

## Thoracic ultrasound: An adjunctive and valuable imaging tool in emergency, resource-limited settings and for a sustainable monitoring of patients

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### Abstract

Imaging workup of patients referred for elective assessment of chest disease requires an articulated approach: Imaging is asked for achieving timely diagnosis. The concurrent or subsequent use of thoracic ultrasound (TUS) with conventional (chest X-rays-) and more advanced imaging procedures (computed tomography and magnetic resonance imaging) implies advantages, limitations and actual problems. Indeed, despite TUS may provide useful imaging of pleura, lung and heart disease, emergency scenarios are currently the most warranted field of application of TUS: Pleural effusion, pneumothorax, lung consolidation. This stems from its role in limited resources subsets; actually, ultrasound is an excellent risk reducing tool, which acts by: (1) increasing diagnostic certainty; (2) shortening time to definitive therapy; and (3) decreasing problems from blind procedures that carry an inherent level of complications. In addition, paediatric and newborn disease are particularly suitable for TUS investigation, aimed at the detection of congenital or acquired chest disease avoiding, limiting or postponing radiological exposure. TUS improves the effectiveness of elective medical practice, in resource-limited settings, in small point of care facilities and particularly in poorer countries. Quality and information provided by the procedure are increased avoiding whenever possible artefacts that can prevent or mislead the achievement of the correct diagnosis. Reliable monitoring of patients is possible, taking into consideration that appropriate expertise, knowledge, skills, training, and even adequate equipment's suitability are not always and everywhere affordable or accessible. TUS is complementary imaging

procedure for the radiologist and an excellent basic diagnostic tool suitable to be shared with pneumologists, cardiologists and emergency physicians.

**Key words:** Thoracic ultrasound; Pneumonia; Pleural effusion; Pneumothorax; Clinical risk management; Overdiagnosis; Wastebasket diagnosis

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**Core tip:** Thoracic ultrasound (TUS), with some technical limitations, may provide useful imaging of pleura, lung and heart disease. The field of application of TUS are pleural effusion, pneumothorax, and lung consolidation. Paediatric and newborn disease are suitable for TUS investigation aimed at the detection of congenital or acquired chest disease avoiding or limiting radiological exposure. TUS improves the effectiveness of medical practice in resource-limited settings, in small point-of-care facilities, in hostile environment and in poorer countries. Monitoring of patients is possible, depending on disease and context, not asking to the procedure more than it can give.

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## FOREWORD

The history of imaging in medicine is an adventurous and generous history of high impact ideas, of courage and ingenious translation. This story originates from Marie Curie and her family, especially her daughter, Irene, a Nobel laureate too<sup>[1]</sup>. They, at the beginning and during the First World War, on 1914, developed and worked inside the mobile field hospitals that Marie Curie had established, training radiographers and technicians and convincing the surgeons to trust in the new technology: It was estimated that over one million wounded men were X-rayed in her units throughout the War<sup>[1]</sup>. It may be now easy to ignore, but this history, here briefly summarized, can help us to understand the root and the link between genius, emergency, limited resources and quality of training in a field which is the daily work of most physicians working with chest imaging.

## OVERVIEW

The recall above reported is needed, even writing of ultrasound, since depicts a detailed model of practice and application of a sustainable innovative diagnostic

and of another extremely useful tool in resource-limited settings and in hostile and dangerous situations. It also represents an organizational paradigm supported by ethical reasons. Despite Marie Curie and other heroic pioneers of radiology suffered from long-term radiation damage, the concept of maximum security for that time was highly respected. If claims of clinical risk management criteria, so often warranted nowadays, are not inspired to ethically, medically and scientifically proven aims and evidence, a botched management may ultimately damage doctors and patients, as well as society and population within an organizational machine scarcely productive if not harmful.

Emergency or elective assessment of chest disease requires often an articulated clinical approach to chest imaging, addressed also to the diagnosis of co-morbidities. Clinicians are often facing complex conditions, due to uncertainty or severity of the clinical presentation or to the hurry in which they are called to operate<sup>[2-4]</sup>.

Indeed, despite elective thoracic ultrasound (TUS) may provide useful imaging of pleura, lung and heart disease, emergency scenarios are its current most developed field of application for detecting unsuspected, or for confirming physical signs of, pleural effusion, pneumothorax, and lung consolidation<sup>[5-7]</sup>. Paediatric and newborn disease are particularly suitable for TUS investigation aimed at the detection of congenital or acquired chest disease avoiding, limiting or postponing radiological exposure<sup>[8,9]</sup>. TUS can improve the effectiveness of elective and emergency medical practice in resource-limited settings, in small point of care facilities and particularly in poorer countries<sup>[10]</sup>. Ultrasound is an excellent risk-reducing tool, which acts by: (1) increasing diagnostic certainty; (2) shortening time to definitive therapy; and (3) decreasing risks from blind procedures that carry an inherent level of complications<sup>[11-15]</sup>. Actually, the help of skilled ultrasound approaches in emergency or elective medicine is a pivotal component for preventing overdiagnosis and wastebasket diagnosis, apart avoiding as much as possible the risk of missing or erroneous diagnosis. Overdiagnosis, is the diagnosis of "disease" that will never cause symptoms, distress, or death during a patient's lifetime, or that are not the real determinant of a clinical presentation. Wastebasket diagnosis, is a vague, or even completely fake, medical label given for essentially non-medical reasons, such as to reassure the patient by providing an official-sounding label, to make the provider look effective, or to obtain approval for treatment; wastebasket diagnosis often and likely represents a heterogeneous group of disease and conditions<sup>[16]</sup>. The diagnostic refinements that can quickly provide a timely and expert patient's assessment by ultrasound are, in our experience, a significant cornerstone fostering precision, clarity and quality in any medical approach.

An important step toward the management of risk is insuring that physicians are properly trained and credentialed according to national guidelines such as those

set by ACEP<sup>[15]</sup>. Proper quality assurance and improvement programs should be in place to identify and correct substandard practice, due to some variability of information of the published reports. Lastly, the standard of care for emergency ultrasound is the performance and interpretation of ultrasound by a physician certified in other specialties or in different settings: In these conditions credentials should have different goals, scope of practice, documentation requirements, and consequently should not be comparable to emergency medicine<sup>[12]</sup>.

## CLINICAL RISK ANALYSIS

The most relevant field of possible application of TUS is the diagnosis of lung consolidation, which is also one of the most critical diagnostic field of radiology. TUS may become a reliable tool capable of diagnosing pneumonia with high accuracy. Nonetheless, in the meanwhile, it is still a complementary source of information more than a promising attractive alternative to chest radiography and thoracic computed tomography (CT) scan: Most published studies, aimed at the definitions of the usefulness of lung ultrasound as a lone procedure for the diagnosis of pneumonia, are seemingly limited by methodological biases. Actually, as excellently summarized in a recent meta-analysis<sup>[17]</sup>, the most reputed studies on this topic, were "conducted to identify the usefulness of lung ultrasound for the diagnosis of pneumonia, but with inconsistent and inconclusive results"<sup>[17]</sup>. Nonetheless, the same accurate meta-analysis reports the results in 1080 subjects from a selected group of nine studies and concludes that "lung ultrasound is a capable of diagnosing pneumonia with high accuracy and is a promising attractive alternative to chest radiography and thoracic CT scan", with a "97% sensitivity and a 94% specificity". In this regard, several matter of concern persists: There are many part of the lung which are blinded to the ultrasound imaging since, due to skeletal barrier no more than 70% of lung is realistically explorable by TUS<sup>[14]</sup>. The other not minor concern is that lung consolidation due to any cause - pneumonia or cancer - is not discriminated by ultrasound, also using more advanced ultrasound techniques, such as transient elastography<sup>[18]</sup>. In both cases the need of a radiological approach, after the preliminary diagnosis of consolidation and mainly if the clinical and/or the ultrasound picture persists, is evident, and the claimed high sensitivity and specificity may need some mitigation<sup>[14]</sup>.

"Risk management in radiology is primarily developed and fostered to help safeguard patients, working personnel and the entire organisation. Protection of the organisation is largely grasped in terms of finance management. Potential drawbacks are linked to unreliable results that could damage its reputation"<sup>[19]</sup>. This is a particularly sensitive topic, since, apart the scientific foundation of some well conducted clinical trial, the

reference to a diffuse "good practice" for TUS diagnosis could still be a slippery slope. "The essence of risk management is to survey all potential reasons for an inaccurate report in advance so that procedures can be put in place to prevent them"<sup>[20]</sup>. There are still relevant variations in imaging tests accuracy, due to technical reasons of the procedure itself or to inconclusive results and reports due to organization or individual professional limitations; therefore, even the analysis of associated risks has lacked uniformity in the cost-utility literature<sup>[21-26]</sup>.

The central themes of the relevance of TUS in the cost-benefit analysis are the difficult appreciation of the times, ways, quality and consequences which are related to a systematic use of the procedure in emergency and the topics related to contexts, in elective, specialized, intensive or primary care, and in other areas yet.

Frequent and relevant applications, by which TUS may affect beneficially modulating the diagnostic and therapeutic pathways, are summarized in Table 1.

Also in these cases, the integration with more advanced radiological procedure is mandatory. This is true in emergency TUS, in which field the topic of unexpected clues is more frequently reported, but it is equally true in elective TUS, performed by radiologists or by internists-pneumologists.

## EMERGENCY: OPPORTUNITIES AND RELIABILITY

Emergency ultrasound is a standard emergency medicine procedure and is included in any definitions of the practice of emergency medicine<sup>[15,16]</sup>. Since several years, also TUS is a component of this framework, which should be articulated within the specificity of the subsets in regards to risk management and to the clinical scenario, differently demanding according to affordability and policies<sup>[14,27-29]</sup>.

The most relevant and relatively recent application of TUS in emergency is the quick detection of pneumothorax, by the significantly wide disappearance of the pleural line sliding<sup>[30-32]</sup>; this is a preliminary clinical diagnosis. It is precious in conditions of extreme facility shortage, where urgent intervention may be required and no timely confirm is available<sup>[33,34]</sup>. Nonetheless, TUS diagnosis of pneumothorax usually requires an urgent confirm, by CXR or CT, better to be available before any intervention procedure<sup>[35]</sup>.

There is a widespread indication to TUS, and notably using the information derived by a great number of artefact, for the diagnosis of acute heart failure<sup>[36]</sup>. Actually, for this purpose, the detection of a great number of B-lines by TUS is not an imaging technique, but a bulk indication of chest-pulmonary pathology. These artefacts, preventing the view of details of the underlying condition, provide a generic information: Patients with congestive heart failure, COPD, pulmonary fibrosis and many other conditions, including the normal lung and

**Table 1 Thoracic ultrasound - main indications**

<p>The physical examination by a non-radiologist MD can be usefully completed by a thorough and fast chest exploration. The aims are</p> <ul style="list-style-type: none"> <li>To clarify symptoms already known (dyspnea, chest pain, fever, cough) or detected signs, such as rales, crackles or dullness</li> <li>To detect unexpected chest abnormalities such as pleural effusion or lung consolidation in subjects with few or no evident respiratory symptom</li> </ul> <p>Information and clues derived by TUS may focus better to further diagnostic definition, by radiology or by other procedures, avoiding time-wasting and even detrimental choices</p> <p>The detection of pneumothorax by TUS is a quite simple and direct diagnosis of a not rare condition (see below), which should be usefully addressed to radiology, often including CT, for confirm. TUS has the great merit of making possible this direct pathway avoiding or postponing the more usual steps of chest pain work-up: Cardiological and laboratory investigations and preventive pharmacological drugs</p> <p>In addition, the detection of subpleural infiltrates after a blunt thoracic trauma, apparently relatively uneventful, can address to a subsequent better focused diagnostic workup</p> <p>Signs and symptoms initially addressing to different organs or body areas</p> <ul style="list-style-type: none"> <li>Upper abdominal pain, easily attributable to gallbladder</li> <li>Lumbar-flank pain, usually attributable to kidneys or spine, should prompt also to a TUS examination, since, with or without fever, the detection of pleural effusion or of downward areas of lung consolidation may address, as not infrequently happens, to a different diagnosis</li> </ul>
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TUS: Thoracic ultrasound; MD: Medical doctors; CT: Computerized tomography.

the empty chest cavity in lung resection patients, may present numerous and diffuse B-lines (ring-down)<sup>[37,38]</sup>. Moreover, it is unpractical the semi-quantitative use of this criterion for monitoring congestion in intensive care<sup>[39-42]</sup>. These limitations are well summarized in several reviews and commentaries<sup>[43,44]</sup>. Also the observation of the increase of the B-lines with ageing, in subjects without specific heart or chest disease<sup>[45,46]</sup>, is a further argument against any great expectation from this criterion. The use of a criterion with so relevant limitations is not neutral, since it averts from the use of more suitable criteria, such as echocardiography or radiology, or TUS itself, more adequately performed<sup>[47-52]</sup>. Despite it was claimed that TUS is a basic application in intensive care units and that can become a useful daily tool in these subsets, such application is not generally used and, actually and quite unexpectedly, after so many years, is still under assessment and evaluation. Reasonably, as smartly and not only polemically commented by an outstanding radiologist, "lung ultrasound in the intensive care unit is an idea that may be too good to be true"<sup>[53]</sup>. Actually, limitations of the procedure should be taken in account even more in subsets which may increase the source of errors and even the accessibility of the structures to ultrasound imaging<sup>[14]</sup>. Similarly, ultrasound diagnosis of pulmonary embolization does not fulfil definite criteria, and a great caution is needed and further efforts are warranted - CT - for reaching a conclusive diagnosis<sup>[54]</sup>.

## NEWBORN AND SMALL CHILDREN

The use of chest ultrasound in paediatrics is probably the most important, while still the less developed. The most relevant studies were often pioneered in children, since there is a greater easiness for the procedure, much alike the investigation by ultrasound (US) of abdomen in newborns, where so much is visible by ultrasound, with the obvious advantage of not using ionizing radiations<sup>[55,56]</sup>. The search for lung diffuse or lobar consolidation was and is the most relevant field of practice, and can allow the avoidance of radiological

investigations<sup>[57-59]</sup>. Moreover, also the detection of congenital abnormalities<sup>[60]</sup> and the investigation for the more frequent conditions, first of all pleural effusion, is a great opportunity for the paediatrician and for the radiologist, addressing appropriately to more in-depth investigations by radiological procedures, if needed<sup>[61,62]</sup>. Despite it was claimed that most chest radiological investigation are useless for the diagnosis of pneumonia in children, in our view there is a persistent need of CXR in several cases, particularly in immune-compromised patients<sup>[63-66]</sup>. The advantage of a systematic screening in paediatric units for an early diagnosis of ventilator-associated pneumonia may become one of the most relevant indication for the dissemination of the procedure<sup>[67,68]</sup>, even with the persisting limitations of the reliability of this tool<sup>[14,18,69]</sup>. Developing Countries too often have very limited resources for imaging facilities, particularly for the care of low-income population. Wasting and even lethal chest disease are still epidemic in many Regions, and the use of TUS is found precious in tuberculosis<sup>[70-74]</sup>. Patterns of sub-pleural granularity are described in patients with pulmonary miliary tuberculosis diagnosed by chest radiography, in acquired immunodeficiency syndrome<sup>[75-81]</sup>, as a complementary tool for any type of chest involvements, and in parasitic disease<sup>[82]</sup>, particularly in cystic and alveolar echinococcosis, frequent in endemic areas, both in adults and in children.

## OCCUPATIONAL AND SPORT MEDICINE, MILITARY AND MOBILE RESCUE SUPPORT

This is a field of a possible rewarding use of TUS, which is nonetheless still quite neglected. Of the occupational disease that may benefit from an early detection of pleural-lung abnormalities, the most relevant are the asbestos-associated disease, in which an early thickening of the pleural line, above 3 mm, is a clue that can advise for scheduling more timely, if not urgent, CT investigations<sup>[14]</sup>. Actually, this sign was found useful



because associated with pulmonary fibrosis in systemic sclerosis<sup>[83,84]</sup>; moreover, the detection of nodes in asbestos exposed patients can be managed safely by US guided fine needle aspirate biopsy<sup>[85]</sup>.

TUS in sport medicine, where there is a great use of musculoskeletal US procedures, is still limited, even if the feature of the procedure make it suitable for the early onsite diagnosis of pneumothorax and lung contusions, of pleural effusion and of lung consolidation, all conditions that are more ominous in a subject performing competitive sport activities<sup>[86]</sup>.

Military rescue support is an important sector of application and of experimental development of TUS, due to the frequent occurrence of traumatic or infectious chest disease in war scenarios<sup>[87-94]</sup>. Its use is warranted in many mobile facilities, including helicopters<sup>[33,95-100]</sup>, even if an integrated use with other procedures, mainly cardiologist, deserves a greater level of precision<sup>[101]</sup>.

## ASSESSMENT AND MANAGEMENT OF COMPREHENSIVE ELECTIVE WORKUPS

Since from its beginning, more than 50 years ago, TUS was developed in association with echocardiography<sup>[102-106]</sup>. There where and there are limitations related to artefacts, to the type of transducers, to the setting of the equipments<sup>[107]</sup> and only recently a greater care is devoted in the investigation of the more suitable probes<sup>[108]</sup>. Considering the mostly debated area of the monitoring of congestion in heart failure patients, the use of pleural effusion as a reference remains still the most objective clue, if present<sup>[109-114]</sup>. Nonetheless, this area of application is quite far from the tasks of the radiologist, and closer to the job of the cardiologist.

Monitoring is possible in several disease and context, with different degrees of reliability related to specific disease (the procedure is highly suitable for the diagnosis of pleural effusion, fairly suitable for the diagnosis of lung consolidation - superficial pneumonitis or cancer-, and pneumothorax). It is warranted not asking to the procedure more than it can give, because available expertise, knowledge, skills and training, but also the equipment's suitability, are not always affordable or accessible; the risk of misunderstanding and of interpreting misleading artefacts that may impair quality and information of the procedure must be limited as much as possible<sup>[115-117]</sup>. The use of TUS for guided chest procedure was and is mainly devoted to pleura and other chest cavities drainage by needle insertion<sup>[118-120]</sup>. Equally important are the procedures aimed at a precision nodule biopsy<sup>[121-124]</sup> or to other diagnostic and therapeutic procedures related to diaphragm neuro-muscular disease<sup>[125]</sup>.

## CHEST RADIOLOGY AND ULTRASOUND: WHAT, WHO, WHERE, WHEN, WHY

Topics of trans-TUS are displayed in several hand-

books<sup>[126,127]</sup>, which are also available as e-books. The question of the possible use of TUS as a screening tool is the same question of lung CT<sup>[128,129]</sup> as a screening tool for lung cancer: Population and individuals at risk should be screened, but the use of TUS as a tool useful for addressing earlier more in depth CT controls is a matter of active current investigation<sup>[83,116]</sup>.

The professionals performing TUS must be optimally trained<sup>[130]</sup>. In our view, and experience, teaching clinical ultrasound along the 3<sup>rd</sup> year curriculum of the School of Medicine is the optimal choice, beginning as earlier as possible, provided that adequately skilled teachers are available<sup>[131-135]</sup>; physical examination skills and ultrasound proficiency between trained and untrained medical students improve together<sup>[136-139]</sup>. Differently, it is quite questionable that very brief periods of training in TUS<sup>[140,141]</sup> could provide sufficient knowledge and skills, unless they are articulated within a comprehensive US diagnostic and teaching curriculum<sup>[142,143]</sup>. This is a very important issue since the relevance of a widespread expertise among medical doctors is of pivotal relevance for a sustainable and reliable approach to the diagnosis and management of youngsters with pneumonia<sup>[61]</sup>, an advancement that is a valuable medical breakthrough in children and limited resources subsets<sup>[144]</sup>. Quoting Thomas Huxley, the biologist, we should say: "Economy does not lie in sparing money, but in spending it wisely". It is exactly what a wise and expert dissemination of knowledge, skills and machine focused to TUS may achieve, if no unrealistic claim will be placed in the procedure, leading to skipping, when needed, *i.e.*, often, the step of conventional or advanced radiology.

## CONCLUSION

The field of application of TUS are pleural effusion, pneumothorax, and lung consolidation, both in emergency and in elective subsets. Paediatric and newborn disease are greatly suitable for TUS investigation aimed at the detection of congenital or acquired chest disease avoiding or limiting radiological exposure. This is a still neglected area of application, and its dissemination must be warranted and supported. In any field of application, TUS improves the effectiveness of medical practice in resource-limited settings, in small point-of-care facilities, in hostile environment and in poorer countries. This is true for all the ultrasound diagnostic applications, and the specific knowledge and skills must be adequately propagated, providing advantages for limiting or more appropriately referring patients in any hospital facility<sup>[144,145]</sup>.

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