



ERS | *monograph*

Thoracic Ultrasound

Edited by Christian B. Laursen,
Najib M. Rahman
and Giovanni Volpicelli

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Editor in Chief
Robert Bals

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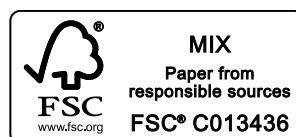
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Contents

Thoracic Ultrasound

Number 79
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Preface	ix
Guest Editors	xi
Introduction	xiii
List of abbreviations	xvi
1. Physics and basic principles <i>Stephen Alerhand, Ole Graumann and Bret P. Nelson</i>	1
2. Technique and protocols <i>Christian B. Laursen, Jesper R. Davidsen and Fergus Gleeson</i>	14
3. Chest wall and parietal pleura <i>Maged Hassan and Najib M. Rahman</i>	31
4. Pneumothorax <i>Nils Petter Oveland</i>	43
5. Pleural effusion <i>Christopher Merrick, Rachele Asciak, Anthony Edey, Fabien Maldonado and Ioannis Psallidas</i>	64
6. Interstitial syndrome <i>Luna Gargani</i>	75
7. Pneumonia <i>Gebhard Mathis</i>	87
8. Pulmonary embolism <i>Giovanni Volpicelli</i>	102
9. Lung tumours <i>Christian Görg, Corinna Trenker and Andreas Schuler</i>	115
10. The diaphragm <i>Giovanni Ferrari, Søren Helbo Skaarup, Francesco Panero and John M. Wrightson</i>	129

11. The upper abdomen	148
<i>Stefan Posth and Ole Graumann</i>	
12. The mediastinum	161
<i>Felix J.F. Herth</i>	
13. Ultrasound of the neck for airway management	172
<i>Michael S. Kristensen and Wendy H. Teoh</i>	
14. Focused cardiac ultrasound	184
<i>Gabriele Via, Anthony Dean, Gabriele Casso, Brian Bridal Løgstrup and Guido Tavazzi</i>	
15. Newborns, infants and children	206
<i>Francesco Raimondi, Fiorella Migliaro, Antonietta Giannattasio, Letizia Capasso, Claudia Lucia Piccolo, Margherita Trinci, Vittorio Miele and Stefania Ianniello,</i>	
16. Ultrasound-guided procedures	226
<i>John P. Corcoran, Mark Hew, Fabien Maldonado and Coenraad F.N. Koegelenberg</i>	
17. Future directions	244
<i>Christian B. Laursen, Najib M. Rahman and Giovanni Volpicelli</i>	



Preface

Robert Bals

US techniques are one of the most elegant diagnostic approaches in clinical medicine. In the hands of an experienced investigator, the US machine can provide deep insight into the physiology and pathology of the body. In most cases, US application is fast, radiation-free and does not cause pain. However, the outcome of the US examination depends largely on the capabilities and experience of the investigator. The development of medical US has an interesting history, further discussed in the Guest Editors' Introduction [1], with the abdomen and the heart being the major targets in recent decades. US-based diagnostics have also been introduced in the respiratory field. As elsewhere, the success of this method in the respiratory field is dependent on training and practice guidance in TUS, as well as the availability of a comprehensive text book. With this latter necessity in mind, we decided to fill this critical gap by devoting an *ERS Monograph* to the subject.



This book provides the reader with a broad and detailed overview on the various application of TUS. The initial chapters summarise the technologies and standard approaches used. Subsequent chapters focus on specific diseases and cover additional areas such as cardiac US, application in children and US use during procedures.

Thanks to the hard work of the book's Guest Editors, Christian B. Laursen, Najib M. Rahman and Giovanni Volpicelli, readers of this *Monograph* will benefit from a book that provides a comprehensive overview of both the background and hands-on application of US. We hope that this important publication will not only aid the respiratory physician in their day-to-day practice but will also help generate more frequent use of TUS in the field.

References

1. Laursen CB, Rahman NM, Volpicelli G. Introduction. *In*: Laursen CB, Rahman NM, Volpicelli G, eds. *Thoracic Ultrasound (ERS Monograph)*. Sheffield, European Respiratory Society, 2018; pp. xiii–xv.

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Guest Editors

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Christian B. Laursen is Associate Professor at the University of Southern Denmark (Odense, Denmark). He is a Consultant and Head of Research at the Department of Respiratory Medicine, Odense University Hospital (Odense).

He qualified in medicine at the University of Southern Denmark and trained in pulmonology at Svendborg Sygehus (Svendborg, Denmark) and Odense University Hospital. He received his PhD in point-of-care ultrasonography at the University of Southern Denmark.

Christian Laursen's research interests lie particularly in clinical ultrasound, interventional pneumology, medical education and technical training. His current research focuses on the use of advanced and multiparametric ultrasound for malignancy in the chest, complex pleuropulmonary infections and interstitial lung diseases.

He is one of the cofounders of an international collaborative research network in thoracic ultrasound education and training. The network currently involves the Oxford Pleural Unit at the Oxford Centre for Respiratory Medicine (Oxford, UK), Southmead Hospital (Bristol, UK), the Copenhagen Academy for Medical Education and Simulation (CAMES) (Copenhagen, Denmark), and the Department of Respiratory Medicine and Regional Centre of Technical Simulation (TechSim) (Odense, Denmark). The aim of the collaboration is to provide evidence-based educational programmes in thoracic ultrasound and related procedures.

Christian Laursen chairs the Danish Society of Respiratory Medicine's Ultrasound Committee and is Course Director of the European Respiratory Society's course in thoracic ultrasound.



Najib M. Rahman



Najib M. Rahman is Associate Professor of Respiratory Medicine. He runs the Oxford Pleural Unit (Oxford, UK) and is Director of the Oxford Respiratory Trials Unit (Oxford).

Having qualified in medicine from the University of Oxford (Oxford), he conducted his post graduate training in Nottingham (UK), then his specialist training in Oxford, including a DPhil in pleural disease (conducting the MIST2 study) and an MSc in clinical trials methodology. He now conducts research in clinical and translational pleural disease in Oxford, and runs randomised and observational studies in pleural infection, pneumothorax, malignant pleural effusion and ultrasound. He has authored over 90 peer reviewed publications.

Giovanni Volpicelli



Giovanni Volpicelli has been an emergency physician at the Emergency Department of San Luigi Gonzaga University Hospital (Torino, Italy) since 1998. In 2016, he qualified as Associate Professor of Internal Medicine.

Giovanni Volpicelli was Chair of the Scientific Committee of the 1st International Consensus Conference on Lung Ultrasound. He is a member of the Scientific Committee of the 2nd International Consensus Conference on Ultrasound in Trauma, and he is a board member of the 1st International Consensus Conference on US in Medical Education. He is Editor-in-Chief of the *Critical Ultrasound Journal*, Academic Editor of *Medicine* and a member of the Editorial Boards of and reviewer for many international journals, including *The New England Journal of Medicine*, *Annals of Internal Medicine*, the *American Journal of Respiratory and Critical Care Medicine*, *Chest*, *Intensive Care Medicine*, *Critical Care Medicine*, *Critical Care*, *Anesthesiology*, and the *American Journal of Emergency Medicine*. He is a scientific reviewer for MORE (McMaster Online Rating of Evidence) at McMaster University (Health Information Research Unit, Hamilton, ON, Canada).

Giovanni Volpicelli is a fellow of the American College of Chest Physicians (ACCP), a member of the American College of Emergency Physicians (ACEP) and a member of the Board of Directors of the World Interactive Network Focused on Critical Ultrasound (WINFOCUS). He coordinates the international program of education on lung ultrasound for WINFOCUS.

Giovanni Volpicelli has authored and co-authored chapters of international books in emergency medicine and emergency ultrasound, and has 93 indexed publications in peer-reviewed international journals with 3450 citations.



Introduction

Christian B. Laursen^{1,2,3}, Najib M. Rahman^{4,5,6} and Giovanni Volpicelli⁷

The sinking of RMS Titanic in 1912 led to the invention of a range of devices as a means of improving the detection of icebergs. During World War I, the technique was further developed into an active sound device using quartz for the detection of submarines. In the following decades and during World War II, the technique was further developed and named sonar (SOund Navigation And Ranging) [1]. The principles and technologies that lead to the development of sonar were also noticed amongst physicians. In 1940, Gohr and Wedekind suggested the use of reflected sound for diagnosing tumours, effusions and abscesses [2]. Dussik was the first to report the clinical use of reflected US as a medical diagnostic tool in his exploration of whether visualisation of intracranial structures and ventricular measurements was possible with US waves [3]. Despite Gohr and Wedekind's initial suggestions and studies published by other authors, the use of TUS as a clinical tool was for many years considered to be limited to the assessment of pleural effusion [2, 4–6]. A description of the use of TUS as a tool for the assessment of horses with respiratory diseases challenged this dogma. Rantanen reported the use of TUS for the assessment and diagnosis of such conditions as lung consolidation, atelectasis, abscesses, pleural effusion, empyema and pneumothorax in horses [7]. Furthermore, Rantanen's paper contains descriptions of vertical and horizontal reverberation artefacts as well as the concept of movement of the "pleural blades" during respiration in normal lungs, and its absence if pneumothorax is present [7]. These signs and artefacts were later to be considered key concepts in TUS [8]. The subsequent studies during the 1990s by researchers such as Targhetta and Lichtenstein lead to the birth of TUS as an essential diagnostic modality in the assessment of patients with known or suspected disease in the chest [9–14].

A milestone was reached when the first international consensus conference producing evidence-based recommendations for point-of-care LUS was published in 2012 [8]. This document achieved the great acknowledgement of becoming the most cited article of the top 50 published in *Intensive Care Medicine*, the journal of the European Society of Intensive Care Medicine; it was even more highly cited than other very

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popular topics in critical care, such as the fluid management of shock and the new definition of acute respiratory distress syndrome [15]. The consensus analysed 320 articles published prior to 2012. The same group of experts is working on the update, analysing around 700 articles on LUS published from 2012 to the present day. This demonstrates the great importance and high impact of TUS in various communities, including, of course, respiratory medicine.

We were thrilled to be asked to be guest editors of this, the very first *ERS Monograph* on TUS. A book solely dedicated to the subject is a clear sign that TUS is now considered to be an essential bedside tool for the modern respiratory physician. Despite this, and the fact that the number of published studies describing the clinical use of TUS is steadily increasing, several aspects are yet to be studied and assessed in robust clinical trials. In comparison with other types of clinical US (e.g. abdominal US, echocardiography) the extent of international consensus on several key aspects remains limited. Furthermore, different forms and TUS approaches have been adopted by many different specialities and societies, making a consensus process even more difficult. In the context of this *Monograph*, we chose to use the following definitions:

- TUS: diagnostic ultrasonography of the thorax. The term chest sonography or LUS is often used synonymously in the literature [8, 16].
- Focused TUS: a focused TUS examination.
- Focused ultrasonography: an ultrasonographic examination performed in a focused manner in order to answer specific and clinically relevant yes/no questions. As opposed to diagnostic ultrasonography, focused ultrasonography is believed to require less training and is less time consuming to perform [17]. An example would be FTUS examination used by an emergency physician to assess a patient with respiratory failure in an emergency department.
- Diagnostic ultrasonography: defined as an US examination in which the examiner aims to identify all possible pathologic conditions in an organ or structure, including the ability to declare “normality”. In order to be able to perform diagnostic ultrasonography, dedicated training and more extensive experience are required [18]. Examples are echocardiography performed by a cardiologist or a TUS examination performed by a respiratory physician.

To compensate for the lack of international consensus and different approaches used, we chose to invite a selection of authors for each chapter who were not only recognised experts but also represented different specialities, use TUS in different settings, and work at different institutions in different countries. We are very pleased that we were able to use this approach, and would like to thank all the authors for their positive attitude and collaborative efforts within the group. We hope that the result is that each chapter reflects not only the opinion of experts at a single site in Europe but a multidisciplinary and multicentre view.

In summary, we hope that this *ERS Monograph* will facilitate increased consensus, research, implementation and evidence-based use of TUS to the benefit of the high number of patients being assessed for diseases of the thorax. This technique must surely now be regarded as essential.

References

1. Ainslie M. Principles of Sonar Performance Modelling. Berlin, Springer, 2010.
2. Gohr H, Wedekind T. Der Ultraschall in der Medizin. *Klin Wochenschr* 1940; 19: 25.
3. Dussik K. Über die möglichkeit hochfrequente mechanische schwingungen als diagnostisches hilfsmittel zu verwerten. *Z Neurol Psychiat* 1942; 174: 153–168.
4. Dudrick SJ, Joyner CR, Miller LD, *et al.* Ultrasound in the early diagnosis of pulmonary embolism. *Surg Forum* 1966; 17: 117–118.
5. Miller LD, Joyner CR, Dudrick SJ, *et al.* Clinical use of ultrasound in the early diagnosis of pulmonary embolism. *Ann Surg* 1967; 166: 381–393.
6. Joyner CR Jr, Miller LD, Dudrick SJ, *et al.* Reflected ultrasound in the study of diseases of the chest. *Trans Am Clin Climatol Assoc* 1967; 78: 28–37.
7. Rantanen NW. Diseases of the thorax. *Vet Clin North Am Equine Pract* 1986; 2: 49–66.
8. Volpicelli G, Elbarbary M, Blaivas M, *et al.* International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med* 2012; 38: 577–591.
9. Targhetta R, Bourgeois JM, Balmes P. Echography of pneumothorax. *Rev Mal Respir* 1990; 7: 575–579.
10. Targhetta R, Chavagneux R, Bourgeois JM, *et al.* Sonographic approach to diagnosing pulmonary consolidation. *J Ultrasound Med* 1992; 11: 667–672.
11. Lichtenstein DA. A bedside ultrasound sign ruling out pneumothorax in the critically ill. Lung sliding. *CHEST J* 1995. 108: 1345.
12. Lichtenstein D, Mézière G, Biderman P, *et al.* The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 1997; 156: 1640–1646.
13. Lichtenstein D, Meziere G. A lung ultrasound sign allowing bedside distinction between pulmonary edema and COPD: the comet-tail artifact. *Intensive Care Med* 1998; 24: 1331–1334.
14. Lichtenstein D, Mézière G, Biderman P, *et al.* The “lung point”: an ultrasound sign specific to pneumothorax. *Intensive Care Med* 2000; 26: 1434–1440.
15. ICM: 50 most cited articles. www.esicm-old.org/news-article/ICM-news-50-MOST-CITED-2012-June-2015. Date last accessed: January 1, 2018.
16. Mathis G, Sparchez Z, Volpicelli G. Chest sonography. In: Dietrich CF. *EFSUMB Course Book*. London, EFSUMB, 2010.
17. Noble VE, Nelson BP. Manual of Emergency and Critical Care Ultrasound. Cambridge, Cambridge University Press, 2011.
18. Minimal Training Requirements for the Practice of Medical Ultrasound in Europe. Appendix 11: Thoracic Ultrasound. 2008 [cited 2016 01.03.16] <http://efsumb.org/guidelines/guidelines01.asp>

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List of abbreviations

CEUS	contrast-enhanced ultrasound
COPD	chronic obstructive pulmonary disease
CT	computed tomography
CXR	chest x-ray
DUS	diaphragm ultrasound
EBUS-TBNA	endobronchial ultrasound-guided transbronchial needle aspiration
EUS-FNA	endoscopic ultrasound fine-needle aspiration
FoCUS	focused cardiac ultrasound
LUS	lung ultrasound
MRI	magnetic resonance imaging
PET	positron emission tomography
PoCUS	point-of-care ultrasound
TUS	thoracic ultrasound
US	ultrasound