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The Geriatric Patient: The Ideal One for Chest Ultrasonography? A Review From the Chest Ultrasound in the Elderly Study Group (GRETA) of the Italian Society of Gerontology and Geriatrics (SIGG)

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Title: The geriatric patient: the ideal one for chest ultrasound? A review from the Chest Ultrasound in the Elderly Study Group (GRETA) of the Italian Society of Gerontology and Geriatrics (SIGG)

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Abstract: Objectives- To investigate on the current evidence on the use of point-of-care chest ultrasound in older patients and geriatric settings, and present the current state-of-art of chest ultrasound applications.

Design- Special article based on a literature review with narrative analyses, and expert clinical knowledge.

Setting and participants- All studies performed in a geriatric setting were included. Observational and intervention studies and meta-analyses including participants aged  $\geq 70$  were also considered, even if not specifically focused on a geriatric setting.

Measures- Data on participant characteristics, diagnostic accuracy of chest ultrasound and outcomes were collected for each considered study. Data were analyzed and discussed with a particular focus on the possible applications and advantages of chest ultrasound in geriatric medicine, underlining the possible areas of future research.

Results- We found only five studies on the diagnostic accuracy and prognostic relevance of chest ultrasonography in geriatrics. However, several studies performed in Emergency Departments, Intensive Care Units and internal medicine wards, included a large number of participants over 70 years old; they suggest that chest ultrasonography may represent a valid aid to the diagnostics of acute dyspnea, pneumonia, acute heart failure, pneumothorax, and pleural diseases, with an accuracy in some cases superior to standard X-rays, especially when mobility-limitation is present. Diaphragm ultrasound may also represent a valid tool to guide mechanical ventilation weaning in older patients with acute respiratory failure.

Conclusions and Implications- Chest ultrasound may represent a valid bedside diagnostic aid to the management of acute respiratory diseases in older patients. However, specific evidence is lacking for geriatric patients. Future research will need to focus on defining the reference

standards and the diagnostic accuracy for frail and multimorbid elderly patients, cost/efficacy and cost/effectiveness of the technique, its impact for clinical outcomes and role for follow-up in the post-acute care.

Parma, 16<sup>th</sup> May 2019

Dear Editor,

I am submitting to Your attention the revised version of the manuscript entitled “**The geriatric patient: the ideal one for chest ultrasound? A review from the Chest Ultrasound in the Elderly Study Group (GRETA) of the Italian Society of Gerontology and Geriatrics (SIGG)**” for consideration of publication in *Journal of the American Medical Directors’ Association* as a Special Article (Manuscript Reference Number JAMDA-D-19-00128).

We have read with great interest the reviewers’ comments, and are grateful for their important suggestions for improving the quality of the manuscript.

The present version has been consistently and thoroughly revised, in accordance with their comments, to provide a balanced and objective overview of the current literature state-of-the-art on thoracic ultrasound and its possible applications in geriatrics.

Namely, we have moved part of the basic concepts on how to perform thoracic ultrasound to Supplemental Material, discussing more deeply the issues of equipment type and cost, possible applications outside the hospital setting, and level of training needed to reach a sufficient competency. We have also introduced a new Table summarizing the key characteristics and results of chest ultrasound studies performed in patients aged in average 70 years or older, with grading and quality of evidence of each study. Finally, we have expanded the image set: a novel Figure was added to the main text, and a larger number has been provided in Supplemental Material.

We hope that the reviewers and you will consider positively our efforts to improve the quality of the manuscript.

Thank You for your kind attention in our work.

Best regards,

Andrea Ticinesi, M.D. Ph.D.

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1 **RESPONSE TO REVIEWERS' COMMENTS**

2 **“The geriatric patient: the ideal one for chest ultrasound? A review from the Chest**  
3 **Ultrasound in the Elderly Study Group (GRETA) of the Italian Society of Gerontology and**  
4 **Geriatrics (SIGG)”**

5

6 **ANSWERS TO REVIEWER #1**

7 **“The topic is of potential interest but would need modification to appear more balanced, and**  
8 **less like an advertisement for ultrasound.”**

9 R: We thank the reviewer for the useful comments and suggestions. We agree that the previous  
10 version of the manuscript was too favorable to chest ultrasound implementation in geriatrics,  
11 underestimating critical issues. The novel version of the article has been completely and thoroughly  
12 revised, avoiding enthusiastic tones and providing a more balanced and objective view of current  
13 evidence.

14

15 **“1. The data on how to do ultrasound should be reduced (eliminate lines 68-77 and Tables 1**  
16 **and 2). Do, however, say more about the logistics of doing ultrasound with people who are ill,**  
17 **immobilized, and/or in nursing homes or homebound.”**

18 R: The paragraph on the ultrasonographic appearance of normal chest has been removed from the  
19 new version of the manuscript. Table 2 and Figure 1 (now Table S1 and Figure S1, respectively),  
20 providing the same information in a more schematic way, have been transferred to Supplemental  
21 Material. We instead left Table 1 in the main text, because we feel that the methodology of  
22 examination and its versatility is one of the major points supporting the assumption of the article's  
23 title (geriatric patients are the ideal ones for chest ultrasound). This point of view has been clarified  
24 also in the text (lines 68-70). Some comments on the logistics of performing ultrasound in  
25 immobilized patients, nursing home residents or homebound older subjects have also been added  
26 (lines 70-72), in accordance with the suggestion.

27

28 **“2. Please add data on types of equipment (including cost and reliability/quality)”**

29 R: A novel paragraph has been added, dealing with these topics (lines 73-80). We mainly  
30 concentrated on the comparison between standard portable equipment and pocket hand-held  
31 equipment, that make it possible to perform chest ultrasonography in virtually any clinical scenario.  
32 A recent study comparing standard and pocket ultrasound equipment in geriatric patients has also  
33 been mentioned (Fröhlich and colleagues, reference 8). We did not discuss the costs of ultrasound  
34 machines because this aspect was beyond the purposes of our article. However, we carefully  
35 assessed the cost-effectiveness issue. There is only one study in the scientific literature examining  
36 the impact of chest ultrasound on healthcare costs (Zieleskiewicz and colleagues, reference 57). Its  
37 results and possible implications for geriatric practice have been discussed in the section on the  
38 possible advantages of lung ultrasound in geriatrics (lines 265-268).

39 **“3. Add information on how much training and experience is needed to achieve competency**  
40 **(again with data).”**

41 R: We thank the reviewer for this important suggestion. In the novel version of the article, a  
42 paragraph discussing the level of training necessary to reach a sufficient agreement with  
43 examinations performed by experienced sonographers has been added (lines 99-104). The scientific  
44 literature supports the concept that chest ultrasound is easier and quicker to learn than abdominal  
45 ultrasound, at least to solve the most common diagnostic dilemmas.

46

47 **“4. The paper should focus more on comprehensively reviewing and summarizing the data on**  
48 **the diagnostic accuracy of ultrasound. Additionally, the presentation of data appears**  
49 **selective and instead should identify and show data related to the areas where ultrasound has**  
50 **been shown to be less helpful.**

51 **One way to do this would be to create a detailed table that might have these headings (\* =**  
52 **requires citation(s):**

53 **Diagnosis / ultrasound sign / gold standard / sensitivity \* / specificity \* / grade of evidence # /**  
54 **differential diagnosis**

55 **# Grading evidence should use an accepted, published method.”**

56 R: We agree with the reviewer that this is a critical point of our manuscript. As said in the article,  
57 the systematic literature search did not retrieve results that could be presented in a comprehensive  
58 and homogeneous way. Studies on chest ultrasonography were in fact conducted in a wide range of  
59 settings and clinical situations, but they hardly ever focused on geriatric patients. Thus, we decided  
60 to summarize evidence coming from studies conducted on adult patients (mean age <70 years old),  
61 and then focus the discussion on the few studies that enrolled a consistent proportion of older  
62 patients (i.e., studies where the mean age of participants was  $\geq 70$  years old). In the new version of  
63 the manuscript, the key characteristics of these studies have been presented also in a table (Table 3),  
64 providing a more balanced view of the areas where ultrasound proved less helpful (such as acute  
65 heart failure) and of the limitations of each study. Namely, we introduced grading and quality  
66 assessment of each study, following the same methodology as Barth and colleagues (reference 53).  
67 The methodology is presented also in Supplemental Material (Table S2 and S3).

68

69 **“5. A larger set of figures on common diagnostic findings as an appendix would helpful.”**

70 R: In the novel version of the manuscript, a novel figure has been added (Figure 2) to highlight  
71 other possible applications of chest ultrasound, and comparing ultrasound with CT images.  
72 Moreover, a larger set of figures on common clinical situations (pneumonia, pleural effusion, acute  
73 heart failure, atelectasis) has been presented in the Supplemental Material.

74

75 **“6. With modification it might be best as a special article.”**

76 R: We thank the reviewer for the precious advice, and hope to have improved the quality of the  
77 article.

78

## 79 **ANSWERS TO REVIEWER #2**

80 **“This is an interesting paper and important topic, and one not largely covered in JAMDA; I**  
81 **especially appreciate its clinical relevance. I have only one overriding comment, and many**  
82 **minor comments related to grammar.**

83 **Overriding comment: This paper does not meet the bar of a systematic review, and is actually**  
84 **better identified as a special article. I suggest Line 4 indicate that this special article is based**  
85 **on a literature review with narrative analyses, and expert clinical knowledge.”**

86 R: We thank the reviewer for appreciation in our work. In the novel version, the article has been  
87 consistently revised to improve the quality of the presentation and provide a more balanced view of  
88 the possible applications of chest ultrasound in geriatrics. We have also tried to improve the  
89 systematic nature of the article introducing a new table (Table 3), where a synthetic overview of  
90 chest ultrasound studies, that were conducted in patients with a mean age over 70 years old, is  
91 presented. We however agree that the best definition of the article methodology is “literature review  
92 with narrative analysis”, and have modified the abstract and the main text accordingly (lines 5-6 and  
93 53-60).

94 **“Line 2: Objectives: Add "and present the current state-of-art of chest ultrasound**  
95 **applications.”**

96 **Please see recommendations for rounding numbers in the Guide for Authors**

97 **Line 35: Change "since" to "because"**

98 **Line 38: Change "several" to "a great deal of"**

99 **Line 42 and elsewhere: Everywhere in your manuscript, after you use the word "this," please**  
100 **be sure a noun follows so that readers are clear regarding your point.**

101 **Line 46: Change "also" to "even"**

102 **Objective (line 51-53): Omit "on" in "on the current evidence ..."** Also, you may need a  
103 **noun after "geriatrics." And, please be more specific regarding what is meant regarding**  
104 **"identify areas of development of the technique."**

105 **Line 54: The literature search was "conducted," not "made." Please also briefly summarize**  
106 **the search in the text.**

107 **Line 56: "Which," not "whom."**

108 **Line 92-93: Please rephrase "while differential diagnosis may result difficult" because the**  
109 **point being made is unclear.**

110 **Line 103: Omit "a"**

111 **Line 111: Change "in" to "an"**

112 **Line 144: Please correct the awkward wording "allowed to reach"**

113 **Line 181: Please correct the awkward wording "allowing to spare the prescription of CTs."**

114 **Line 190: Please correct the awkward wording "for performing thoracentesis in safety..."**

115 **Line 233: Change "Actions" to "Action"**

116 **Line 236: Change "systems" to "system"**

117 **Line 248: Omit "by operators."**

118 **Line 252: Omit "may contribute to." Also, put the word "literature" after "state-of-the-art"**

119 **(and note the addition of "the" in that phrase).**

120 **Line 261: Change the phrase to "state-of-the-art"**

121 **Line 292: Omit "an" before "implementation"**

122 **Line 293: Omit "the" in "on the reference standards in the elderly"**

123 **Line 294: Make "setting" plural**

124 **Table 1:**

125 **\* Probes: Change "to detect" to "detection of"**

126 **\* Methodology: Change "Small movements of ...are allowed to ..." to "Allow small**

127 **movements of ...to assure ..." Change "Measurement of diaphragm..." to "Measure**

128 **diaphragm ..."**

129 **Table 3:**

130 **\* Do not use abbreviations (the table is short enough that abbreviations are not necessary)**

131 **\* Close the parenthesis in the first box"**

132 R: We thank the reviewer for the accurate check, and apologize for grammatical and typo mistakes.

133 In the novel version, the article has been completely and thoroughly revised in accordance with

134 suggestions. The key information on the literature search strategy have also been added in the main

135 text.

136

## **The geriatric patient: the ideal one for chest ultrasound?**

**A review from the Chest Ultrasound in the Elderly Study Group (GRETA) of the Italian Society of Gerontology and Geriatrics (SIGG)**

Andrea Ticinesi<sup>a,b\*</sup>, M.D., Ph.D.; Simone Scarlata<sup>c</sup>, M.D.; Antonio Nouvenne<sup>a,b</sup>, M.D., Ph.D.;  
Fulvio Lauretani<sup>a,b</sup>, M.D., Ph.D.; Raffaele Antonelli Incalzi<sup>c</sup>, M.D.; Andrea Ungar<sup>d</sup>, M.D., Ph.D.

On behalf of the GRETA (Gruppo di Ricerca sull'Ecografia Toracica nell'Anziano) Group of the  
Italian Society of Gerontology and Geriatrics (SIGG)

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**Running head:** Chest ultrasound in geriatrics

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**Abstract word count:** 295 - **Main text word count:** 3147

**Article summary:** The current applications of bedside chest ultrasound in the management of the geriatric patient are critically reviewed in this paper, highlighting that this technique may facilitate the diagnostic process and follow-up of older patients with cardio-respiratory illness.

1 **ABSTRACT**

2 **Objectives-** To investigate on the current evidence on the use of point-of-care chest ultrasound in  
3 older patients and geriatric settings, and present the current state-of-art of chest ultrasound  
4 applications.

5 **Design-** Special article based on a literature review with narrative analyses, and expert clinical  
6 knowledge.

7 **Setting and participants-** All studies performed in a geriatric setting were included. Observational  
8 and intervention studies and meta-analyses including participants aged  $\geq 70$  were also considered,  
9 even if not specifically focused on a geriatric setting.

10 **Measures-** Data on participant characteristics, diagnostic accuracy of chest ultrasound and  
11 outcomes were collected for each considered study. Data were analyzed and discussed with a  
12 particular focus on the possible applications and advantages of chest ultrasound in geriatric  
13 medicine, underlining the possible areas of future research.

14 **Results-** We found only five studies on the diagnostic accuracy and prognostic relevance of chest  
15 ultrasonography in geriatrics. However, several studies performed in Emergency Departments,  
16 Intensive Care Units and internal medicine wards, included a large number of participants over 70  
17 years old; they suggest that chest ultrasonography may represent a valid aid to the diagnostics of  
18 acute dyspnea, pneumonia, acute heart failure, pneumothorax, and pleural diseases, with an  
19 accuracy in some cases superior to standard X-rays, especially when mobility-limitation is present.  
20 Diaphragm ultrasound may also represent a valid tool to guide mechanical ventilation weaning in  
21 older patients with acute respiratory failure.

22 **Conclusions and Implications-** Chest ultrasound may represent a valid bedside diagnostic aid to  
23 the management of acute respiratory diseases in older patients. However, specific evidence is  
24 lacking for geriatric patients. Future research will need to focus on defining the reference standards  
25 and the diagnostic accuracy for frail and multimorbid elderly patients, cost/efficacy and

26 cost/effectiveness of the technique, its impact for clinical outcomes and role for follow-up in the  
27 post-acute care.

28

29 **Key words:** lung ultrasound; point-of-care; respiratory diseases; diagnostic accuracy

30 **INTRODUCTION**

31 In modern medicine, point-of-care ultrasonography has become one of the most popular tools for  
32 assisting the diagnostic process in hospitalized patients, as a technologic complement to physical  
33 examination and laboratory biomarkers.<sup>1</sup> Although partly dependent on the skills of each operator,  
34 it is considered a safe and rapid imaging technique providing responses to several clinical questions  
35 directly at the bedside and at the moment of need.<sup>1</sup>

36 Chest ultrasound is perhaps one of the least expected applications of point-of-care ultrasonography,  
37 because respiratory structures, and particularly the lung parenchyma, cannot be directly explored by  
38 ultrasounds. In fact, lung parenchyma has a high acoustic impedance preventing the definition of  
39 anatomically faithful images.<sup>1</sup> However, ultrasonographic evaluation of the lung may provide a  
40 great deal of clinically relevant information in both health and disease, thanks to a simple and  
41 highly reproducible semeiotics.<sup>1-3</sup> This technique has entered clinical practice for the diagnosis of  
42 respiratory diseases in several settings, ranging from Emergency Departments (EDs) to Intensive  
43 Care Units (ICUs) to acute Internal Medicine and Pulmonology wards.<sup>2,3</sup>

44 Unfortunately, chest ultrasound is not so popular in Geriatric wards. Possible barriers for bedside  
45 implementation of this technique may include reduced availability of portable equipment, limited  
46 access to specific training courses, perception of ultrasound as a scarcely reproducible examination,  
47 especially in subjects with severe mobility-limitations and dementia.

48

49

50 **OBJECTIVES AND METHODS**

51 Our aim was to investigate the current evidence on the use of point-of-care chest ultrasound in older  
52 patients and geriatric wards, present its current applications and identify areas for future research in  
53 the geriatric setting.

54 A literature search was conducted on PubMed as of December 19<sup>th</sup>, 2018, using the search strategy  
55 reported in the Supplementary Material, that used “chest ultrasound”, “lung ultrasound”, “geriatric”  
56 and “older individuals” as the main key words.

57 The results of the search showed substantial lack of papers with a geriatric focus (16 manuscripts,  
58 of which only 5 reporting original data). Thus, we decided to present the current state-of-the-art of  
59 chest ultrasound applications in medical patients with a narrative approach, focusing on studies  
60 where participants with a mean age  $\geq 70$  years old were enrolled and highlighting the points of  
61 interest for older patients and applications for geriatric medicine.

62

63 **CHEST ULTRASOUND METHODOLOGY AND RELATED ISSUES**

64 The recommendations on the best way to perform a bedside chest ultrasound<sup>1</sup> are summarized in  
65 Table 1. There are no specific recommendations for geriatric patients in the scientific literature. The  
66 main critical issue in older individuals is severe mobility-disability, preventing the patient to  
67 maintain the sitting position for the time of the examination. However, some protocols include the  
68 possibility of performing ultrasound with the patient lying supine, or with the aid of a second  
69 operator, helping the patient to remain seated<sup>4</sup>, so that the methodology of examination fits to the  
70 patient's motoric performance (Table 1). This versatility represents a consistent advantage of  
71 ultrasound, compared to X-ray. It also makes ultrasound an ideal diagnostic tool for low-resource or  
72 low-care-intensity settings, including nursing homes and home-based palliative care, because it can  
73 be delivered directly at the bedside preventing patient's distress for transfers.<sup>5</sup>

74 Modern ultrasound equipment is generally portable, making it possible to reach the patient bedside  
75 in hospital facilities. Smaller, hand-held pocket-size devices are however becoming increasingly  
76 popular, making it possible to perform ultrasound in any clinical scenario. The image quality of  
77 these devices is generally considered inferior than standard portable ultrasound, but recent studies  
78 report good levels of diagnostic accuracy in ED patients<sup>6</sup> and subjects with interstitial lung disease.<sup>7</sup>  
79 Pocket-size ultrasound was compared with standard ultrasound in geriatric patients in only one  
80 study.<sup>8</sup> Although not focused only on chest examination, it demonstrated that pocket-size  
81 ultrasound performed the same as standard equipment in presence of a pre-test clinical suspicion.<sup>8</sup>

82 The ultrasonographic appearance of a normal chest is well described in the literature<sup>1-3,9-10</sup>, and is  
83 summarized in the Supplemental Material (Table S1, Figure S1). In the most common pathological  
84 respiratory conditions of elderly patients, such as pneumonia, pleural effusion, pulmonary edema  
85 and interstitial lung disease, specific alterations appear on chest ultrasound images, mainly in the  
86 form of artifacts<sup>1,10</sup> (Table 2; Figure 1; see also Supplemental Material Figures S2-S9 for a wider set  
87 of images). Chest ultrasound can also provide reliable diagnostic signs also for less common  
88 conditions, including pneumothorax, lung abscess, lung cancer and pleural mesothelioma (Table 2;

89 Figure 2; Supplemental Material Figure S10). Although these signs do not always correspond to  
90 precise anatomical alterations, they are associated with well-known patho-physiological alterations  
91 typical of each disease (Table 2).<sup>1,10</sup>

92 To make a correct diagnosis, chest ultrasonography requires in many cases an integration of  
93 imaging with clinical data. For example, B lines, the main sign associated with “wet lungs” typical  
94 of acute heart failure, can be detected also in areas surrounding an isolated alveolar consolidation,  
95 such as those seen in pneumonia<sup>11</sup>. In case of thoracic trauma, B lines and consolidation patterns  
96 may coexist and indicate a lung contusion. The differential diagnosis of isolated lung consolidations  
97 may also be particularly challenging, since they can be associated with pneumonia, cancer,  
98 pulmonary embolism or atelectasis. The characterization of consolidations is generally easier when  
99 they are positioned in subpleural regions, while deeper lesions are more difficult to detect.<sup>12</sup>

100 Apart from these critical issues, the achievement of technical competency in lung ultrasound is  
101 generally easier and quicker than abdominal ultrasound. Different studies have shown that novice  
102 sonographers have a fair to excellent agreement with experienced sonographers in making basic  
103 diagnoses after training courses lasting no more than few days.<sup>13-15</sup> Moreover, the inter-operator  
104 agreement in ultrasound image obtainment and interpretation is high ( $\geq 90\%$ ) when the examination  
105 is repeated on the same patient by sonographers with different level of experience.<sup>4</sup>

106

107

## 108 **APPLICATIONS OF CHEST ULTRASOUND IN DIFFERENT CLINICAL SITUATIONS**

### 109 **Acute dyspnea and acute respiratory failure**

110 Chest ultrasound has been particularly studied in management of acute dyspnea in the ED, where it  
111 can be performed even in the absence of a specific diagnostic question.<sup>16</sup> It has been implemented  
112 also in ICUs, for detecting the causes of acute respiratory failure and monitoring the evolution of  
113 respiratory conditions.<sup>17</sup>

114 According to a recent meta-analysis including studies with a high number of older patients, chest  
115 ultrasound has very good diagnostic performance in the detection of the most common causes of  
116 acute dyspnea in the ED.<sup>16</sup> The pooled Areas Under the Receiver Operating Characteristics  
117 (AUROCs) curves were 0.948 for pneumonia, 0.914 for acute heart failure and 0.906 for COPD  
118 exacerbations.<sup>16</sup>

119 In the largest of these studies, chest ultrasound was able to differentiate cardiac vs noncardiac  
120 causes of dyspnea with a significantly higher accuracy (sensitivity 97%, specificity 97.4%) than  
121 chest X-ray or clinical-anamnestic workup in 1,005 patients with a mean age of 77.<sup>18</sup>

122 In a group of 130 older patients aged in average 81 years old admitted with acute dyspnea in an  
123 internal medicine ward, the diagnostic performance was slightly lower than that reported in other  
124 studies (sensitivity 93.8%, specificity 86.1%), though remaining excellent and non-inferior than X-  
125 ray.<sup>19</sup> In an ED setting, the diagnostic accuracy of chest ultrasound for differentiating cardiogenic  
126 causes of dyspnea in 236 patients with a mean age of 80 was lower than expected (sensitivity  
127 57.7%, specificity 87.9%)<sup>20</sup>, indicating that older age may have some negative impact on chest  
128 ultrasound diagnostic performance.

129 Despite these limitations, the implementation of chest ultrasound in the ED implies faster treatment  
130 and disposition. In the only randomized trial published to date, 320 patients presenting to the ED  
131 with acute dyspnea (mean age 73) received point-of-care ultrasonography vs usual care.<sup>21</sup> Four  
132 hours after ED admission, the number of patients with a correct presumptive diagnosis was

133 significantly higher in the ultrasound group, implying quicker symptom relief and disposition in  
134 appropriate care settings.<sup>21</sup>

135 In critical patients admitted to ICUs, chest ultrasound is a very useful technique also for monitoring  
136 fluid repletion in acute circulatory failure, assessing Acute Respiratory Distress Syndrome (ARDS),  
137 investigating pneumonia as a possible cause of fever and assisting physicians during invasive  
138 maneuvers.<sup>22</sup> Lung ultrasound outperformed chest X-ray in detecting the cause of acute respiratory  
139 failure<sup>23</sup> and differentiating cardiogenic acute pulmonary edema from other diseases, including  
140 ARDS, in patients under 70 years old.<sup>24</sup> In the only study specifically focused on a geriatric ICU  
141 population (51 patients aged from 73 to 91), lung ultrasound was able to recognize the presence of  
142 ARDS with a fairly good accuracy (AUROCs 0.783 and 0.902 at the first and third day of stay,  
143 respectively), and the diagnostic performance significantly improved when lung ultrasonography  
144 was performed in combination with echocardiography (AUROCs 0.924 and 0.956, respectively).<sup>25</sup>  
145 Interestingly, simplified protocols of chest ultrasound assessment (such as the BLUE and FALLS  
146 protocols) have been developed in the ICU setting, to overcome the limitations implied by limited  
147 patient mobility.<sup>26</sup> Although these limitations are shared also by many geriatric patients outside the  
148 ICU, no studies have evaluated the diagnostic performance of these protocols in a geriatric setting.

149

## 150 **Pneumonia**

151 In a recent literature meta-analysis, the diagnostic performance of lung ultrasound for detection of  
152 pneumonia in ED was optimal (pooled AUROC 0.97).<sup>27</sup> The presence of parenchymal  
153 consolidations with dynamic air bronchogram or focal interstitial syndrome at lung ultrasound in  
154 patients with compatible clinical signs and symptoms was diagnostic of pneumonia in almost all  
155 cases, with very few false negative examinations. In this context, ultrasound exhibits a high  
156 concordance with CT<sup>28</sup>, and a lower concordance with X-ray findings.<sup>29</sup>

157 These considerations apply also to patients admitted to medical wards. Two meta-analyses of the  
158 existing studies performed in this setting identified a summary AUROC of 0.99 for the diagnosis of

159 pneumonia,<sup>30,31</sup> while another more recent meta-analysis showed a summary AUROC of 0.90, with  
160 ultrasound outperforming X-ray (summary AUROC 0.59).<sup>32</sup> The diagnostic capacity of ultrasound  
161 is reduced only in case of deep lesions not involving subpleural plans (8% of pneumonic  
162 consolidations detected by CT), as suggested by two studies performed in groups of 342 and 362  
163 adult (mean age <65) internal medicine patients, respectively.<sup>33,34</sup> Once the diagnosis is established,  
164 ultrasound may also represent a useful tool for monitoring the resolution of pneumonic infiltrations  
165 at follow-up.<sup>33</sup>

166 Very few investigations have assessed the diagnostic performance of ultrasonography for  
167 pneumonia in geriatric patients. In a group of 169 older patients (mean age 83) hospitalized for  
168 acute respiratory symptoms, the diagnostic accuracy for pneumonia of ultrasound was significantly  
169 higher than that of X-ray (0.90 vs 0.67), and the difference was particularly pronounced in those  
170 subjects with frailty and severe mobility-disability.<sup>4</sup>

171

## 172 **Acute heart failure**

173 The diagnostic performance of lung ultrasound in detecting acute heart failure has been well  
174 demonstrated in ED and ICU settings as superior to that of X-ray, particularly when  
175 echocardiography is also performed.<sup>18</sup>

176 In internal medicine wards, bedside ultrasound can be very useful for monitoring treatment response  
177 and modulating diuretic therapy.<sup>35,36</sup> B-lines are in fact expression of extravascular lung water and  
178 their number is related to the severity of congestion<sup>37</sup>. Residual B-lines at discharge predict hospital  
179 readmission and mortality.<sup>35</sup> During hospital stay, a close ultrasonographic follow-up, with daily or  
180 alternate day assessment, can help to adjust diuretic dosage and speed up the discharge time.<sup>36</sup>

181 Moreover, bedside lung ultrasound can be used to estimate the volemic state and the possible  
182 presence of fluid overload. The addition of inferior vena cava ultrasonography can be particularly  
183 useful in this context.<sup>36</sup>

184 Unfortunately, the application of repeated lung ultrasound monitoring in geriatric acute heart failure  
185 patients has not been specifically addressed by the existing literature to date. However, lung  
186 ultrasound has proven useful in assessing lung congestion in older patients with end-stage renal  
187 disease undergoing dialysis<sup>38</sup>.

188

### 189 **Pneumothorax**

190 In a recent meta-analysis of the literature, lung ultrasound has proven as significantly more sensitive  
191 than chest X-ray for the detection of pneumothorax (78.6% vs 39.8%), with similar specificity.<sup>39</sup>  
192 The diagnostic accuracy is particularly high for small lesions, that cannot generally be detected by  
193 standard X-rays, and would generally require a CT examination for prompt diagnosis.<sup>40</sup> Ultrasound  
194 can also help to stage the pneumothorax severity, identifying the percentage of lung collapse or the  
195 distance between lung parenchyma and visceral pleura.<sup>41</sup> However, all the existing studies were  
196 focused on the detection of traumatic or iatrogenic pneumothorax in critical care, and none was  
197 specifically focused on older individuals.

198

### 199 **Pleural diseases**

200 The detection and monitoring of pleural effusion is probably the oldest and simplest application of  
201 chest ultrasound. Its diagnostic accuracy is very high, especially for mild effusions that cannot be  
202 easily detected with X-rays.<sup>42</sup> Additionally, ultrasound is an excellent guide for thoracentesis  
203 procedures, limiting the risk of iatrogenic pneumothorax.<sup>42</sup>

204 Ultrasound can also help to estimate the severity of a pleural effusion. Besides the simple count of  
205 intercostal spaces where the effusion can be visualized, more precise methods of assessment have  
206 been proposed. The ultrasonographic measurement of the distance from visceral pleura to chest  
207 wall, the distance from lung base to apex of diaphragm cupola and the height of the effusion allows  
208 the calculation of fluid volume using validated equations.<sup>43</sup> The maximal distance between visceral  
209 and parietal pleura can be also used as a proxy of fluid volume.<sup>44</sup> The estimations of fluid volume

210 obtained using these methods were significantly correlated with the volume obtained by  
211 thoracentesis drainage.<sup>45</sup>

212 Chest ultrasound also exhibited a higher accuracy than X-ray for the detection of complicated  
213 effusions, pleural adhesions and exudative effusions.<sup>42,45</sup> Moreover, it exhibited an optimal  
214 diagnostic performance also for the detection of parapneumonic effusions, since it can be very  
215 helpful also for identifying the parenchymal consolidations.<sup>46</sup>

216 Unfortunately, none of the existing studies on the ultrasonographic assessment of pleural effusions  
217 was specifically focused on older patients.

218 Recent research has also demonstrated that chest ultrasonography is an excellent tool for the  
219 detection of asbestos-related pleural plaques and other small non-malignant lesions, visualized as  
220 focal pleural line thickenings.<sup>47,48</sup> The diagnostic accuracy in this field may be even superior to that  
221 of CT,<sup>47</sup> and ultrasound may also be useful for the follow-up of lesions detected with CT.<sup>48</sup>

222

### 223 **Pulmonary embolism**

224 A meta-analysis showed that chest ultrasound exhibits a good diagnostic accuracy (sensitivity 87%,  
225 specificity 81.8%) for pulmonary embolism, though inferior to that of contrast-enhanced CT.<sup>49</sup>  
226 Thus, chest ultrasound in pulmonary embolism may represent only a complementary diagnostic test,  
227 and not a routine procedure. However, in patients with a clearly positive lung ultrasound  
228 examination, the prescription of contrast-enhanced CT could be avoided, reducing costs and  
229 radiation exposure, and with definite advantages in subjects with chronic kidney disease.<sup>50</sup>

230

### 231 **Diaphragm dysfunction assessment**

232 The assessment of diaphragmatic motion with M-Mode chest ultrasound is a highly reproducible  
233 technique that can be easily applied in clinical practice.<sup>51</sup> In a group of elderly (age  $\geq 80$ ) patients  
234 admitted with acute respiratory failure to a Chinese ICU and subdued to at least 48 hours of

235 mechanical ventilation, the M-mode ultrasound-diagnosed diaphragmatic dysfunction was  
236 significantly associated with ventilation weaning failure and poor outcomes.<sup>52</sup>  
237 Alternatively, diaphragmatic dysfunction can be assessed with B-mode ultrasound, measuring  
238 changes in diaphragm thickness during tidal volume ( $\Delta Tdi$ ). In mechanically ventilated patients,  
239 this parameter was significantly associated with a longer ICU stay and increased risk of hospital  
240 death.<sup>53</sup> In a group of elderly patients (mean age 78) undergoing noninvasive mechanical ventilation  
241 (NIV) for acute COPD exacerbation,  $\Delta Tdi < 20\%$  was the best single clinical parameter to predict  
242 NIV failure and adverse outcomes.<sup>54</sup>  
243  
244

## 245 **GERIATRIC CHEST ULTRASOUND: A CALL FOR ACTION**

246

### 247 **Overview of results**

248 The results of chest ultrasound studies performed either in a geriatric setting or in a population with  
249 mean age  $\geq 70$  years old are summarized in Table 3, with their evidence grade and quality ranking,  
250 determined according to the methods already used by Barth and colleagues (see also Supplemental  
251 Material).<sup>55</sup> Altogether, these studies support the implementation of bedside chest ultrasound in  
252 geriatric wards, but their number and quality is too scarce to formulate specific recommendations.  
253 Studies focused on older patients and geriatric settings are thus urgently needed.

254

### 255 **The possible advantages of chest ultrasound in geriatrics**

256 A number of circumstances indicate that the geriatric patient may represent the ideal recipient of  
257 chest ultrasound implementation programs. First, the aging respiratory system is characterized by  
258 some peculiarities that make X-rays and, to a lesser extent, CT more difficult to perform and less  
259 accurate to interpret even when a respiratory disease is absent.<sup>56</sup> The age-related modifications of  
260 lower airways, increases in interstitial connective tissue and reduction of parenchymal  
261 vascularization may in fact contribute to define the so-called “dirty chest”.<sup>56-58</sup> Ultrasound is  
262 influenced by all these phenomena as well, but its diagnostic performance is maintained thanks to  
263 its defined semeiotics and the clinical interpretation of signs.

264 Second, mobility-limitations or reduced capacity to follow instructions due to cognitive impairment  
265 represent additional issues in older patients, limiting the quality of chest X-ray or CT scans and  
266 reducing their diagnostic accuracy.<sup>59</sup> Ultrasound is only marginally influenced by these factors,  
267 exhibiting good performance also in the sickest and in those with severe disability.<sup>4</sup>

268 Finally, ultrasound is cheaper and safer than traditional imaging examinations, and its routine use  
269 optimizes follow-up of critical patients, reducing the number of X-rays and, possibly, CTs, with

270 lower costs and radiation exposure.<sup>60</sup> This advantage is particularly useful in geriatric patients, who  
271 have often a high level of clinical complexity requiring several diagnostic resources.

272

### 273 **Areas of development**

274 Although ultrasound images are less influenced by age-related changes in anatomy and physiology  
275 of the respiratory system than X-ray, its normal reference standards in healthy older persons are still  
276 unclear, and should be carefully studied.

277 Aging can also affect diaphragmatic structure and function independently of the presence of  
278 respiratory diseases. Thus, normative data on this aspect are needed, in order to clarify the  
279 usefulness of diaphragmatic ultrasound in clinical practice.

280 Besides the evaluation of diagnostic accuracy in different clinical situations and settings, other  
281 critical points deserving future investigations in older patients may include:

- 282 - The effects of multimorbidity, and particularly cardio-respiratory multimorbidity,<sup>61</sup> on  
283 ultrasonographic findings in patients with acute respiratory symptoms;
- 284 - The diagnostic advantages of combining chest ultrasound with point-of-care  
285 echocardiography in the evaluation of acute dyspnea;
- 286 - The usefulness of simplified protocols of ultrasonographic evaluations, such as the FALLS  
287 and BLUE protocols;<sup>26</sup>
- 288 - The role of chest ultrasound in the detection of diaphragm sarcopenia, either isolated or in  
289 the context of systemic sarcopenia;
- 290 - The cost/efficacy and cost/effectiveness of chest ultrasonography;
- 291 - The role of chest ultrasound in the post-acute and long-term follow-up of older patients with  
292 cardio-respiratory diseases.

293 Moreover, the effects of chest ultrasound implementation in clinical practice on patient-related  
294 outcomes should be particularly investigated. In this field, education of geriatricians and residents

295 in geriatrics on point-of-care ultrasound principles could help to improve the quality of care and  
296 contribute to improve outcomes.

297

298 **CONCLUSIONS AND IMPLICATIONS**

299 Chest ultrasound is an easy, accurate and versatile diagnostic tool for the management of acute  
300 respiratory symptoms and conditions in many clinical settings, including acute-care hospital wards,  
301 nursing homes and community services. However, very few studies have explored this diagnostic  
302 technique specifically in a geriatric environment. Even if no evidence-based recommendations on  
303 the use of bedside chest ultrasound can be specifically made for geriatric patients, implementation  
304 of this technique in geriatric research and practice is desirable, considering the large amount of  
305 evidence in younger patients and in different clinical settings.

306

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310

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313

314

315

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468 **TABLE 1**

469 Summary of the main recommendations, retrieved by the scientific literature and international  
 470 consensus, on how the bedside chest ultrasound should be performed.

ISSUE	RECOMMENDATIONS
Patient position	<ul style="list-style-type: none"> <li>- Sitting on the bed side (ideal position)</li> <li>- Maintained in the sitting position by a second operator (for those with severe mobility-disability)</li> <li>- Lying supine on the bed (only for bedridden patients)</li> <li>- Supine position is ideal for diaphragm assessment</li> </ul>
Use of probes	<ul style="list-style-type: none"> <li>- Use both convex 3.5-5 MHz and linear 4-8 mHz probes</li> <li>- Convex probes assure a panoramic view, allow detection of gross lesions and focus on deeper plans</li> <li>- Linear probes assure a careful examination of surface structures (ling-pleura interface, small pleural and subpleural lesions) at the expense of a reduced penetration of ultrasounds into deeper anatomical plans</li> </ul>
Ultrasound modality	<ul style="list-style-type: none"> <li>- Examination of pleura and lungs should be performed in B-mode</li> <li>- M-mode can be useful for a study of the diaphragm</li> </ul>
Methodology of examination	<ul style="list-style-type: none"> <li>- Split each hemithorax into an antero-lateral (from parasternal to posterior axillary lines) and a posterior sector (from posterior axillary to paravertebral lines), and divide each sector into a superior and inferior half</li> <li>- Investigate systematically the four areas of each hemithorax</li> <li>- Put the probe in each intercostal space, perpendicularly, obliquely and in parallel to the course of the ribs</li> <li>- In bedridden patients, limit investigation to the antero-lateral sectors</li> <li>- Allow small movements of rotation and tilting of the probes to assure an optimal visualization of structures</li> <li>- Measure diaphragm thickness, excursion in forced respiration, variation of thickness between end inspiration and expiration</li> </ul>

471

472 **TABLE 2**

473 Overview of the main ultrasonographic signs that can be detected when examining the chest and  
 474 their correlation with respiratory diseases.

<b>ULTRASOUND SIGN</b>	<b>MOST PROBABLE DIAGNOSIS</b>	<b>DIFFERENTIAL DIAGNOSIS</b>
Hypoechoic space between chest wall and lung (possibly with quadrilater or sinusoid shape, “quad sign” and “sinusoid sign”)	Pleural effusion	Pleural thickening Pleural cancer Intraparenchymal cysts
Absent pleural line sliding	Pneumothorax	Acute Respiratory Distress Syndrome Local fibrosis
Dynamic air bronchogram within a parenchymal hyperechoic consolidation	Pneumonia	Atelectasis Pulmonary infarction Pulmonary contusion Cancer
Increased parenchymal echogenicity with loss of pleural line and hypoechoic vascular structures	Pneumonia	Atelectasis Pulmonary infarction Pulmonary contusion Cancer
Peripheral wedge-shaped consolidation	Pulmonary embolism	Pneumonia Cancer
Static air bronchogram within a parenchymal hyperechoic consolidation	Atelectasis	Pulmonary infarction Pulmonary contusion Cancer
Increased B-lines with a widespread distribution	Cardiogenic pulmonary edema	Acute Respiratory Distress Syndrome Pneumonia Interstitial lung disease
B-lines with focal distribution (focal interstitial syndrome)	Pneumonia	Pulmonary infarction Pulmonary contusion Acute heart failure
Reduced diaphragm thickness and thickening ratio / reduced excursion	Diaphragm dysfunction	Neuromuscular disease Chronic Obstructive Pulmonary Disease Severe focal lung disease (pneumonia, cancer, atelectasis)

475  
476

477 **TABLE 3**

478 Summary of the results of the main studies on chest ultrasound in which a population with a mean age  $\geq 70$  years old was enrolled. Grading and  
 479 quality of evidence is also provided using the method proposed by Barth et al.<sup>53</sup>

480

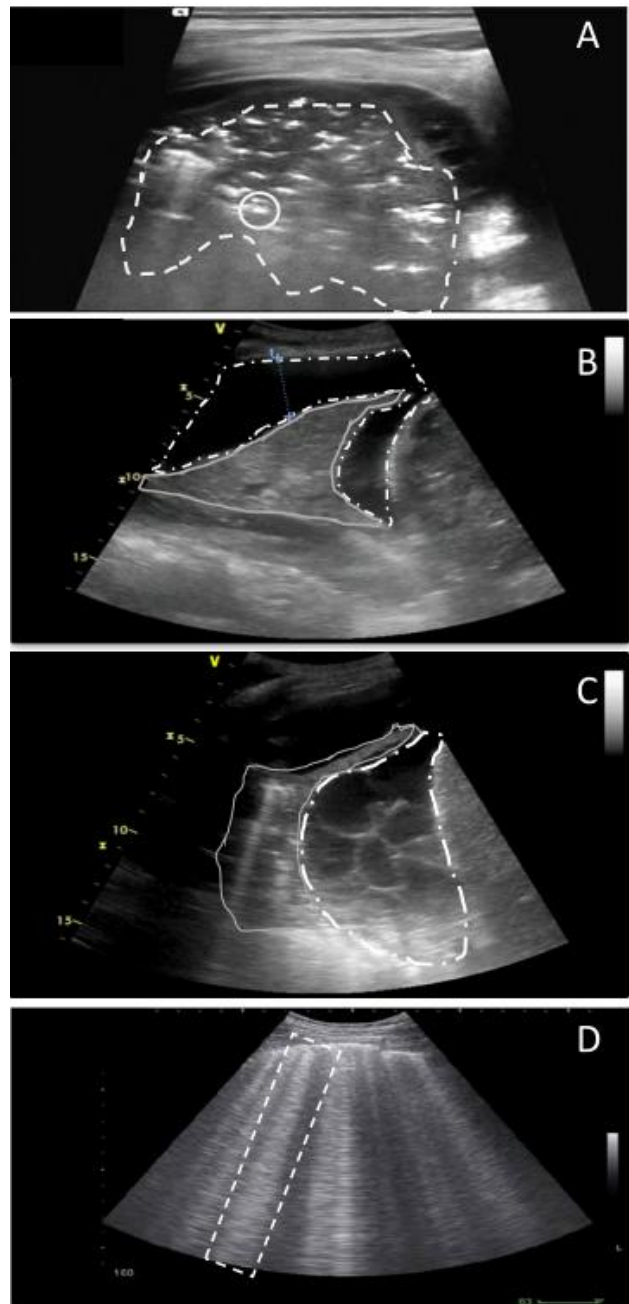
First author, journal, year, [ref]	Setting and design	Number of patients	Mean age	Main outcome	Gold standard	Sensitivity	Specificity	Grade of evidence	Quality of evidence	Key finding
Pivetta, Chest, 2015, [18]	7 EDs, observational	1005	77	Cardiogenic vs other dyspnea	Blind review of medical record	0.97	0.97	C	Adequate	Ultrasound can improve the diagnostic accuracy of acute dyspnea in the ED
Perrone, Eur J Intern Med, 2017, [19]	IM ward, observational	150	81	Cardiogenic vs other dyspnea	Discharge diagnosis	0.94	0.86	C	Poor	Bedside ultrasound improves the diagnostic workup of dyspnea in wards
Sartini, Intern Emerg Med, 2017, [20]	ED, observational	236	80	Cardiogenic vs other dyspnea	Expert review of medical records	0.58	0.88	C	Poor	To diagnose acute heart failure, ultrasound should be integrated with clinical information
Laursen, Lancet Respir Med, 2014, [21]	ED, prospective parallel-group trial	320	73	Assignment to the right treatment for dyspnea	Masked audit on clinical records	NA	NA	B	Good	Ultrasound allows quicker and more appropriate treatment of dyspnea, and faster disposition from ED
Ticinesi, Medicine, 2016, [4]	IM/geriatric ward, observational	169	83	Pneumonia vs other respiratory conditions	Blind review of medical record	0.92	0.94	C	Adequate	Ultrasound has higher diagnostic accuracy for pneumonia than X-ray, especially in frail patients
Huang, BMC Pulm Med, 2018, [25]	ICU, prospective	51	82	ARDS vs no ARDS	Chest CT	0.88	0.89	C	Adequate	Lung ultrasound was consistent with CT findings in the diagnosis of ARDS
Cogliati, Int J Cardiol, 2016, [35]	IM ward, prospective	150	81	Prediction of adverse events in AHF	Echo-cardiography	NA	NA	C	Adequate	Persistence of ultrasound signs of acute heart failure is associated with mortality
Mozzini, Intern Emerg Med, 2018, [36]	IM ward, prospective parallel-group trial	120	84	Prediction of LOS and therapeutic adjustments	Echo-cardiography	NA	NA	C	Adequate	Lung ultrasound reduced LOS and predicted therapeutic variations in AHF

in AHF										
Huang, J Thorac Dis, 2017, [50]	ICU, prospective	40	84	Mechanical ventilator weaning in ARF	NA	NA	NA	C	Poor	Diaphragmatic dysfunction, assessed by M-mode ultrasound, predict mechanical ventilator weaning failure
Marchioni, Crit Care, 2018, [52]	ICU, prospective	75	78	NIV weaning in AECOPD	NA	NA	NA	C	Adequate	Change in diaphragm thickness predict NIV weaning failure and mortality

481 ED=Emergency Department; IM=Internal Medicine; NA=Not Assessed; ICU=Intensive Care Unit; ARDS=Acute Respiratory Distress Syndrome;  
482 CT=Computed Tomography; AHF=Acute Heart Failure; ARF=Acute Respiratory Failure; NIV=Non-Invasive Ventilation; AECOPD=Acute  
483 Exacerbation of Chronic Obstructive Pulmonary Disease  
484

485 **FIGURE 1**

486 Principal pathologic findings at chest ultrasound using a convex probe. **A:** hyperechoic,  
487 consolidated lung parenchima (dotted line). The hyperechoic spots are consistent with an air  
488 bronchogram (continued line circle); **B:** Free flowing non septated, anechoic, pleural effusion  
489 (dotted line). The compressed lung parenchima is not ventilated and, consequently, atelectatic,  
490 clearly detectable and hypoechoic (continued line); **C:** Complex, loculated pleural effusion (dotted  
491 line) surrounding a partially collapsed lower lobe (continued line); **D:** Ultrasonographic B lines,  
492 long wide bands of hyperechoic artifact likened to the beam of a flashlight (dotted line).



493

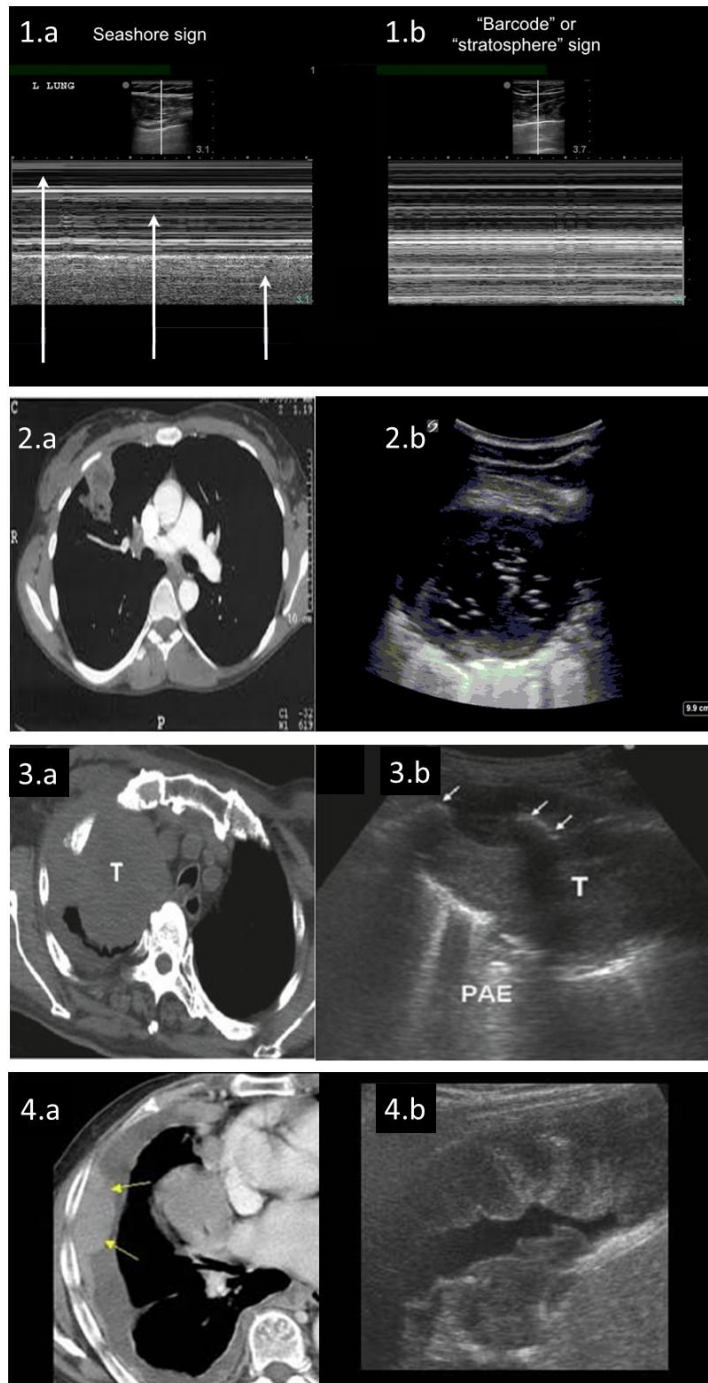
494 **FIGURE 2**

495 **Panel 1. Ultrasound diagnosis of Pneumothorax (linear probe).** In panel 1.a, the M-mode image  
496 demonstrates a linear, laminar pattern in the tissue superficial to the pleural line and a granular or  
497 “sandy” appearance deep to the pleural line, suggesting the absence of pneumothorax (seashore  
498 sign). In panel 1.b, the M-mode image shows a linear, laminar pattern in the pleural interface, and a  
499 similar linear pattern deep to the pleural line (stratosphere sign or barcode sign), indicating the  
500 presence of pneumothorax.

501 **Panel 2. Ultrasound diagnosis of lung abscess (convex probe).** Panel 2.a: Computed tomography  
502 showing a surrounding, thick and irregular consolidation containing a fluid, inner level. In panel  
503 2.b, high amplitude echoes are clearly visible as well as multiple echogenic small air inclusions.

504 **Panel 3. Ultrasound diagnosis of lung tumour (convex probe).** Panel 3.a: Computed tomography  
505 showing a large right apical mass infiltrating the chest wall. Panel 3.b: corresponding  
506 ultrasonographic view of a hypoechoic lesion with posterior acoustic enhancement (PAE) and  
507 irregular borders. The visceral pleura is interrupted since it is infiltrated by the tumor (white  
508 arrows).

509 **Panel 4. Ultrasound diagnosis of malignant pleural mesothelioma (convex probe).** Panel  
510 4.a: Computed tomography of large pleural, confluent, masses (yellow arrows), wide thickening of  
511 soft tissue attenuation involving the right chest wall and the diaphragm and associated with  
512 malignant pleural effusion. Panel 4.b: Ultrasound demonstrating large, anechoic effusion, above a  
513 flattened diaphragm, extensively infiltrated by thick, irregular nodularity arising from the  
514 diaphragm and the visceral pleura.



1 **ABSTRACT**

2 **Objectives-** To investigate on the current evidence on the use of point-of-care chest ultrasound in  
3 older patients and geriatric settings, and present the current state-of-art of chest ultrasound  
4 applications.

5 **Design-** ~~Systematic review with narrative analysis~~Special article based on a literature review with  
6 narrative analyses, and expert clinical knowledge.

7 **Setting and participants-** All studies performed in a geriatric setting were included. Observational  
8 and intervention studies and meta-analyses including participants aged  $\geq 70$  were also considered,  
9 even if not specifically focused on a geriatric setting.

10 **Measures-** Data on participant characteristics, diagnostic accuracy of chest ultrasound and  
11 outcomes were collected for each considered study. Data were analyzed and discussed with a  
12 particular focus on the possible applications and advantages of chest ultrasound in geriatric  
13 medicine, underlining the possible areas of future research.

14 **Results-** We found only five studies on the diagnostic accuracy and prognostic relevance of chest  
15 ultrasonography in geriatrics. However, several studies performed in Emergency Departments,  
16 Intensive Care Units and internal medicine wards, included a large number of participants over 70  
17 years old; they suggest that chest ultrasonography may represent a valid aid to the diagnostics of  
18 acute dyspnea, pneumonia, acute heart failure, pneumothorax, and pleural diseases, with an  
19 accuracy in some cases superior to standard X-rays, especially when mobility-limitation is present.  
20 Diaphragm ultrasound may also represent a valid tool to guide mechanical ventilation weaning in  
21 older patients with acute respiratory failure.

22 **Conclusions and Implications-** Chest ultrasound may represent a valid bedside diagnostic aid to  
23 the management of acute respiratory diseases in older patients. However, specific evidence is  
24 lacking for geriatric patients. Future research will need to focus on defining the reference standards  
25 and the diagnostic accuracy for frail and multimorbid elderly patients, cost/efficacy and

26 cost/effectiveness of the technique, its impact for clinical outcomes and role for follow-up in the  
27 post-acute care.

28

29 **Key words:** lung ultrasound; point-of-care; respiratory diseases; diagnostic accuracy

30 **INTRODUCTION**

31 In modern medicine, point-of-care ultrasonography has become one of the most ~~powerful and~~  
32 ~~versatile popular~~ tools for assisting the diagnostic process in hospitalized patients, as a technologic  
33 complement to physical examination and laboratory biomarkers.<sup>1</sup> Although partly dependent on the  
34 skills of each operator, it is considered a safe and rapid imaging technique providing immediate  
35 responses to several clinical questions directly at the bedside and ~~exactly~~ at the moment of need.<sup>1</sup>

36 Chest ultrasound is perhaps one of the least expected applications of point-of-care ultrasonography,  
37 ~~since because~~ respiratory structures, and particularly the lung parenchyma, cannot be directly  
38 explored by ultrasounds. In fact, lung parenchyma has a high acoustic impedance preventing the  
39 definition of anatomically faithful images.<sup>1</sup> However, ultrasonographic evaluation of the lung may  
40 provide several a great deal of clinically relevant information in both health and disease, thanks to a  
41 simple and highly reproducible semeiotics.<sup>1-3</sup> This technique has entered clinical practice for the  
42 diagnosis of respiratory diseases in several settings, ranging from Emergency Departments (EDs) to  
43 Intensive Care Units (ICUs) to acute Internal Medicine and Pulmonology wards.<sup>2,3</sup>

44 Unfortunately, ~~this is probably not the case for chest ultrasound is not so popular in~~ Geriatric wards.  
45 Possible barriers for bedside implementation of this technique may include reduced availability of  
46 portable equipment, ~~and~~ limited access to specific training courses, perception of ultrasound as a  
47 scarcely reproducible examination, especially in subjects with severe mobility-limitations and  
48 dementia. However, chest ultrasound is a practical and easy to learn technique, even for those who  
49 have little experience with abdominal ultrasound. In fact, under specific questions, bedside chest  
50 ultrasound is an effective diagnostic tool also in the hands of relatively unskilled healthcare  
51 professionals, such as medical residents.<sup>4</sup>

52

53

54 **OBJECTIVES AND METHODS**

55 Our aim was to investigate ~~on~~ the current evidence on the use of point-of-care chest ultrasound in  
56 older patients and geriatrics wards, present its current applications and ~~to~~ identify areas ~~of~~  
57 development of the technique for future research in the geriatric setting.

58 A literature search was ~~made~~ conducted on PubMed as of December 19<sup>th</sup>, 2018, using the search  
59 strategy reported in the Supplementary Material, that used “chest ultrasound”, “lung ultrasound”,  
60 “geriatric” and “older individuals” as the main key words.

61 The results of the search showed substantial lack of papers ~~on the topic~~ with a geriatric focus (16  
62 manuscripts, of ~~whom~~ which only 5 reporting original data). Thus, we decided to present the current  
63 state-of-~~the~~-art of chest ultrasound applications in medical patients with a narrative approach,  
64 focusing on studies where participants with a mean age  $\geq 70$  years old were enrolled and  
65 highlighting the points of interest for older patients and applications for geriatric medicine.

66

67 ~~THE SEMEIOTICS OF CHEST ULTRASOUND~~ METHODOLOGY AND RELATED  
68 ISSUES

69 The recommendations on the best way to perform a bedside chest ultrasound<sup>1</sup> are summarized in  
70 Table 1. There are no specific recommendations for geriatric patients in the scientific literature. The  
71 main critical issue in older individuals is severe mobility-disability, preventing the patient to  
72 maintain the sitting position for the time of the examination. However, some protocols include the  
73 possibility of performing ultrasound with the patient lying supine, or with the aid of a second  
74 operator, helping the patient to remain seated<sup>4,5</sup>, so that the methodology of examination fits to the  
75 patient's motoric performance (Table 1). This versatility represents a consistent advantage of  
76 ultrasound, compared to X-ray. It also makes ultrasound an ideal diagnostic tool for low-resource or  
77 low-care-intensity settings, including nursing homes and home-based palliative care, because it can  
78 be delivered directly at the bedside preventing patient's distress for transfers.<sup>5</sup>  
79 Modern ultrasound equipment is generally portable, making it possible to reach the patient bedside  
80 in hospital facilities. Smaller, hand-held pocket-size devices are however becoming increasingly  
81 popular, making it possible to perform ultrasound in any clinical scenario. The image quality of  
82 these devices is generally considered inferior than standard portable ultrasound, but recent studies  
83 report good levels of diagnostic accuracy in ED patients<sup>6</sup> and subjects with interstitial lung disease.<sup>7</sup>  
84 Pocket-size ultrasound was compared with standard ultrasound in geriatric patients in only one  
85 study.<sup>8</sup> Although not focused only on chest examination, it demonstrated that pocket-size  
86 ultrasound performed the same as standard equipment in presence of a pre-test clinical suspicion.<sup>8</sup>  
87 ~~In normal situations (Figure 1), the ultrasound images should visualize the skin, the hypodermis and~~  
88 ~~the muscles in superficial plans. On a deeper level of that of the ribs, the pleural line, corresponding~~  
89 ~~to the pleura lung interface, should appear as a hyperechogenic line moving in synchrony with~~  
90 ~~breath.<sup>2</sup> The normal lungs appear below the pleural line as a black space, possibly containing~~  
91 ~~horizontal artifacts appearing as parallel equidistant lines, the so called A lines, representing~~  
92 ~~reverberations of acoustic interfaces situated above.<sup>2</sup> At the caudal extreme of the lungs, in~~

93 ~~correspondence of the costophrenic recess, a “curtain sign” may appear, representing the movement~~  
94 ~~of abdominal organs with diaphragm contraction and breath.<sup>3</sup> The diaphragm appears as a~~  
95 ~~hyperechogenic line surrounding the liver and the spleen, and moving in synchrony with breathing~~  
96 ~~acts<sup>3,6</sup> (Figure 1). A description of normal lung sonographic findings is provided in Table 2.~~  
97 The ultrasonographic appearance of a normal chest is well described in the literature<sup>1-3,9-10</sup>, and is  
98 summarized in the Supplemental Material (Table S1, Figure S1). In the most common pathological  
99 respiratory conditions of elderly patients, such as pneumonia, pleural effusion, pulmonary edema  
100 and interstitial lung disease ~~and pneumothorax~~, specific alterations appear on chest ultrasound  
101 images, mainly in the form of artifacts<sup>1,107</sup> (Table ~~32~~; Figure ~~21~~; see also Supplemental Material  
102 Figures S2-S10 for a wider set of images). Chest ultrasound can also provide reliable diagnostic  
103 signs also for less common conditions, including pneumothorax, lung abscess, lung cancer and  
104 pleural mesothelioma (Table 2; Figure 2; Supplemental Material Figure S10). Although these signs  
105 do not always correspond to precise anatomical alterations, they are associated with well-known  
106 patho-physiological alterations typical of each disease (Table 2).<sup>1,107</sup> ~~Thus, they have a high~~  
107 ~~diagnostic value, because each of the main acute respiratory diseases is associated with a~~  
108 ~~reproducible semeiotics<sup>1-7</sup> (Table 3).~~  
109 ~~Despite the simple classification of ultrasonographic signs, t~~o allow the formulation of an  
110 accurate~~make a correct~~ diagnosis, chest ultrasonography requires in many cases an integration of  
111 imaging with clinical ~~and anamnestic~~ data. For example, B lines, the main sign associated with “wet  
112 lungs” typical of acute heart failure, can be detected also in areas surrounding an isolated alveolar  
113 consolidation, such as those seen in pneumonia<sup>8,11</sup> ~~(Figure 1)~~. In case of thoracic trauma, B lines and  
114 consolidation patterns may coexist and indicate a lung contusion. The differential diagnosis of  
115 isolated lung consolidations may also be particularly challenging, since they can be associated with  
116 pneumonia, cancer, pulmonary embolism or atelectasis. The ~~visualization and~~ characterization of  
117 consolidations ~~are~~ is generally easier when they are positioned in subpleural regions, while

118 ~~differential diagnosis may result difficult for deeper lesions~~deeper lesions are more difficult to  
119 detect.<sup>9,12</sup>  
120 Apart from these critical issues, the achievement of technical competency in lung ultrasound is  
121 generally easier and quicker than abdominal ultrasound. Different studies have shown that novice  
122 sonographers have a fair to excellent agreement with experienced sonographers in making basic  
123 diagnoses after training courses lasting no more than few days.<sup>13-15</sup> Moreover, the inter-operator  
124 agreement in ultrasound image obtainment and interpretation is high ( $\geq 90\%$ ) when the examination  
125 is repeated on the same patient by sonographers with different level of experience.<sup>4</sup>

126

127

## 128 APPLICATIONS OF CHEST ULTRASOUND IN DIFFERENT CLINICAL SITUATIONS

### 129 Acute dyspnea and acute respiratory failure

130 Chest ultrasound has been particularly studied in ~~the context of~~ management of acute dyspnea in the  
131 ED, where it can be ~~applied-performed~~ even in the absence of a specific diagnostic question.<sup>40-16</sup> It  
132 has been implemented also in ICUs, for detecting the causes of acute respiratory failure and  
133 monitoring the evolution of respiratory conditions.<sup>44-17</sup>

134 According to a recent meta-analysis including studies with a high number of older patients, chest  
135 ultrasound has ~~a~~-very good diagnostic performance in the detection of the most common causes of  
136 acute dyspnea in the ED.<sup>40-16</sup> The pooled Areas Under the Receiver Operating Characteristics  
137 (AUROCs) curves were 0.948 for pneumonia, 0.914 for acute heart failure and 0.906 for COPD  
138 exacerbations.<sup>40-16</sup>

139 In the largest of these studies, chest ultrasound was able to differentiate cardiac vs noncardiac  
140 causes of dyspnea with a significantly higher accuracy (sensitivity 97%, specificity 97.4%) than  
141 chest X-ray or clinical-anamnestic workup in 1,005 patients with a mean age of 77.<sup>42-18</sup>

142 ~~Older age may however have some negative impact on the diagnostic accuracy of chest ultrasound~~  
143 ~~in differentiating causes of acute dyspnea.~~ In a group of 130 older patients aged in average 81 years  
144 old admitted with acute dyspnea ~~to in~~ an internal medicine ward, the diagnostic performance was  
145 slightly lower than that reported in other studies (sensitivity 93.758%, specificity 86.14%), though  
146 remaining excellent and non-inferior than X-ray.<sup>43-19</sup> In an ED setting, the diagnostic accuracy of  
147 chest ultrasound for differentiating cardiogenic causes of dyspnea in 236 patients with a mean age  
148 of 80 was lower than expected (sensitivity 57.7%, specificity 87.9%).<sup>44-20</sup>, indicating that older age  
149 may have some negative impact on chest ultrasound diagnostic performance.

150 Despite these limitations, the implementation of chest ultrasound in the ED implies faster treatment  
151 and disposition. In the only randomized ~~controlled~~ trial published to date, 320 patients presenting to  
152 the ED with acute dyspnea (mean age 73) received point-of-care ultrasonography vs usual care.<sup>45-21</sup>  
153 Four hours after ED admission, the number of patients with a correct presumptive diagnosis was

154 significantly higher in the ultrasound group, implying quicker symptom relief and disposition in  
155 appropriate care settings.<sup>21,45</sup>  
156 In critical patients admitted to ICUs, chest ultrasound is a very useful technique ~~not only for~~  
157 ~~differentiating the causes of acute respiratory failure, but~~ also for monitoring fluid repletion in acute  
158 circulatory failure, assessing Acute Respiratory Distress Syndrome (ARDS), investigating  
159 pneumonia as a possible cause of fever and assisting physicians during invasive maneuvers.<sup>16, 22</sup>  
160 Lung ultrasound outperformed chest X-ray in detecting the cause of acute respiratory ~~failure~~<sup>17</sup>  
161 ~~failure~~<sup>23</sup> and differentiating cardiogenic acute pulmonary edema from other diseases, including  
162 ARDS, in patients under 70 years old.<sup>24,18</sup> In the only study specifically focused on a geriatric ICU  
163 population (51 patients aged from 73 to 91), lung ultrasound was able to recognize the presence of  
164 ARDS with a fairly good accuracy (AUROCs 0.783 and 0.902 at the first and third day of stay,  
165 respectively), and the diagnostic performance significantly improved when lung ultrasonography  
166 was performed in combination with echocardiography (AUROCs 0.924 and 0.956, respectively).<sup>25,19</sup>  
167 Interestingly, ~~some~~ simplified protocols of chest ultrasound assessment (such as the BLUE and  
168 FALLS protocols) have been developed in the ICU setting, to overcome the limitations implied by  
169 limited patient mobility.<sup>20, 26</sup> Although these limitations are shared also by many geriatric patients  
170 outside the ICU, no studies have evaluated the diagnostic performance of these protocols in a  
171 geriatric setting.

172

### 173 **Pneumonia**

174 In a recent literature meta-analysis, the diagnostic performance of lung ultrasound for detection of  
175 pneumonia in ED was optimal (pooled AUROC 0.97).<sup>24, 27</sup> ~~The presence of a clinical suspicion,~~  
176 ~~combined with the ultrasonographic detection~~ presence of parenchymal consolidations with  
177 dynamic air bronchogram or focal interstitial syndrome at lung ultrasound; in patients with  
178 compatible clinical signs and symptoms allowed to reach a correct diagnosis ~~was diagnostic of~~  
179 pneumonia in almost all cases, with very few false negative examinations. In this context,

180 | ultrasound exhibits a high concordance with ~~CT~~<sup>22</sup>~~CT~~<sup>28</sup>, and a lower concordance with X-ray  
181 | findings.<sup>23-29</sup>

182 | These considerations apply also to patients admitted to medical wards. Two meta-analyses of the  
183 | existing studies performed in this setting identified a summary AUROC of 0.99 for the diagnosis of  
184 | pneumonia,<sup>24,30,25-31</sup> while another more recent meta-analysis showed a summary AUROC of 0.90,  
185 | with ~~a diagnostic performance significantly better than that of~~ultrasound outperforming X-ray  
186 | (summary AUROC 0.59).<sup>26-32</sup> The diagnostic capacity of ultrasound is reduced only in case of deep  
187 | lesions not involving subpleural plans (8% of pneumonic consolidations detected by CT), as  
188 | suggested by two studies performed in groups of 342 and 362 adult (mean age <65) internal  
189 | medicine patients, respectively.<sup>27,33,28-34</sup> Once the diagnosis is established, ultrasound may also  
190 | represent a useful tool for monitoring the resolution of pneumonic infiltrations at follow-up.<sup>27,33</sup>

191 | Very few investigations have assessed the diagnostic performance of ultrasonography for  
192 | pneumonia in geriatric patients. In a group of 169 older patients (mean age 83) hospitalized for  
193 | acute respiratory symptoms, the diagnostic accuracy for pneumonia of ultrasound was significantly  
194 | higher than that of X-ray (0.90 vs 0.67), and the difference was particularly pronounced in those  
195 | subjects with frailty and severe mobility-disability.<sup>5,4</sup>

196 |

### 197 | **Acute heart failure**

198 | The diagnostic performance of lung ultrasound in detecting acute heart failure has been well  
199 | demonstrated in ED and ICU settings as superior to that of X-ray, particularly when  
200 | echocardiography is also performed.<sup>42-18</sup>

201 | In internal medicine wards, bedside ultrasound can be very useful for monitoring treatment response  
202 | and modulating diuretic therapy.<sup>29,35,30-36</sup> B-lines are in fact expression of extravascular lung water  
203 | and their number is related to the severity of congestion<sup>37</sup>. ~~The presence of~~ Residual B-lines at  
204 | discharge ~~is a significant predictor of~~predict hospital readmission and mortality.<sup>29-35</sup> During hospital

205 stay, a close ultrasonographic follow-up, with daily or alternate day assessment, can help to adjust  
206 diuretic dosage and speed up the discharge time.<sup>30-36</sup>  
207 Moreover, bedside lung ultrasound can be used to estimate the volemic state and the possible  
208 presence of fluid overload. The addition of inferior vena cava ultrasonography can be particularly  
209 useful in this context.<sup>30-36</sup>

210 Unfortunately, the application of repeated lung ultrasound monitoring in geriatric acute heart failure  
211 patients has not been specifically addressed by the existing literature to date. However, lung  
212 ultrasound has proven useful in assessing lung congestion in older patients with end-stage renal  
213 disease undergoing dialysis.<sup>38</sup>

214

### 215 **Pneumothorax**

216 In a recent meta-analysis of the literature, lung ultrasound has proven as significantly more **accurate**  
217 **sensitive** than chest X-ray for the detection of pneumothorax (~~sensitivity~~ 78.6% vs 39.8%), with  
218 similar specificity ~~98.4% vs 99.3%~~.<sup>34-39</sup> ~~This is particularly true~~ The diagnostic accuracy is  
219 particularly high for small lesions, that cannot generally be detected by standard X-rays, ~~allowing to~~  
220 ~~spare the prescription of CTs and would generally require a CT examination for prompt diagnosis~~.<sup>32</sup>

221 <sup>40</sup> Ultrasound can also help to stage the pneumothorax severity, identifying the percentage of lung  
222 collapse or the distance between lung parenchyma and visceral pleura.<sup>33-41</sup> However, all the existing  
223 studies were focused on the detection of traumatic or iatrogenic pneumothorax in critical care, and  
224 none was specifically focused on older individuals.

225

### 226 **Pleural diseases**

227 The detection and monitoring of pleural effusion is probably the oldest and simplest application of  
228 chest ultrasound. Its diagnostic accuracy is very high, especially for mild effusions that cannot be  
229 easily detected with X-rays.<sup>34-42</sup> Additionally, ultrasound is an excellent guide for **performing**  
230 thoracentesis ~~in safety and~~ procedures, limiting the risk of iatrogenic pneumothorax.<sup>34-42</sup>

231 Ultrasound can also help to estimate the severity of a pleural effusion. Besides the simple count of  
232 intercostal spaces where the effusion can be visualized, more precise methods of assessment have  
233 been proposed. ~~These methods are generally based on t~~The ultrasonographic measurement of the  
234 distance from visceral pleura to chest wall, the distance from lung base to apex of diaphragm cupola  
235 and the height of the effusion, ~~and~~ allows the calculation of fluid volume using validated  
236 equations.<sup>35-43</sup> The maximal distance between visceral and parietal pleura can be also used as a  
237 proxy of fluid volume.<sup>36-44</sup> The estimations of fluid volume obtained using these methods were  
238 significantly correlated with the volume obtained by thoracentesis drainage.<sup>37-45</sup>  
239 Chest ultrasound also exhibited a higher accuracy than X-ray for the detection of complicated  
240 effusions, pleural adhesions and exudative effusions.<sup>34,42,37-45</sup> Moreover, it exhibited an optimal  
241 diagnostic performance also for the detection of parapneumonic effusions, since it can be very  
242 helpful also for identifying the parenchymal consolidations.<sup>38-46</sup>  
243 Unfortunately, none of the existing studies on the ultrasonographic assessment of pleural effusions  
244 was specifically focused on older patients.  
245 Recent research has also demonstrated that chest ultrasonography is an excellent tool for the  
246 detection of asbestos-related pleural plaques and other small non-malignant lesions, visualized as  
247 focal pleural line thickenings.<sup>39,47,40-48</sup> The diagnostic accuracy in this field may be even superior to  
248 that of CT,<sup>39-47</sup> and ultrasound may also be useful for the follow-up of lesions detected with CT.<sup>40-48</sup>  
249

## 250 **Pulmonary embolism**

251 A meta-analysis showed that chest ultrasound exhibits a good diagnostic accuracy (sensitivity 87%,  
252 specificity 81.8%) for pulmonary embolism, though inferior to that of contrast-enhanced CT.<sup>41-49</sup>  
253 Thus, chest ultrasound in pulmonary embolism may represent only a complementary diagnostic test,  
254 and not a routine procedure. However, in patients with a clearly positive lung ultrasound  
255 examination, the prescription of contrast-enhanced CT could be avoided, reducing costs and  
256 radiation exposure, and with definite advantages in subjects with chronic kidney disease.<sup>42-50</sup>

257

## 258 **Diaphragm dysfunction assessment**

259 The assessment of diaphragmatic motion with M-Mode chest ultrasound is a highly reproducible  
260 technique that can be easily applied in clinical practice.<sup>6,51</sup> In a group of elderly (age  $\geq 80$ ) patients  
261 admitted with acute respiratory failure to a Chinese ICU and subduced to at least 48 hours of  
262 mechanical ventilation, the M-mode ultrasound-diagnosed diaphragmatic dysfunction was  
263 significantly associated with ventilation weaning failure and poor outcomes.<sup>5243</sup>  
264 Alternatively, diaphragmatic dysfunction can be assessed with B-mode ultrasound, measuring  
265 changes in diaphragm thickness during tidal volume ( $\Delta Tdi$ ). In mechanically ventilated patients,  
266 this parameter was significantly associated with a longer ICU stay and increased risk of hospital  
267 death.<sup>5344</sup> In a group of elderly patients (mean age 78) undergoing noninvasive mechanical  
268 ventilation (NIV) for acute COPD exacerbation,  $\Delta Tdi < 20\%$  was the best single clinical parameter  
269 to predict NIV failure and adverse outcomes.<sup>5445</sup>

270

271

## 272 GERIATRIC CHEST ULTRASOUND: A CALL FOR ACTIONS

273

### 274 Overview of results

275 The results of chest ultrasound studies performed either in a geriatric setting or in a population with  
276 mean age  $\geq 70$  years old are summarized in Table 3, with their evidence grade and quality ranking,  
277 determined according to the methods already used by Barth and colleagues (see also Supplemental  
278 Material).<sup>55</sup> Altogether, these studies support the implementation of bedside chest ultrasound in  
279 geriatric wards, but their number and quality is too scarce to formulate specific recommendations.  
280 Studies focused on older patients and geriatric settings are thus urgently needed.

281

### 282 **The possible advantages of chest ultrasound in geriatrics**

283 A number of circumstances indicate that the geriatric patient may represent the ideal recipient of  
284 chest ultrasound implementation programs. First, ~~The~~ the aging respiratory systems is characterized  
285 by some peculiarities that make ~~traditional imaging diagnostics~~ X-rays and, to a lesser extent, CT  
286 more difficult to perform and less accurate to interpret even when a respiratory disease is absent<sup>56</sup>.  
287 ~~These may include changes in lung volumes, mucociliary clearance, bronchial responsiveness,~~  
288 ~~tracheal and bronchial dilation, bronchial wall thickening, air trapping and secretions, that make~~  
289 ~~imaging interpretation challenging even in the absence of defined illnesses.~~<sup>46</sup> The age-related  
290 modifications of lower airways, ~~combined with~~ increases in interstitial connective tissue and  
291 reduction of parenchymal vascularization, may in fact contribute to define the so-called “dirty  
292 chest” ~~on X-rays.~~<sup>47,56-58</sup> Ultrasound is influenced by all these phenomena as well, but its diagnostic  
293 performance is maintained thanks to its defined semeiotics and the clinical interpretation of  
294 signs. ~~This consideration can also apply to chest CT, although the diagnostic accuracy of the~~  
295 ~~technique is certainly superior to X-ray.~~<sup>48</sup>  
296 ~~Moreover~~ Second, mobility-limitations or reduced capacity to follow instructions due to cognitive  
297 ~~impairment is represent another important~~ additional issues in older patients, limiting the quality of

298 chest X-ray or CT scans and reducing their diagnostic accuracy.<sup>59</sup> Ultrasound is only marginally  
299 influenced by these factors, exhibiting good performance also in the sickest and in those with severe  
300 disability.<sup>4</sup> The acquisition of a good chest X-ray scan requires that the patient maintains the upright  
301 posture. Unfortunately, in many cases this is not possible due to osteoarticular diseases, sarcopenia,  
302 critical illness, disability, and even severe cognitive impairment with reduced capacity to follow  
303 instructions by operators. Thoracolumbar curvatures may particularly affect respiratory function  
304 and limit the acquisition of good radiographic images. As a result, the diagnostic performance of  
305 chest X-ray may dramatically decrease, with a significant prevalence of misdiagnosis, delayed  
306 treatment, and poorer outcomes.<sup>49</sup>  
307 Chest ultrasound may contribute to bypass many of these problems. However, the current literature  
308 state of art on thoracic ultrasound applications shows a substantial lack of studies specifically  
309 focused on elderly patients or performed in a geriatric environment. The few existing studies were  
310 conducted in the field of acute dyspnea management and pneumonia diagnosis, and all support the  
311 implementation of this technique. Research performed in ED, ICU, and internal medicine ward  
312 settings also suggests several possible advantages of applying chest ultrasound in the geriatric  
313 practice. Specifically focused studies are however needed.  
314 Finally, ultrasound is cheaper and safer than traditional imaging examinations, and its routine use  
315 optimizes follow-up of critical patients, reducing the number of X-rays and, possibly, CTs, with  
316 lower costs and radiation exposure.<sup>60</sup> This advantage is particularly useful in geriatric patients, who  
317 have often a high level of clinical complexity requiring several diagnostic resources.

318

### 319 **Areas of development**

320 At the current state of art Although ultrasound images are less influenced by age-related changes in  
321 anatomy and physiology of the respiratory system than X-ray, ~~the-its~~ normal reference standards of  
322 chest ultrasound imaging in healthy older persons are still unclear, and should be carefully studied.

323 ~~The age-related changes in anatomy and physiology of the respiratory system can modify the~~  
324 ~~ultrasonographic appearance of a normal chest,<sup>46-48</sup> and should be carefully studied.~~

325 Aging can also affect diaphragmatic structure and function independently of the presence of  
326 respiratory diseases. Thus, normative data on this aspect are needed, in order to clarify the  
327 usefulness of diaphragmatic ultrasound in clinical practice.

328 ~~Future research should also help to clarify several critical points of the application of bedside chest~~  
329 ~~ultrasound in older patients with respiratory diseases.~~ Besides the evaluation of diagnostic accuracy  
330 in different clinical situations and settings, ~~these other~~ critical points deserving future investigations  
331 in older patients may ~~concern~~ include:

- 332 - The effects of multimorbidity, and particularly cardio-respiratory multimorbidity,<sup>50-61</sup> on  
333 ultrasonographic findings in patients with acute respiratory symptoms;
- 334 - The diagnostic advantages of combining chest ultrasound with point-of-care  
335 echocardiography in the evaluation of acute dyspnea;
- 336 - The usefulness of simplified protocols of ultrasonographic evaluations, such as the FALLS  
337 and BLUE protocols;<sup>206</sup> ~~in geriatric patients;~~
- 338 - The role of chest ultrasound in the detection of diaphragm sarcopenia, either isolated or in  
339 the context of systemic sarcopenia;
- 340 - The cost/efficacy and cost/effectiveness of chest ultrasonography ~~in the elderly;~~
- 341 - The role of chest ultrasound in the post-acute and long-term ~~care~~ follow-up of older patients  
342 with cardio-respiratory diseases.

343 Moreover, the effects of chest ultrasound implementation in clinical practice on patient-related  
344 outcomes should be particularly investigated. In this field, education of geriatricians and residents  
345 in geriatrics on point-of-care ultrasound principles could help to improve the quality of care and  
346 contribute to improve outcomes.

347

348 **CONCLUSIONS AND IMPLICATIONS**

349 Chest ultrasound is an easy, accurate and versatile diagnostic tool for the management of acute  
350 respiratory symptoms and conditions in many clinical settings, including acute-care hospital wards,  
351 nursing homes and community services. However, very few studies have explored this diagnostic  
352 technique specifically in a geriatric environment. Even if no evidence-based recommendations on  
353 the use of bedside chest ultrasound can be specifically made ~~specifically~~ for geriatric patients, ~~an~~  
354 implementation of this technique in geriatric research and practice is desirable, considering the large  
355 amount of evidence in younger patients and in different clinical settings. ~~Future research should be~~  
356 ~~focused on the reference standards in the elderly, on the advantages and cost effectiveness of the~~  
357 ~~implementation of the technique in both acute and post acute care setting and on the relationship of~~  
358 ~~its findings with multimorbidity and sarcopenia.~~

359

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361 **Conflict of interest**

362 The authors have nothing to disclose.

363

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367

368

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525

526 **TABLE 1**

527 Summary of the main recommendations, retrieved by the scientific literature and international  
 528 consensus, on how the bedside chest ultrasound should be performed.

ISSUE	RECOMMENDATIONS
Patient position	<ul style="list-style-type: none"> <li>- Sitting on the bed side (ideal position)</li> <li>- Maintained in the sitting position by a second operator (for those with severe mobility-disability)</li> <li>- Lying supine on the bed (only for bedridden patients)</li> <li>- Supine position is ideal for diaphragm assessment</li> </ul>
Use of probes	<ul style="list-style-type: none"> <li>- Use both convex 3.5-5 MHz and linear 4-8 mHz probes</li> <li>- Convex probes assure a panoramic view, allow <del>to</del> <u>detect</u> <u>detection of</u> gross lesions and focus on deeper plans</li> <li>- Linear probes assure a careful examination of surface structures (ling-pleura interface, small pleural and subpleural lesions) at the expense of a reduced penetration of ultrasounds into deeper anatomical plans</li> </ul>
Ultrasound modality	<ul style="list-style-type: none"> <li>- Examination of pleura and lungs should be performed in B-mode</li> <li>- M-mode can be useful for a study of the diaphragm</li> </ul>
Methodology of examination	<ul style="list-style-type: none"> <li>- Split each hemithorax into an antero-lateral (from parasternal to posterior axillary lines) and a posterior sector (from posterior axillary to paravertebral lines), and divide each sector into a superior and inferior half</li> <li>- Investigate systematically the four areas of each hemithorax</li> <li>- Put the probe in each intercostal space, perpendicularly, obliquely and in parallel to the course of the ribs</li> <li>- In bedridden patients, limit investigation to the antero-lateral sectors</li> <li>- <u>Allow small movements</u> <del>Small movements</del> of rotation and tilting of the probes <del>are allowed</del> to assure an optimal visualization of structures</li> <li>- Measurement <del>of</del> diaphragm thickness, excursion in forced respiration, variation of thickness between end inspiration and expiration</li> </ul>

529

530 **TABLE 2**  
 531 Overview of the main ultrasonographic signs that can be detected when examining the chest in  
 532 normal situations.

<b>SIGN/STRUCTURE</b>	<b>ULTRASONOGRAPHIC FEATURES AND CLINICAL MEANING</b>
Visceral pleura	Fine echogenic line which is normally included in the thick line of total reflection of ultrasound waves at the air-filled lung
Parietal pleura	Fine, sometimes weak echogenic line, often obscured by reverberation artifacts. With highest resolution transducers, the line of parietal pleura may appear divided into two layers: the parietal pleura and the external endothoracic fascia
Pleural cavity	Echo-free to hypoechoic space due to the presence of a small amount of fluid. Often undetectable.
“Gliding sign”	Bright, linear interface produced by the air-filled lung covered by visceral pleura, moving backwards and forwards with respiration
Comet tail artifacts	Small uneven irregularities at the visceral pleural surface. Such vertical artifacts are common in interstitial lung disease (B-lines), but can be occasionally seen in the normal lung.
A-lines	Horizontal, multiple artifacts arising from pleural surface reverberation on the deeper lung plans, typically parallel to the pleural plane. Distance between A-lines is equal to, or a multiple of, the distance between the skin and the parietal pleura. The presence of A-lines testifies to adequate lung expansion and homogeneous ventilation.

533

534 | **TABLE 32**

535 | Overview of the main ultrasonographic signs that can be detected when examining the chest and  
 536 | their correlation with respiratory diseases.

<b><u>US-ULTRASOUND SIGN</u></b>	<b><u>MOST PROBABLE DIAGNOSIS</u></b>	<b><u>DIFFERENTIAL DIAGNOSIS</u></b>
Hypoechoic space between chest wall and lung (possibly with quadrilater or sinusoid shape, “quad sign” and “sinusoid sign”)	Pleural effusion	Pleural thickening Pleural cancer Intraparenchymal cysts
Absent pleural line sliding	Pneumothorax	<del>ARDS</del> — <u>Acute Respiratory Distress Syndrome</u> Local fibrosis
Dynamic air bronchogram within a parenchymal hyperechoic consolidation	Pneumonia	Atelectasis Pulmonary infarction Pulmonary contusion Cancer
Increased parenchymal echogenicity with loss of pleural line and hypoechoic vascular structures	Pneumonia	Atelectasis Pulmonary infarction Pulmonary contusion Cancer
Peripheral wedge-shaped consolidation	Pulmonary embolism	Pneumonia Cancer
Static air bronchogram within a parenchymal hyperechoic consolidation	Atelectasis	Pulmonary infarction Pulmonary contusion Cancer
Increased B-lines with a widespread distribution	Cardiogenic pulmonary edema	<del>ARDS</del> <u>Acute Respiratory Distress Syndrome</u> Pneumonia Interstitial lung disease
B-lines with focal distribution (focal interstitial syndrome)	Pneumonia	Pulmonary infarction Pulmonary contusion Acute heart failure
Reduced diaphragm thickness and thickening ratio / reduced excursion	Diaphragm dysfunction	Neuromuscular disease <del>COPD</del> <u>Chronic Obstructive Pulmonary Disease</u> Severe focal lung disease (pneumonia, cancer, atelectasis)

537 | ~~US=Ultrasound; ARDS=Acute Respiratory Distress Syndrome; COPD=Chronic Obstructive~~  
 538 | ~~Pulmonary Disease.~~

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**TABLE 3**

Summary of the results of the main studies on chest ultrasound in which a population with a mean age  $\geq 70$  years old was enrolled. Grading and quality of evidence is also provided using the method proposed by Barth et al.<sup>53</sup>

<u>First author, journal, year, [ref]</u>	<u>Setting and design</u>	<u>Number of patients</u>	<u>Mean age</u>	<u>Main outcome</u>	<u>Gold standard</u>	<u>Sensitivity</u>	<u>Specificity</u>	<u>Grade of evidence</u>	<u>Quality of evidence</u>	<u>Key finding</u>
<u>Pivetta, Chest, 2015, [18]</u>	<u>7 EDs, observational</u>	<u>1005</u>	<u>77</u>	<u>Cardiogenic vs other dyspnea</u>	<u>Blind review of medical record</u>	<u>0.97</u>	<u>0.97</u>	<u>C</u>	<u>Adequate</u>	<u>Ultrasound can improve the diagnostic accuracy of acute dyspnea in the ED</u>
<u>Perrone, Eur J Intern Med, 2017, [19]</u>	<u>IM ward, observational</u>	<u>150</u>	<u>81</u>	<u>Cardiogenic vs other dyspnea</u>	<u>Discharge diagnosis</u>	<u>0.94</u>	<u>0.86</u>	<u>C</u>	<u>Poor</u>	<u>Bedside ultrasound improves the diagnostic workup of dyspnea in wards</u>
<u>Sartini, Intern Emerg Med, 2017, [20]</u>	<u>ED, observational</u>	<u>236</u>	<u>80</u>	<u>Cardiogenic vs other dyspnea</u>	<u>Expert review of medical records</u>	<u>0.58</u>	<u>0.88</u>	<u>C</u>	<u>Poor</u>	<u>To diagnose acute heart failure, ultrasound should be integrated with clinical information</u>
<u>Laursen, Lancet Respir Med, 2014, [21]</u>	<u>ED, prospective parallel-group trial</u>	<u>320</u>	<u>73</u>	<u>Assignment to the right treatment for dyspnea</u>	<u>Masked audit on clinical records</u>	<u>NA</u>	<u>NA</u>	<u>B</u>	<u>Good</u>	<u>Ultrasound allows quicker and more appropriate treatment of dyspnea, and faster disposition from ED</u>
<u>Ticinesi, Medicine, 2016, [4]</u>	<u>IM/geriatric ward, observational</u>	<u>169</u>	<u>83</u>	<u>Pneumonia vs other respiratory conditions</u>	<u>Blind review of medical record</u>	<u>0.92</u>	<u>0.94</u>	<u>C</u>	<u>Adequate</u>	<u>Ultrasound has higher diagnostic accuracy for pneumonia than X-ray, especially in frail patients</u>
<u>Huang, BMC Pulm Med, 2018, [25]</u>	<u>ICU, prospective</u>	<u>51</u>	<u>82</u>	<u>ARDS vs no ARDS</u>	<u>Chest CT</u>	<u>0.88</u>	<u>0.89</u>	<u>C</u>	<u>Adequate</u>	<u>Lung ultrasound was consistent with CT findings in the diagnosis of ARDS</u>
<u>Cogliati, Int J Cardiol, 2016, [35]</u>	<u>IM ward, prospective</u>	<u>150</u>	<u>81</u>	<u>Prediction of adverse events in AHF</u>	<u>Echo-cardiography</u>	<u>NA</u>	<u>NA</u>	<u>C</u>	<u>Adequate</u>	<u>Persistence of ultrasound signs of acute heart failure is associated with mortality</u>
<u>Mozzini, Intern Emerg Med, 2018, [36]</u>	<u>IM ward, prospective parallel-group trial</u>	<u>120</u>	<u>84</u>	<u>Prediction of LOS and therapeutic adjustments</u>	<u>Echo-cardiography</u>	<u>NA</u>	<u>NA</u>	<u>C</u>	<u>Adequate</u>	<u>Lung ultrasound reduced LOS and predicted therapeutic variations in AHF</u>

in AHF

<u>Huang, J Thorac Dis, 2017, [50]</u>	<u>ICU, prospective</u>	<u>40</u>	<u>84</u>	<u>Mechanical ventilator weaning in ARF</u>	<u>NA</u>	<u>NA</u>	<u>NA</u>	<u>C</u>	<u>Poor</u>	<u>Diaphragmatic dysfunction, assessed by M-mode ultrasound, predict mechanical ventilator weaning failure</u>
<u>Marchioni, Crit Care, 2018, [52]</u>	<u>ICU, prospective</u>	<u>75</u>	<u>78</u>	<u>NIV weaning in AECOPD</u>	<u>NA</u>	<u>NA</u>	<u>NA</u>	<u>C</u>	<u>Adequate</u>	<u>Change in diaphragm thickness predict NIV weaning failure and mortality</u>

544 ED=Emergency Department; IM=Internal Medicine; NA=Not Assessed; ICU=Intensive Care Unit; ARDS=Acute Respiratory Distress Syndrome;

545 CT=Computed Tomography; AHF=Acute Heart Failure; ARF=Acute Respiratory Failure; NIV=Non-Invasive Ventilation; AECOPD=Acute

546 Exacerbation of Chronic Obstructive Pulmonary Disease

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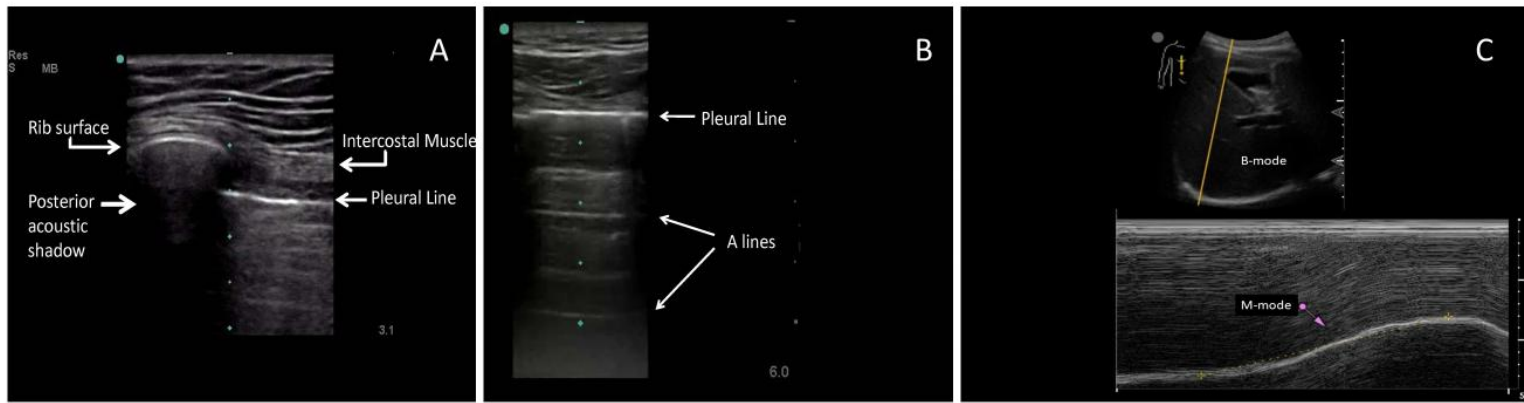
**FIGURE 1**

549

Normal ultrasonographic findings in chest ultrasound using a sector, longitudinal scan (panels A and B) and a convex array probe for an abdominal,

550

transhepatic view of the diaphragm at both b and m modes (panel C).

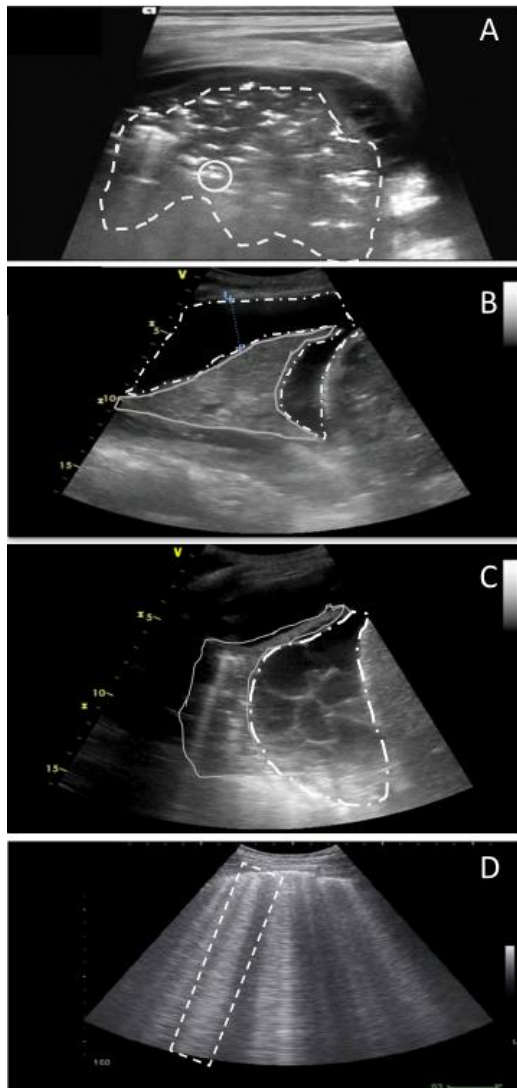


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553 **FIGURE 21**  
554 Principal pathologic findings at chest ultrasound using a convex probe. **A:** hyperechoic,  
555 consolidated lung parenchyma (dotted line). The hyperechoic spots are consistent with an air  
556 bronchogram (continued line circle); **B:** Free flowing non septated, anechoic, pleural effusion  
557 (dotted line). The compressed lung parenchyma is not ventilated and, consequently, atelectatic,  
558 clearly detectable and hypoechoic (continued line); **C:** Complex, loculated pleural effusion (dotted  
559 line) surrounding a partially collapsed lower lobe (continued line); **D:** Ultrasonographic B lines,  
560 long wide bands of hyperechoic artifact likened to the beam of a flashlight (dotted line).



561

562 **FIGURE 2**

563 **Panel 1. Ultrasound diagnosis of Pneumothorax (linear probe).** In panel 1.a, the M-mode image  
564 demonstrates a linear, laminar pattern in the tissue superficial to the pleural line and a granular or  
565 “sandy” appearance deep to the pleural line, suggesting the absence of pneumothorax (seashore  
566 sign). In panel 1.b, the M-mode image shows a linear, laminar pattern in the pleural interface, and a  
567 similar linear pattern deep to the pleural line (stratosphere sign or barcode sign), indicating the  
568 presence of pneumothorax.

569 **Panel 2. Ultrasound diagnosis of lung abscess (convex probe).** Panel 2.a: Computed tomography  
570 showing a surrounding, thick and irregular consolidation containing a fluid, inner level. In panel  
571 2.b, high amplitude echoes are clearly visible as well as multiple echogenic small air inclusions.

572 **Panel 3. Ultrasound diagnosis of lung tumour (convex probe).** Panel 3.a: Computed tomography  
573 showing a large right apical mass infiltrating the chest wall. Panel 3.b.: corresponding  
574 ultrasonographic view of a hypoechoic lesion with posterior acoustic enhancement (PAE) and  
575 irregular borders. The visceral pleura is interrupted since it is infiltrated by the tumor (white  
576 arrows).

577 **Panel 4. Ultrasound diagnosis of malignant pleural mesothelioma (convex probe).** Panel  
578 4.a: Computed tomography of large pleural, confluent, masses (yellow arrows), wide thickening of  
579 soft tissue attenuation involving the right chest wall and the diaphragm and associated with  
580 malignant pleural effusion. Panel 4.b: Ultrasound demonstrating large, anechoic effusion, above a  
581 flattened diaphragm, extensively infiltrated by thick, irregular nodularity arising from the  
582 diaphragm and the visceral pleura.

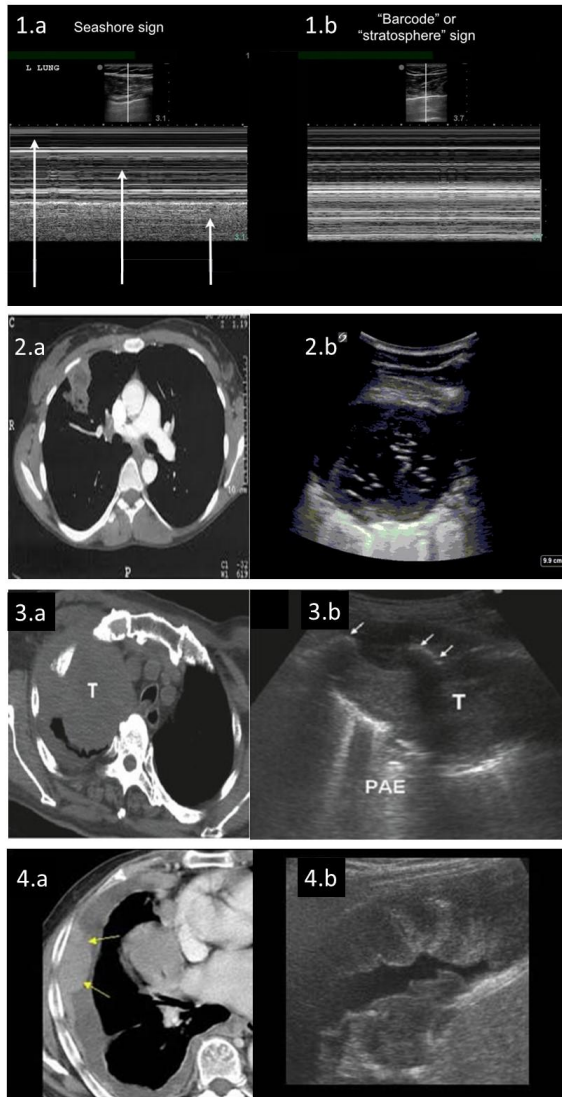


Figure 1  
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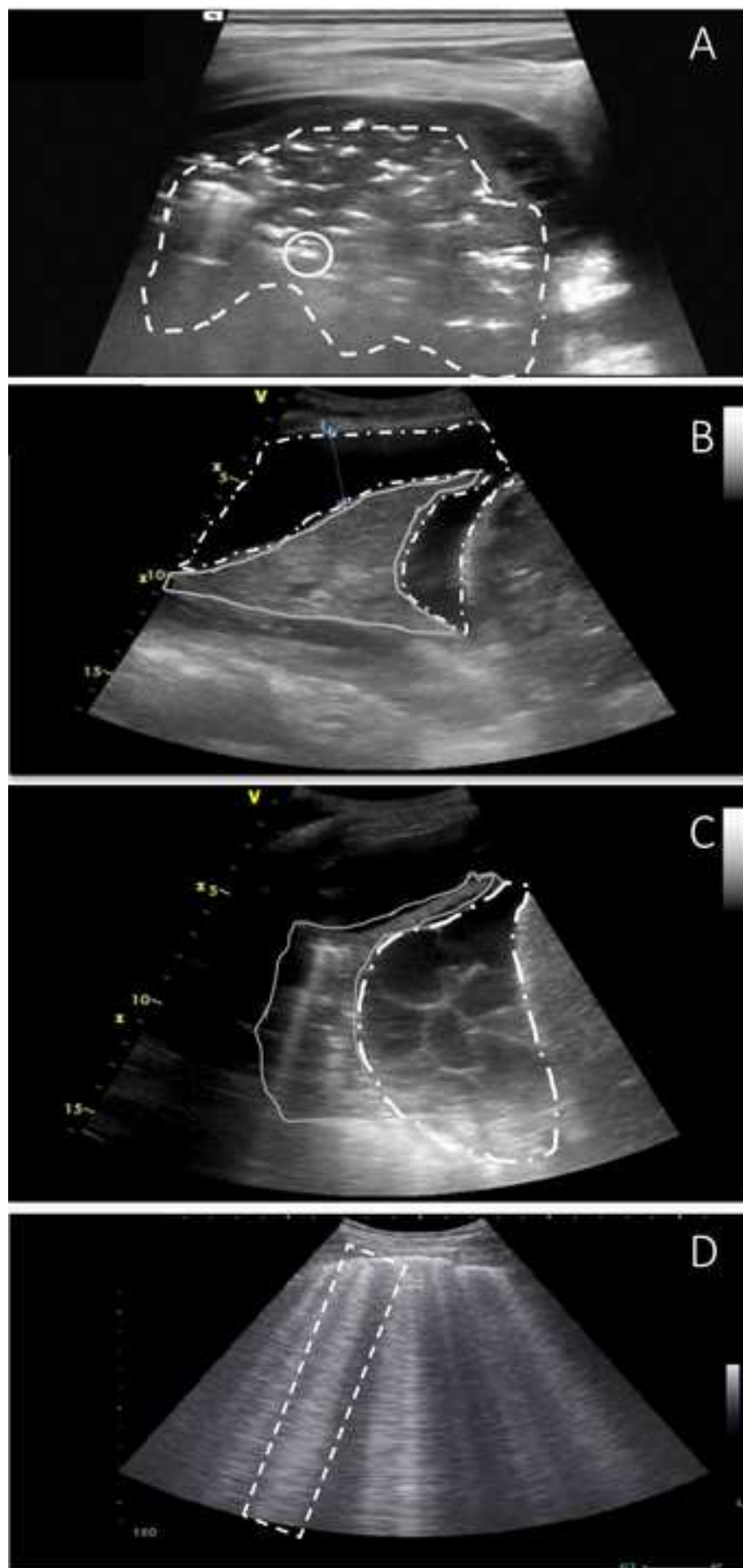
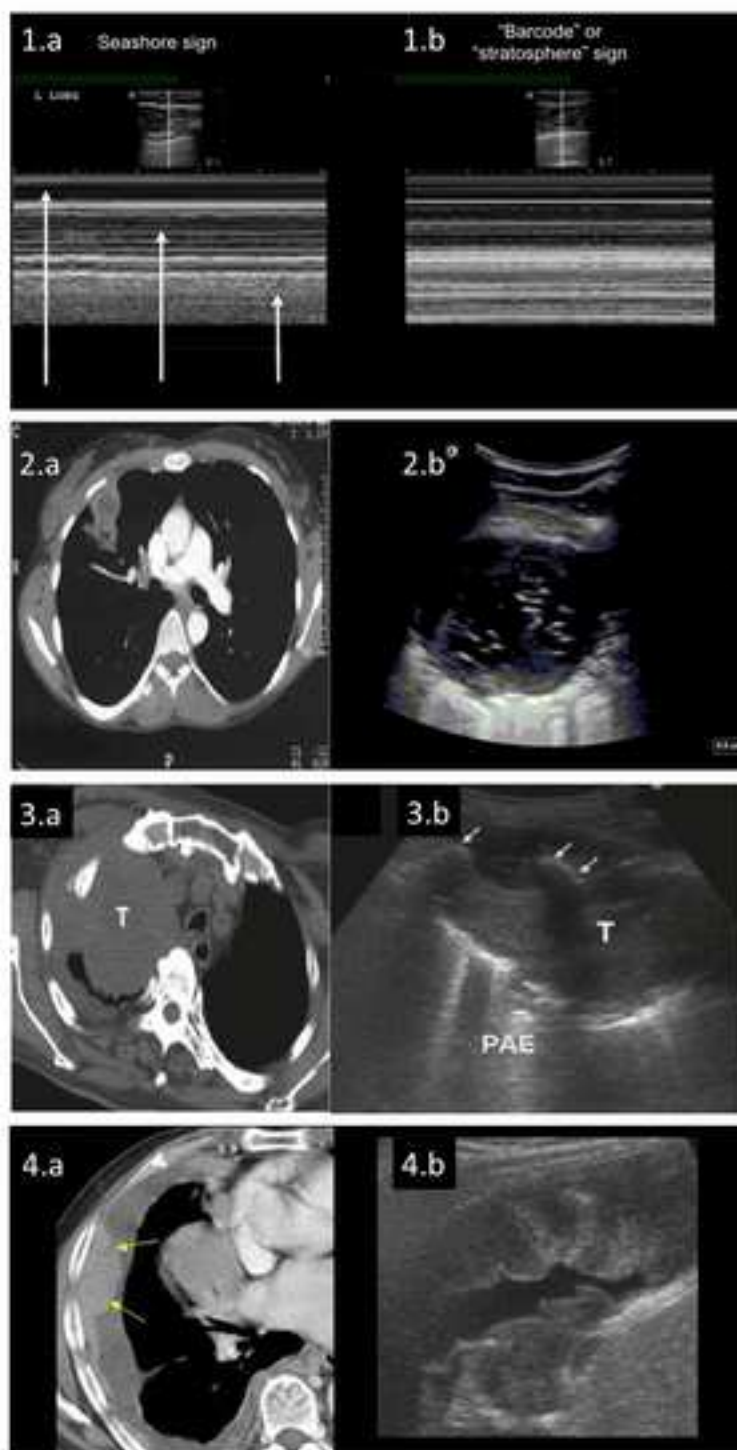


Figure 2  
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**Supplementary Material**

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