipulation, or clumsiness from unskilled young radiology operators.

We complete the hands-on training with ultrasound-guided catheterization in the lab, using tofu bricks, for cheap.

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Critical Ultrasound, Not Just a New Technique: Also a Philosophy

32

Created in 1915, adapted to the patient in the 1950s, adapted to the critically ill since the 1990s, becoming widely appreciated since the 2005, ultrasound should first be considered through scientific appraisals: life-saving, cost-saving, and evidence-based medicine, which would definitely prove its value.

It may also be considered a bit of a philosophy. The saved time, the spared irradiation, the increased comfort to the patient, and the comfort of the clinician to immediately manage critical situations cannot be scientifically measured and are perhaps more important. All these critical advantages yield a certain elegance to the method.

While the community accelerates its race toward modernity, with the same obsession, still faster (with apparent winners like multislice CT, latest generation MRI, or sophisticated echocardiographic equipment), we keep our philosophy. Each time our simple system answers the question and saves a life (or just clarifies or simplifies a situation), the victory shifts to the other side. Those who consider CT, MRI, etc., as a duty for the patient, possibly forget that the majority of people on earth will never see these (not so ideal) techniques. Ultrasound, as useful in a sophisticated ICU as in a remote, austere area appears as a universal tool for multiple settings.

Contributive not only in intensive care medicine, but also in emergency medicine, pediatrics, anesthesiology, cardiology, pulmonology, trauma surgery, thoracic surgery, internal medicine, family medicine, austere medicine and remote medicine, ultrasound will one day, for sure, be introduced in the medical studies. Years were lost, but instead of thinking of those who did not profit from its pacific power, we concentrate our thoughts on those who will, in the near future, massively take advantage of this visual medicine.

Acknowledgements We wanted this book to have the thinnest possible volume (and carefully aimed at limiting redundancies). For all those who helped us in this huge project, from far or near, a comprehensive list would make the book suddenly thicker, and we sincerely apologize for this. They should know that we did not forget them. Harry, David, Sidney and Nathalie lived the project day by day from its birth since 1989, from edition to edition. They saw the seeds planted, they see the fruits arising. As they come, we thank Ralph, Alexandre, Raffie, Aloy, and again Symeng, where the author spent countless hours of composure. Same greetings for Marc and Martha. A special thank to Nathalie Lascols, who initiated the creation of the CEURF. All the "small" people surrounding our conferences.... Several names feature through the text, most coming from CEURF attendees or our colleagues, with their kind authorization. Gilbert Mezière, our usual coauthor, who was of unvaluable help in our very last articles, should find here the mark of our indefectible respect...

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Glossary

A-lines Hyperechoic, roughly horizontal lines, arising at regular intervals from the pleural line.

A1, A2…-lines Number of A-lines arising from the pleural line. The term "A+ lines" means that at least one A-line has been detected.

A/B-profile (BLUE protocol) Predominance of A-lines at one lung, of B-lines at the other, in stage 1.

Anechoic Free of echo. The tone is black by convention.

A-predominance (FALLS protocol) Detection of either an A-profile, A′-profile or A/B-profile.

A-profile (BLUE protocol) Association of predominant A-lines and lung sliding in stage 1.

A′-profile (BLUE protocol) Association of predominant A-lines and abolished lung sliding in stage 1.

Artifact Artificial image created by the physical principles of propagation of the ultrasound beams. The shape is always geometrical with precise symmetric axes. Artifacts do not correspond to real anatomical structures.

Bat Sign In the initial and basic step of any lung ultrasound, the bat sign identifies in a longitudinal view the upper and lower ribs (the wings) and, deeper, the pleural line (the back of the bat). This step makes it possible to correctly locate the lung surface in any conditions.

Bat-wing Sign Special pattern displayed by a peritoneal effusion, surrounded by convex limits. This sign is of interest for detecting nonanechoic effusions (i.e., the most severe cases)

Bed Level (at) When the probe explores the lateral chest wall in a supine patient and cannot explore more posterior (without moving the patient) because of the bed, the probe is said to be applied at bed level (or FDL).

B-lines This designates a kind of comet-tail artifact that is in addition precisely defined as arising from the pleural line, well-defined, as echoic as the pleural line, erasing the A-lines, spreading out without fading to the edge of the screen and moving with lung sliding. Elementary (but insufficient) sign of interstitial syndrome.

b-line (lower case) This term indicates that only one B-line is visible in a view.

B7-lines This term designates lung rockets whose elements are about 7 mm apart. Three to four comet tails are thus visible in an intercostal space. It means interstitial syndrome (with septal thickening).

B3 lines This term designates lung rockets whose elements are about 3 mm apart (B3), or even contiguous. Seven to ten B-lines fit in an intercostal space. This means interstitial syndrome (with ground-glass areas).

BLUE hands Two hands applied on the thorax, one above another, thumbs excepted, beginning just below the clavicula immediately show the lung location (the lowest finger being usually at the chest/abdomen junction. The term "BLUE hands" means that the hands are those, theoretically, of the patient (from any size, any age).

BLUE protocol Protocol for immediate diagnosis in acutely blue patients. It associates bedside lung ultrasound in an emergency and a protocol of venous ultrasound adapted to the critically ill. The BLUE protocol proposes simple profiles helping in assessing the cause of an acute respiratory failure.

BLUE points Standardized locations immediately accessible and allowing immediate diagnosis of the main life-threatening disorders. In the BLUE protocol, two anterior points and one subposterior point are used.

B-predominance (FALLS protocol) Detection of either a B-profile or a B′-profile.

Carmen Maneuver This is a basic probe movement in critical ultrasound. The probe is applied onto the skin, without excessive pressure. It is gently shifted to the left, then to the right (when the probe is in a longitudinal position), or to the top, then to the bottom (in a transversal position), making advantage of the gliding of the skin over the underskin, i.e., staying at the same position. It makes critical ultrasound easier by easily controlling the three dimensions, and showing structures which do not appear at first application of the probe, without losing the target.

B-profile (BLUE protocol) Association of predominant lung rockets and lung sliding in stage 1.

B′-profile (BLUE protocol) Association of predominant lung rockets and abolished lung sliding in stage 1.

C-lines Real image (see this term), curving, centimetric, arising from the pleural line. Small pleural-based lung consolidation in other words.

C-profile (BLUE protocol) Detection of alveolar syndrome in stage 1.

CLOT Protocol (Catheter-linked occult thromboses protocol) Daily analysis of the venous areas which have received canulation in long-staying patients, performed routinely and after any acute worsening. It allows early detection and follow-up of the deep venous thromboses, allowing help in the diagnosis of pulmonary embolism in these challenging patients.

Comet-tail Artifact This term designates a repetition artifact which is hyperechoic and roughly vertical. It can arise *or not* from the pleural line. It can be long *or not*. It can be well-defined or ill-defined. It can erase other underlying structures or not. Many comet-tail artifacts can be described, the B-line (for interstitial syndrome) being only one of them.

Consolidation Index Simple measurement of an alveolar consolidation using an area at a given point and assuming that the consolidation has roughly three similar dimensions.

Culminating (Sign, Point) This term refers to the sky-earth axis and indicates something near the sky.

Dark Lung (Ultrasound Dark Lung) Situation where a diffusely hypoechoic pattern is recorded at the chest wall, with no static or dynamic element that can affirm a solid or fluid predominance. The radiograph usually shows a white lung.

Dependent (Sign, Point) This term refers to the sky-earth axis and indicates something near the earth.

DIAFORA Logistics This term refers to using Doppler when necessary, using an outside machine, an outside operator, and if necessary, transporting the patient (as done for the CT examinations). DIAFORA means Doppler intermittently asked from outside for rare applications. It allows the physician to rapidly benefit from a low-cost machine, which will be of daily help meanwhile. The concept is based on the rarity of these situations, based also on the degree of emergency, which usually can wait for open hours.

Doppler Hand This designates the free hand of the operator, which replaces the Doppler function for

compressing the veins, even at reputedly noncompressible areas (the V-point).

Dynamic Air Bronchogram Alveolar consolidation within which hyperechoic punctiform particles (indicating the air bronchograms) have a centrifugal inspiratory movement. This is characteristic of nonretractile consolidation (pneumonia in clinical practice).

Echoic In principle, a tone with the same echostructure as a reference structure (classically, the liver). Usually, "echoic" designates a structure rather "hyperechoic", i.e., near a white tone.

E-lines E for emphysema. Comet-tail artifacts, long and without fading, arising from superficial layers located above the pleural line, with the particularity of being aligned, indicating a thin air layer formed within two parietal layers. This pattern should never be confused with B-lines.

Escape Sign In face of a suspicion of occlusive venous thrombosis, a slight pressure of the probe makes the whole of the soft tissues move, but the proximal and distal walls of the vein do not change. The vein seems to escape, like a blood saussage, from the probe. This indicates the noncompressibility of the vein, when compared to the surrounding soft tissues which receive appropriate pressure.

F-lines From "Fantôme," and the first name of a colleague. These ghost images that can look like air bronchograms in normal scans of the lung.

FALLS-protocol Protocol using lung ultrasound for guiding fluid therapy, based on the fact that A-lines indicate low PAOP (suggesting clearance for fluid therapy), and B-lines suggest high PAOP (suggesting stopping fluid therapy, schematically).

G-lines For "gut." Describes any kind of artifact (horizontal, comet-tail, ring-down) visible at the abdominal area.

Gain Setting the device to provide a well-balanced reference image. The upper parts of the screen can be lightened or darkened (near gain), as can the lower parts (far gain). Experience alone can conclude that the gain is correctly set.

Grotowski Law This is an adaptation of the probability laws in a series in the critical care setting, using the help of the visual medicine (ultrasound). In this field, death is a frequent event. Using a multiplication of probabilities, enhanced by the use of ultrasound, the risk of deleterious management appears more and more infinitesimal. For instance, the error risk of the ultrasound approach of the BLUE protocol, combined with the clinical data and basic tests, can be advantageously compared with approaches using usual tools which can have side effects (helical CT in each dyspneic patient for instance).

If a diagnosis is rare, and if precisely the patient has an atypical presentation of this (presumed) rare disease, another disease, more frequent, should be sought for.

As a last example, if a common procedure based on a potential mistake can anyway be of help to the patient, its use should be considered. Aeroportia is a rare diagnosis. Mistakes can be made (confusion with aerobilia) but hesitation at this moment could be deleterious. In a patient with septic shock plus possible aeroportia, a liberal policy of laparotomy would (in this rare event, reminder) do more good than harm. Even if the ultrasound sign of aeroportia was misleading, it should be considered that laparotomy is often useful in the management of septic shock of unknown origin – for a precise evaluation of the real risk.

Gut Sliding Dynamic generated by the visceral peritoneal layer against the parietal layer in rhythm with respiration.

H-lines The curved hyperechoic artifacts that are visible when the probe is on its stand. At their center, they can be considered roughly horizontal, and have a remote link with the A-lines, indicating air (of the room).

Hyperechoic Tone located between the reference pattern (classically the liver) and what is called the white tone.

Hypoechoic Tone located between the reference pattern and a black, anechoic tone.

I-lines Comet-tail artifacts, arising from the pleural line, hyperechoic, well-defined, moving with lung sliding, but short (vanishing after 1–3 cm). Supposedly normal.

Induced Sinusoid Sign A peritoneal effusion can be echoic (mimicking tissue), but the probe pressure decreases the thickness of this image, demonstrating its fluid and free nature.

Interpleural Variation See "sinusoid."

Isoechoic Tone equal to a reference structure (classically, the liver).

J-lines Small (1–3 mm in size) horizontal echoic artifacts which are superposed (every 1–2 mm) up to the edge of the screen, resulting in shaping a B-line.

Jellyfish Sign Visualization of particular dynamics of the inferior pulmonary strip within a substantial pleural effusion. In rhythm with respiration and heart beats, this is reminiscent of a jellyfish.

K-line K for "Klingon." Parasite artifacts due to environmental interferences – usually arising from the top of the screen.

Lateralization Maneuver Maneuver consisting of placing the arm of the supine patient at the contralateral shoulder. Several centimeters of the posterior aspect of the lung are thus accessible and can be explored using ultrasound, probe pointing toward the sky.

Limited Investigation Ultrasound approach of a shocked patient. The limited investigation (considering hemodynamic therapy) assesses simple heart function (contractility), simple lung ultrasound (the FALLS-protocol) and an analysis of the inferior and superior caval veins (using a simple unit and a simple microconvex probe).

Lower BLUE Point When the BLUE hands are applied on the thoracic wall, the point defined by the middle of the lower palm – for immediate diagnosis of pneumothorax and interstitial syndrome.

Lung Line Deep border of a pleural effusion, regular by definition (see the quad sign), indicating also the visceral pleura. Sign specific to pleural effusion.

Lung Point Sudden and fleeting appearance, generally on inspiration, of a lung sign with lung sliding and/or lung rockets and/or alteration of A-lines, at a precise area of the chest wall where abolished lung sliding and exclusive A-lines were previously observed.

Lung Pulse Visualization at the pleural line of vibrations in rhythm with the heart rate.

Lung Rockets Lung rockets designate several B-lines visible in a single view (3 or more).

Lung Sliding Dynamics – a sort of to-and-fro twinkling – visible at the precise level of the pleural line.

M-lines horizontal hyperechoic artifacts generated below a rib surface.

Mangrove variant M-mode variant of lung sliding with end-expiratory pause, mimicking stratosphere sign from far.

Merlin's Space (From Elisabeth Merlin) Image framed by the pleural line, the shadow of the ribs and the lower border of the screen. The Merlin's space can be artifactual (normal subject, interstitial edema, pneumothorax) or anatomic (alveolar or pleural syndrome).

M-mode Analysis of dynamics passing along a precise line. A posteriori, the reading of the image alone detects the observed dynamics. M-mode is opposed to two-dimensional observations.

N-lines (N for Neri, or noir.) Vertical artifacts arising from the pleural line, long, well-defined, moving with lung sliding, erasing A-lines. One criterion distinguishes them from B-lines: they are anechoic (black).

Nude Profile (BLUE protocol) Normal examination, meaning A-profile, absence of PLAPS and free venous axes.

O-lines O for non-A, non-B. Absence of any artifact, either horizontal or vertical, arising from the pleural line. Assimilated to A-lines.

Out-of-plane (Effect) An image that leaves the plane of the ultrasound beam and can give a false impression of dynamics (a pseudo-dynamic pattern). This effect must be distinguished from the true dynamics.

Phrenic Point One of the four standardized points of lung ultrasound, used to analyze phrenic function. Intersection between the middle axillary line and the horizontal line prolongating the lowest BLUE finger (see BLUE hands)

Plankton Sign Numerous punctiform echoic images within an anechoic or echo-poor collection. These images have slow, whirling dynamics, as in weightlessness.

P-lines Many A-lines passing through a narrow intercostal space may give the illusion of a vertical artifact.

PLAPS Posterior and/or lateral alveolar and/or pleural syndrome. In other words, detection of either consolidation or effusion or both at the posterior wall.

PLAPS Index A standardized area of measurement in a standardized position of the patient (supine, slightly turned to the opposed way), a standardized location (the PLAPS point), and a standardized probe (a microconvex probe that can be inserted far to the posterior wall). The expiratory distance between pleural line and lung line roughly correlate with the abundance of the effusion.

PLAPS Point One of the three main BLUE points. Area of investigation delimited by the horizontal line continuing the lower BLUE-point and posterior axillar line (or more posteriorly if possible, without moving a supine patient), accessible in stage 3 using a short probe. The PLAPS point indicates all free pleural effusions and most alveolar consolidations in the critically ill.

Pleural Line Echoic line located between two ribs, slightly deeper (0.5 cm), in a longitudinal view of an intercostal space. It represents the interface between parietal tissues and thoracic air. See bat sign.

Posterior Shadow Completely anechoic image, with an artifactual shape and located behind a bony structure.

Quad Sign Quad shaped by the four borders of a pleural effusion, when seen in the intercostal approach: pleural line, shadows of bones, and the deep lower border, called the lung line (visceral pleura).

R-lines From the first name of a colleague who pointed out them. Comet-tail artifacts having all the criteria of the B-lines except their location: in a parasternal short axis of the heart, they arise from the deep pericardial line.

Seashore Sign M-motion pattern of a normal lung. The parietal layers are motionless and generate horizontal lines (reminiscent of still waves) at the upper part of the screen. The image above and from the pleural line generates a granular pattern (reminiscent of sand) since it reflects lung sliding that propagates to the end of the screen.

SESAME-Protocol Kind of protocol near to the Limited Investigation, but devoted for extremely severe shock (imminent cardiac arrest). The main difference is that this very fast protocol begins by the lung first, then the heart. SESAME is the abbreviation of an acronym showing that, provided there is an ultrasound information, either the cause or the mechanism of shock is taken into consideration in the therapeutic decision.

Shred Line The deep border of a partially filling alveolar consolidation, which makes a shredded line with the aerated deep lung tissue. This sign is specific to alveolar consolidation.

Shred Sign Sign indicating that a tissue-like mass abutting the pleural line has a shredded lower border (the shred line).

Sinusogram Ultrasound visualization of the walls of the maxillary sinus.

Sinusoid Sign Curve acquired in M-mode at the level of a pleural effusion. The superficial limit (the parietal pleura) is motionless, whereas the deep limit (the visceral pleura) displays an inspiratory centrifugal excursion. One can again speak of interpleural variation.

Sky-Earth Axis The axis where gravity plays. This is useful for understanding the logic of the BLUE points (see this term).

Splanchnogram Direct visualization of an abdominal organ when the probe is applied in a supine patient, which means that no free gas (pneumoperitoneum) collects at the abdominal wall.

Stage 1 Examination (lung ultrasound) Anterior lung analysis in a supine patient at the earth level.

Stage 2 Examination (lung ultrasound) Adjunction of the lateral wall to stage 1.

Stage 3 Examination (lung ultrasound) Insertion of a small microconvex probe at the posterior wall in a supine patient, as posterior as possible.

Stage 4 Examination (lung ultrasound) Comprehensive lung examination, with lateral positioning for complete posterior analysis, plus analysis of the apical areas.

Static Air Bronchogram Alveolar consolidation within which hyperechoic punctiform particles (indicating the air bronchograms) have no visible movement.

Stratosphere Sign Time-motion pattern composed of horizontal lines in an intercostal view. This pattern is reminiscent of a bar code, but a more striking image is a flying fortresses squadron in the stratosphere, a pattern characteristic of pneumothorax.

Tissue-like Sign Label indicating that alveolar consolidation (a fluid disorder) yields a tissue-like pattern, reminiscent of a liver in mesenteric ischemia (with possible gas collections)

T-lines In M-mode, fine lines strictly arising from the M-mode equivalent of the pleural line are an equivalent of the lung pulse, and mean absence of pneumothorax.

Two-dimensional A two-dimensional image provides a view in two dimensions, as opposed to a M-mode acquisition. Also see "Real-time."

U-line Arciform upper extremity of air artifacts that shape a kind of U (upside down) found at the colon area.

Ultrasound-aided Procedure A procedure is ultrasound aided when done after ultrasound location, as opposed to a procedure carried out with permanent ultrasound guidance.

Upper BLUE Point When the BLUE hands are applied on the thoracic wall, the point between the origin of the medius and ring finger of the upper hand indicates a location for immediate diagnosis of pneumothorax and interstitial syndrome.

V-line Short comet-tail artifact, which can be found in the wall of the gallbladder (vésicule in French).

V-point A precise location at the thigh (posterior aspect just above the knee) where the "Doppler hand" should be located for efficient superficial vein compression.

W-lines Comet-tail artifacts, long, without fading, arising from superficial layers located above the pleural line, not aligned. These indicate anarchically organized air bubbles in soft tissues (see E-lines).

X-lines Rare situation where a genuine B-line does not obliterate an A-line, making an image of crossing (forming an X shape).

Z-lines Z for the last letter of the alphabet. Comet-tail artifacts arising from the pleural line, not well defined, not hyperechoic like the pleural line, not erasing A-lines and vanishing after a few centimeters, as opposed to B-lines. A Z-line should never be confused with a B-line.

Index