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# Diagnostic échographique des pneumopathies acquises sous ventilation mécanique en réanimation pédiatrique

Justine Uguen

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**THESE POUR LE DIPLOME D'ETAT  
DE DOCTEUR EN MEDECINE**

**Diagnostic échographique des pneumopathies acquises sous  
ventilation mécanique en réanimation pédiatrique**

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# Abréviations

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VAP : ventilator-associated-pneumonia  
MV : mechanical ventilation  
PICU : pediatric intensive care unit  
CXR: chest X-Ray  
CDC : center of disease control  
LUS : lung-ultra-sound  
BL : B-Lines  
SPC : sub-pleural consolidation  
CS : consolidation  
DAB : dynamic air bronchogram  
PE: pleural effusion  
CAP : community-acquired-pneumonia  
PRISM : PICU admission Pediatric Risk of Mortality scores  
PELOD : PEdiatric Logistic Organ Dysfonction score  
ARDS : acute-respiratory-distress-syndrome  
BAL: bronchoalveolar lavage  
PSB : protected specimen brush  
ETA : endotracheal aspirate  
CFU : colony forming units  
Ml : milliliter  
NPV : negative predictive value  
PPV : positive predictive value  
CRP : C-reactive protein  
Ped-VAE : Pediatric ventilator-associated-event  
PEEP : positive end-expiratory pressure  
FiO2 : fraction of inspired oxygen  
NICU : neonatal-intensive-care-unit  
CEPPIS : chest echography and pulmonary infection Score  
CPIS : clinical pulmonary infection score  
LUPPIS : lung ultrasound and pentraxin-3 pulmonary infection score  
SRLF : société de réanimation en langue française  
ICU : intensive-care-unit

# Introduction

---

Ventilator-associated-pneumonia (VAP) refers to diagnosis of nosocomial pneumonia occurring 48 hours or more after initiation of mechanical ventilation (MV).

The physiopathology of VAP can be explained by different factors: presence of bacteria in the oropharynx, especially in the area of dental plaque, stagnation of secretions above the balloon and in the subglottic space, and micro-inhalations (1). This colonisation of the respiratory tract is favoured by effective cough reduction increased by curarisation and by the irritation of the respiratory mucous membranes.

Ventilator-associated-pneumonia and bloodstream infections are the two most common healthcare-associated infections in pediatric intensive care units (PICU). According to the studies, the overall prevalence of VAP varies from 2% to 32% (2). The incidence is between 1 to 63 VAP per 1000 ventilator days (3) and is higher in university hospitals and in developing countries (4). Early VAP is defined as VAP occurring within 48 to 96 hours after intubation; those occurring after 96 hours of intubation are referred to as late VAP.

Intrinsic factors predisposing for VAP are immunodeficiency, genetic syndrome, subglottic or tracheal stenosis, gastroesophageal reflux, young age (<1year) (5)(6)(7). Extrinsic factors are the length of ventilation, continuous sedation, curarisation, use of steroids, central vascular lines, reintubation and self-extubation, bloodstream infection, prior antibiotic therapy, bronchoscopy, transport out of the PICU, use of enteral feeding and proton pump inhibitors and trauma(8)(9).

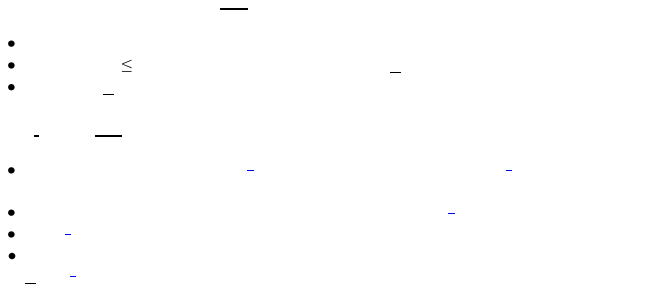
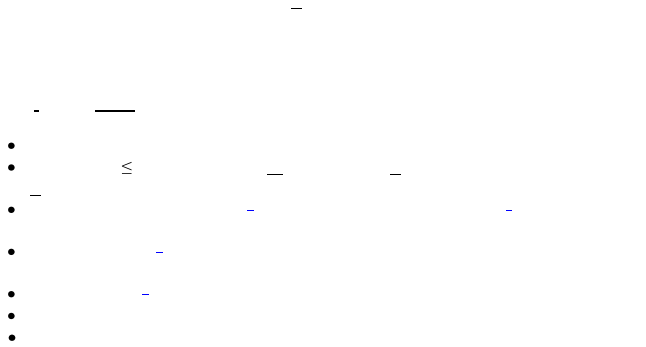
Several studies have shown that VAP increases the duration of ventilation, the length of hospitalization and the hospital cost (10)(11). It is the leading cause of antibiotic use in PICU (12) and it is known to cause increased mortality for affected patients (20% versus 7% for patients without VAP (13)).

In PICU at the Saint Denis University Hospital on La Réunion (France), the VAP prevalence from 23/03/2015 to 28/11/2018 was 19,5% (28 VAP/143 patients ventilated more than 48 hours). The rate per year was 11% in 2015, 21% in 2016, 16% in 2017 and 29% in 2018. The average diagnosis of VAP was made after 15,3 days of intubation. Fifty-seven percent of the patients were hospitalized in PICU for pulmonary reasons. The most frequently germs found were *Klebsiella pneumoniae* (14%), *Pseudomonas aeruginosa* (14%), *Strenotrophomonas maltophilia* (10%) and *Enterobacter aerogenes* (10%). *Staphylococcus aureus*, *Acinetobacter*

*baumani* and *Haemophilus influenzae* were each found in 3% of patients, respectively. Twenty-one percent presented no pathogen.

Although VAP is a real issue in PICU, there is no gold-standard for the diagnosis in the literature (14). However, the diagnosis is most frequently made through the combined use of clinical criteria and chest X-ray (CXR). A commonly used validated pediatric population score for the VAP diagnosis, the Centers of disease control and prevention (CDC) 2018 score (14) (Figure 1) had a sensitivity of 86% and a specificity of 77% (15). It includes clinical criteria such as: fever  $>38^{\circ}\text{C}$  or temperature instability, leukopenia ( $\leq 4000$  white blood cells  $\text{WPC}/\text{mm}^3$ ) or leukocytosis ( $\geq 12\ 000$  for children  $> 12$  years old and  $\geq 15\ 000$   $\text{WPC}/\text{mm}^3$  for children  $\leq 12$  years old), new onset or change in character of sputum, new onset or worsening cough or dyspnea or tachypnea, rales or bronchial breath sounds, worsening gas exchange or increased oxygen requirements or ventilator demand. For infants  $\leq 1$  year old, bradycardia ( $< 100$   $\text{beats}\cdot\text{min}^{-1}$ ) or tachycardia ( $> 170$   $\text{beats}\cdot\text{min}^{-1}$ ) are also included. Concerning radiological criteria, one or two CXR (for patients underlying pulmonary or cardiac disease) with new or progressive infiltrate, consolidation cavitation or pneumatocele (in infants  $\leq 1$  year old) allow to confirm VAP in suspected patients.

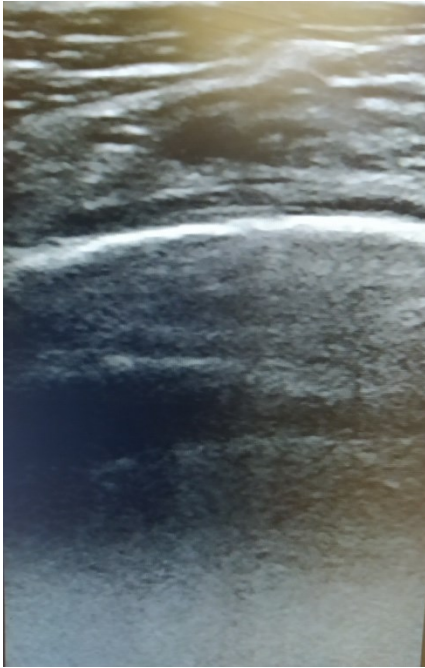
Radiological diagnosis of VAP presents some limitations like the absence of radiological signs in early VAP, such as areas not visible on CXR, resulting in a lack of diagnosis of VAP with size inferior of 1 cm (16). For the diagnosis of VAP, consolidations with an aerial bronchogram have a sensibility of 58 to 89% when those of an infiltrate vary from 50 to 78% and a low specificity of 33 to 42% (16). In addition, irradiation of the patient with daily CXR may be deleterious (17). Chest computed tomography provides a better diagnosis than CXR, but is comparatively highly irradiating and requires moving the patient out of the PICU (18).

<ul style="list-style-type: none"> <li>•</li> <li>•</li> <li>•</li> <li>•</li> </ul>	
<p>infants <math>\leq 1</math></p> <p>for example:</p>	
	<p>ALTERNATE CRITERIA, for child <math>&gt;1</math> year old or <math>\leq 12</math> years old, at least ____</p> <p>• <math>\leq</math> _____ ) or leukocytosis (<math>\geq 15,000</math> WBC/mm</p> <p>• _____</p> <p>• _____</p> <p>• _____</p> <p>• _____</p>

**Figure 1** Diagnostic score of ventilator-associated-pneumonia by the Centers of disease control and prevention (CDC) 2018

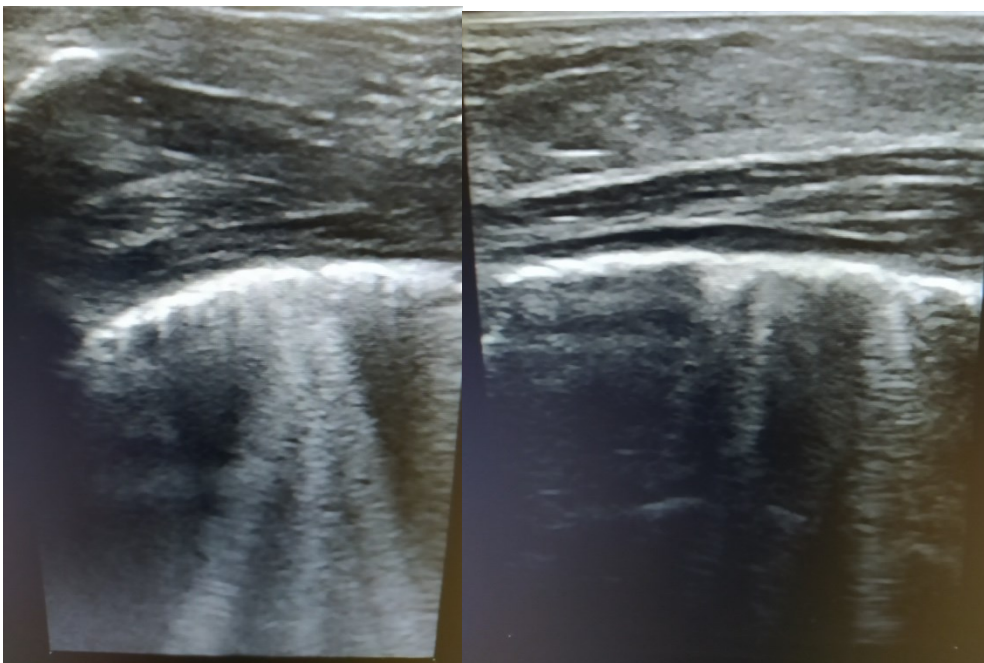
Lung ultrasound (LUS) is a non-irradiating examination and can be performed daily at the bedside in PICU. In a healthy lung, the air does not reflect the ultrasound so only the pleural line can be seen. During ventilation, the lung expands and the visceral pleural line slides against the parietal line. This is called pleural gliding. The reverberation of these lines is visualized by horizontal lines, the A lines, which are artefacts. A normally ventilated lung is defined by the pleural gliding and the A lines(19) (Figure 2).





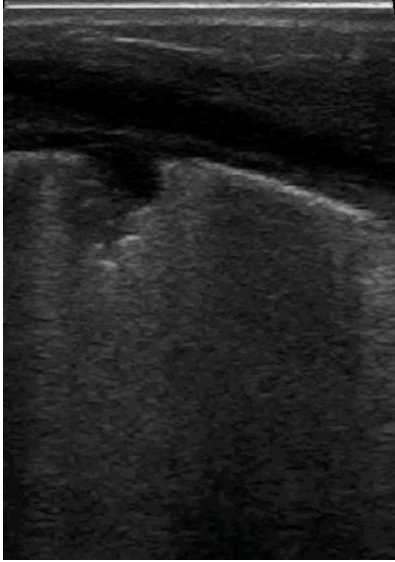
**Figure 2** Normal lung in ultra-sound view

B-lines (BL) are hyperechoic vertical lines starting from the pleural line, erasing the A lines. They are generated when lung density increases (increase in hydrostatic pressure or altered capillary permeability) and are significant from 3 B-Lines(19) (Figure 3). They may be physiological in the healthy or bedridden patient(20). Seen together they are defined as “lung rocket” artefact.



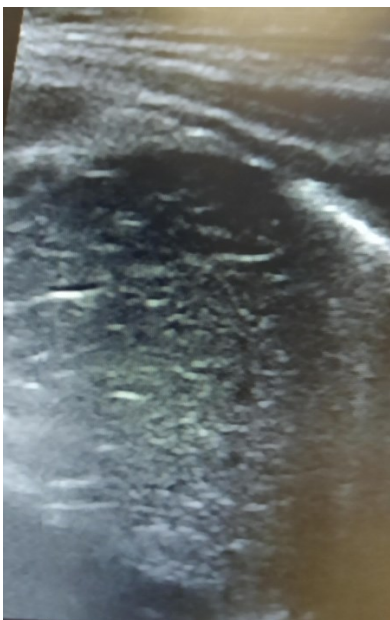
**Figure 3** Lung ultrasound view of B-lines

Sub-pleural consolidations (SPC) are small consolidations juxtaposed to the pleura with irregular contours (Figure 4). It is an intermediate stage in the loss of aeration due to pneumonia, between the BL and the appearance of alveolar consolidation.



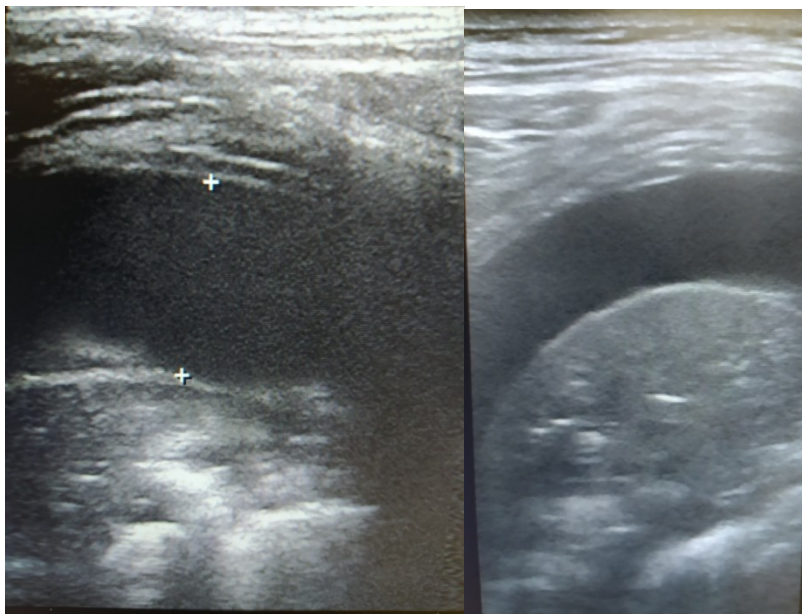
**Figure 4** Sub-pleural consolidation.

Consolidations (CS) with or without air bronchogram are visualized when the loss of ventilation is complete, and the lung appears as a tissue structure (Figure 5). It is quite limited. Air bronchogram visualized inside are hyper-echoic. On inhalation, the penetration of air through the bronchial tree into the consolidations reinforces their appearance and forms a dynamic air bronchogram (DAB). If it is static or absent, it can be a sign of atelectasis, pneumonia or pulmonary edema(21).



**Figure 5** Lung ultrasound view of consolidation without dynamic air bronchogram

Pleural effusion (PE) is visualised as an anechogenic zone separating the two pleural sheets (Figure 6).



**Figure 6** Lung ultrasound views of pleural effusion

The efficiency of LUS has been proven in the diagnosis of community-acquired pneumonia (CAP) in children and it is feasible and safe to substitute LUS for CXR(22). The DAB had a specificity of 97% and a sensitivity of 86%(23).

Lung ultrasound has been successfully applied in adults and neonates for the diagnosis and monitoring of VAP(24)(25). Subpleural consolidations and DAB were the most useful sonographic signs to diagnose VAP in suspected adult patients(26). Some publications suggest that LUS allows VAP diagnosis earlier than CXR(27). However, to our knowledge, no substantial scientific evidence is yet available on whether LUS reliably improves the diagnosis of VAP in PICU.

The primary outcome of this study was to evaluate the LUS performances in the diagnosis of VAP in children. The secondary outcomes were to describe the LUS signs of VAP in children; to evaluate the inter-observer agreement of LUS; to determine the local incidence and ecology of VAP and to compare the diagnostic delay of VAP by LUS and by the CDC score.

## Lung ultrasound in diagnosis of ventilator-associated-pneumonia in pediatric intensive care unit: a prospective study.

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### Abstract

**Objective:** Lung ultrasound (LUS) is an accurate tool to diagnose community-acquired-pneumonias in children and ventilator-associated-pneumonia (VAP) in adults and neonates. The objective is to evaluate the LUS performances in the diagnosis of VAP in a pediatric intensive care unit (PICU).

**Design:** Monocentric, prospective study between November 1, 2018 and July 31, 2020.

**Setting:** 5-bed PICU in a tertiary care university hospital.

**Patients:** All patients under 18 years old that were admitted to the PICU, intubated and mechanically ventilated for more than 48 hours were included.

**Interventions:** LUS was performed daily and compared to diagnostic of VAP by the center of disease control (CDC) 2018 score identified as the “gold-standard”. Five signs of VAP were studied by LUS (dynamic air bronchogram (DAB), sub-pleural consolidations (SPC), consolidations, B-Lines (BL) and pleural effusion).

**Measurements and main results:** Fifty-seven patients were included. Median age was 8 [2,7-34.1] months. Nineteen (33%) children developed a VAP, among which 9 (47%) had a microbiological confirmation. The incidence of VAP was 18 (95% CI 10.8-28.1)/1000 days of ventilation. For LUS diagnosis, the most accurate sign was DAB with 94.1 [90.8-96.5] % specificity and 25.0 [7.3-52.4] % sensitivity. With microbiological confirmation, sensitivity

was improved (50 [15.7-84.3] %). Accuracy was improved with the association of LUS and the clinical score: DAB had a positive and negative predictive value of 80 [28.4-99.5] %, and 96 [93.1-97.9] % and BL sensitivity and specificity were 100 [79.4-100] % and 95.5 [92.4-97.6] %, respectively. The simultaneous presence of clinical and microbiological CDC score, DAB and SPC allowed to achieve 67.6 [9.2-99.2] % positive predictive value and 98.0 [95.7-99.3] % negative predictive value.

Conclusion: DAB was the most accurate sonographic sign to diagnose VAP in suspected patients. Association between clinical score and LUS had better diagnosis accuracy than LUS alone.

## Introduction

Ventilator-associated-pneumonia (VAP) and bloodstream infections are the two most common healthcare-associated infections in pediatric intensive care units (PICU). According to the studies, the overall prevalence of VAP varies from 2% to 32% (2). The incidence is between 1 to 63 VAP per 1000 ventilator days (3) and is higher in university hospitals and in developing countries (4).

Several studies have shown that VAP increases the duration of ventilation, the length of hospitalization and the hospital cost (10)(11). It is the leading cause of antibiotic use in PICU (12) and it is known to cause increased mortality for affected patients (20% versus 7% for patients without VAP (13)).

Although VAP is a real issue in PICU, there is no gold-standard for the diagnosis in the literature (14). However, the diagnosis is most frequently made through the combined use of clinical criteria and chest X-ray (CXR). A commonly used validated pediatric population score for the VAP diagnosis, the Centers of Disease Control and Prevention (CDC) 2018 score (14), had a sensitivity of 86% and a specificity of 77%(15). It includes clinical criteria such as: fever  $>38^{\circ}\text{C}$  or temperature instability, leukopenia ( $\leq 4000$  white blood cells WPC/ $\text{mm}^3$ ) or leukocytosis ( $\geq 12\ 000$  for children  $> 12$  years old and  $\geq 15\ 000$  WPC/ $\text{mm}^3$  for children  $\leq 12$  years old), new onset or change in character of sputum, new onset or worsening cough or dyspnea or tachypnea, rales or bronchial breath sounds, worsening gas exchange or increased oxygen requirements or ventilator demand. For infants  $\leq 1$  year old, bradycardia ( $< 100$  beats. $\text{min}^{-1}$ ) or tachycardia ( $> 170$  beats. $\text{min}^{-1}$ ) are also included. Concerning radiological criteria, one or two CXR (for patients underlying pulmonary or cardiac disease) with new or progressive infiltrate, consolidation cavitation or pneumatocele (in infants  $\leq 1$  year old) allow to confirm VAP in suspected patients.

Radiological diagnosis of VAP presents some limitations like the absence of radiological signs in early VAP, such as areas not visible on CXR, resulting in a lack of diagnosis of VAP with size inferior of 1 cm (16). For the radiological diagnosis of VAP, consolidations with an aerial bronchogram have a sensibility of 58 to 89% when those of an infiltrate vary from 50 to 78% and a low specificity of 33 to 42% (16). In addition, irradiation of the patient with daily CXR may be deleterious (17). Chest computed tomography provides a better diagnosis than CXR, but is comparatively high irradiating and requires moving the patient out of the PICU (18).

Lung ultrasound (LUS) is a non-irradiating examination and can be performed daily at the bedside in PICU. The efficiency of LUS has been proven in the diagnosis of community-acquired pneumonia (CAP) in children and it is feasible and safe to substitute LUS for CXR(22). The dynamic air bronchogram (DAB) had a specificity of 97% and a sensitivity of 86%(23). Lung ultrasound has been successfully applied in adults and neonates for the diagnosis and monitoring of VAP(24)(25). Subpleural consolidations and DAB were the most useful sonographic signs to diagnose VAP in suspected adult patients(26). Some publications suggest that LUS allows VAP diagnosis earlier than CXR(27). However, to our knowledge, no substantial scientific evidence is yet available on whether LUS reliably improves the diagnosis of VAP in PICU.

The primary outcome of this study was to evaluate the LUS performances in the diagnosis of VAP in children patients. The secondary outcomes were to describe the LUS signs of VAP in children; to evaluate the inter-observer agreement of LUS; to determine the local incidence and ecology of VAP and to compare the diagnostic delay of VAP by LUS and by the CDC criteria.

## **Materials and methods**

### *Study design and setting*

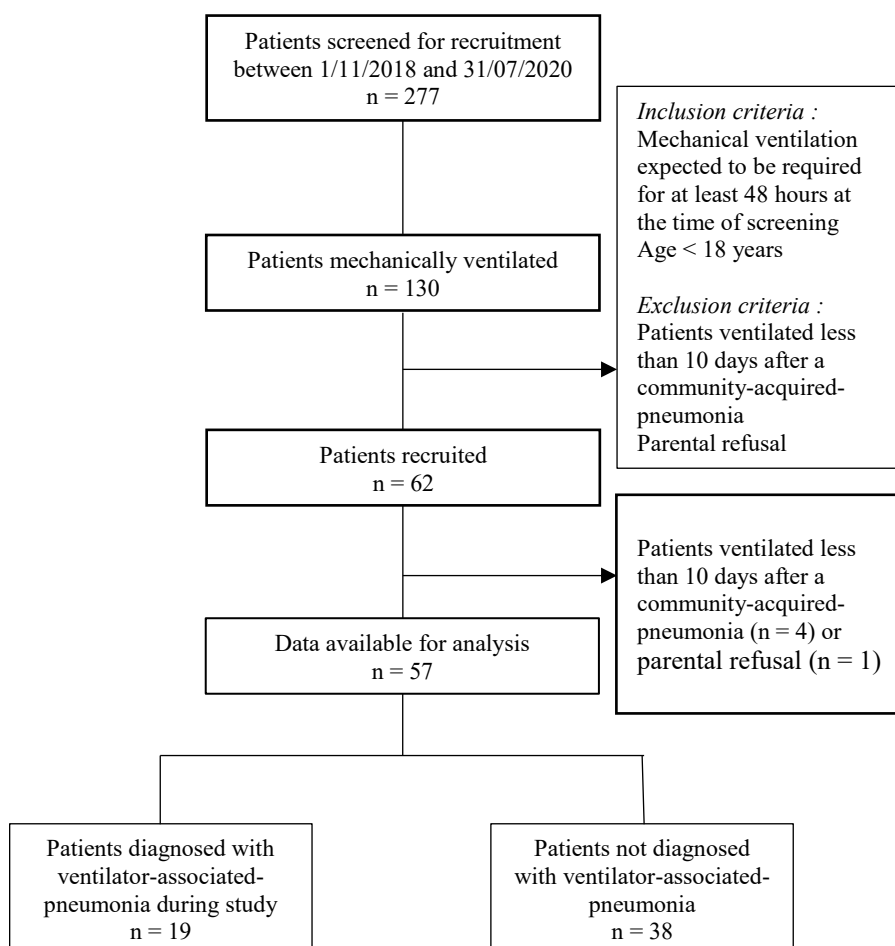
This single-center observational study prospectively involved mechanically ventilated children admitted in our mixed PICU (post-surgical and medicine) between November 1, 2018 and July 31,2020. Our PICU is located in a tertiary care university hospital in the North of La Réunion island (French overseas department in the Indian Ocean). It is a 5-bed multidisciplinary care unit.

### *Participants*

All the patients from birth up to 18 years old admitted in our unit, and mechanically ventilated for more than 48 hours (oro-tracheal or naso-tracheal intubation or tracheotomy) were included. The patients were discharged from the study on the day of diagnosis of VAP or, in the absence of VAP, 48 hours after extubation. Data of patients with CAP at intubation were analysed after healing (10 days after pneumonia diagnosis).

Sixty-two patients were ventilated more than 48 hours. Four patients were excluded because they had a CAP and were ventilated less than 10 days after diagnosis. One patient was excluded due to parent refusal. As a result, a total of 57 patients were prospectively included (Figure 7).

**Figure 7:** Flow-chart



### Data collection

Data collected during the PICU stay concerned demographic information, underlying illness, patient severity (with Pediatric Risk of Mortality scores (PRISM II) (28), and PEdiatric Logistic Organ Dysfunction score (PELOD-2) at discharge (29)), PICU length of stay, duration of mechanical ventilation, and mortality. Data on risk factors such as enteral feeding, proton pump inhibitors and corticosteroids use, curarization, number of re-intubation, supine positioning and presence of endotracheal cuff pressure were collected (13)(8).

We used as gold-standard of VAP diagnosis a clinical and radiologic score, according to criteria established by CDC score 2018. Clinical scores were calculated daily by the medical

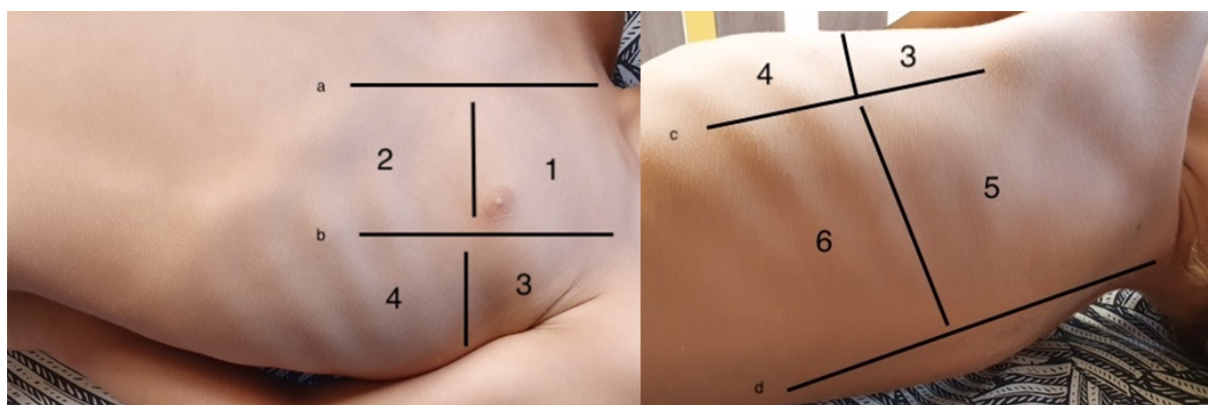


team caring for the patient until 48 hours after extubation. A frontal CXR was performed when clinical criteria were present. Chest X-ray were interpreted by an expert paediatric radiologist from the University Hospital of the PICU to confirm the VAP diagnosis. Respiratory cultures, as bronchoalveolar lavage (BAL), protected specimen brush (PSB) or endotracheal aspirate (ETA), were obtained by the clinical team caring for the patient and analysed in our bacteriology laboratory. Threshold values for cultured specimens were  $\geq 10^3$  colony-forming units (CFU) per milliliter (mL) for PSB,  $\geq 10^4$  CFU/mL for BAL and  $\geq 10^5$  CFU/mL for ETA(30).

Prior to the study, all physicians had the same training in LUS, including reminders about the terminology used in the study during one hour. LUS was performed daily by a member of the medical team (residents or senior doctors) using a linear probe, L-15 or L-12 according to the patient's size (respective frequency range 7-15MHz; 3-12MHz) with a commercial bedside ultrasound system (CX50 POC system Philips Ultrasounds, Andover, USA).

Each hemithorax was divided in 3 areas between the anterior and the posterior axillary lines: anterior, lateral and posterior (Figure 8). Each area was divided into superior and inferior halves. Six zones were studied for each of the two lungs. A clip for each view was realized and reviewed retrospectively by one of the investigators blind to the diagnosis of VAP to analyse the LUS performances. To calculate the inter-observer reliability between medical team and investigators, we used all over the clips realized on the 57 patients included.

**Figure 8:** LUS examination areas



a= parasternal line, b= anterior axillary line, c= posterior axillary line, d= paravertebral line, 1= antero-superior area, 2= antero-inferior area, 3= latero-superior area, 4= latero-inferior area, 5=postero-superior area 6= postero-inferior area

Five LUS signs were collected: air bronchogram (DAB), sub-pleural consolidation (SPC)  $\geq 2$  per area(26), lung consolidation (CS) without DAB, B-lines (BL)  $\geq 3$  per area(19) and pleural effusion (PE).

### *Statistical analyses*

Qualitative variables were expressed as numbers and percentages, and quantitative variables were expressed as medians [Q1-Q3]. VAP/no VAP patients were compared using the Pearson's chi-squared test or the Fisher exact test for categorical variables, and the Student's t-test or the Mann-Whitney U test for quantitative variables as appropriate, respectively. The significance level was set to 5%. VAP incidence was expressed as the number of VAP infections per 1000 mechanical ventilator days. Sensitivity, specificity, positive/negative predictive value were calculated for each LUS sign with and without CDC criteria. Statistical uncertainty was indicated by reporting [95% Confidence Intervals]. Inter-observer agreement was based on the analysis of the two independent series of measurement. Reproducibility was evaluated by Cohens's kappa coefficient. All analyses were performed using Stata V13 software (StataCorp LP, College Station, TX).

### *Ethics statement*

This study was approved by the "Comité de Protection des Personnes Sud Méditerranée III" (number 2019.07.02 bis\_ 19.05.15.40407). The data were collected, recorded and stored after having informed and obtained written consent from a parent or legal guardian for each participant.

## **Results**

Population characteristics are detailed in Table 1. Age at intubation was 8 [2.7-34.1] months, respiratory failure was the main reason for hospitalization (61,4%). The length of intubation was 14 [9-20] days and the length of stay in PICU was 26 [17-47] days, 7 patients died during the PICU hospitalization.

The LUS performances in patients with VAP are summarized in Table 2. The presence of both signs (DAB and SPC) was highly specific (95.9 [92.9-97.8] %). B-lines had the best sensitivity (100 [79.4-100] %) and the best negative predictive value (NPV) (100 [86.8-100] %) and DAB (94.1 [90.8-96.5] %) the best specificity.

**Table 1** : Patients' main clinical characteristics

	<b>Total population<sup>a</sup> (n=57)</b>	<b>VAP<sup>a</sup> (n=19)</b>	<b>no VAP<sup>a</sup> (n=38)</b>	<b>p<sup>b</sup></b>
<b>Sex</b>				<b>0.001</b>
Female	25 (43.9)	14 (73.7)	11 (29.0)	
Male	32 (56.1)	5 (26.3)	27 (71.1)	
<b>Age at intubation (months)</b>	8.0 [2.7-34.1]	8.7 [3.6-128.1]	7.8 [2.1-29.3]	<b>0.015</b>
<b>Age categories</b>				0.47
New-born [0-1months]	8 (14.0)	2 (10.5)	6 (15.8)	
Infant [1month – 2years]	31 (54.4)	9 (47.4)	22 (57.9)	
Child [2 - 18years]	18 (31.6)	8 (42.1)	10 (26.3)	
<b>Weight (kg)</b>	13.2 [4.2-17]	6.5 [4.2-27]	5.35 [4.2-13]	0.536
<b>Chronic pathology</b>				
Pulmonary	18 (31.5)	6 (31.6)	12 (31.6)	1
Cardiovascular	18 (31.5)	6 (31.6)	12(31.6)	1
Neurological	15(26.3)	5 (26.3)	10(26.3)	1
Immunosuppressed	2 (3.5)	0	2 (5.3)	0.548
<b>Reason for hospitalization</b>				
Cardio-vascular	14(24.6)	4(21.1)	10(26.3)	0.754
Respiratory	35(61.4)	12(63.2)	23(60.5)	0.847
Neurological	8(14.0)	5(26.3)	3(7.9)	0.102
Other	14(24.5)	4(21)	10(26.3)	0.754
<b>PRISM</b>	17.5 [11-25]	22 [16-30]	14 [11-22]	0.051
<b>PELOD</b>	20.5 [10.5-31]	21 [20-32]	20 [10-31]	0.308
<b>PICU entry mode</b>				0.65
Domicile/Emergencies	7 (12)	3 (15.8)	4 (10.5)	
Medical evacuation	23 (40.6)	7 (36.8)	16 (42.1)	
Operating room	10 (17.5)	2 (10.5)	8 (21.1)	
Other service	17 (29.8)	7 (36.8)	10 (26.3)	
<b>Community-acquired-pneumonia</b>	21(36.8)	5(26.3)	16(42.1)	0.244
<b>Length of intubation (days)</b>	14 [9-20]	19 [11-35]	12 [7-17]	0.08
<b>Endotracheal tube cuff</b>	43 (75.4)	15 (79.0)	28 (73.7)	0.754
<b>Reintubation</b>	20 (35)	6(31.6)	14(36.8)	0.695
<b>Type of mechanical ventilation</b>				0.758
Oro-tracheal	37 (64.9)	13 (68.4)	24 (63.2)	
Naso-tracheal	16 (28.1)	6 (31.6)	10 (26.3)	
Tracheotomy	2 (3.5)	0	2 (5.3)	
<b>Non-invasive ventilation before intubation</b>	27 (47.4)	11 (57.9)	16 (42.1)	0.26
<b>ARDS</b>	23 (41.1)	10 (55.6)	13 (34.2)	0.129
<b>Pulmonary hypertension</b>	20 (35.1)	9 (47.4)	11 (29.0)	0.17
<b>Extra-corporal membrane oxygenation</b>	11 (19.3)	5 (26.3)	6 (15.8)	0.478
<b>Supine positioning</b>	48 (84.2)	16 (84.2)	32 (84.2)	1
<b>Proton pump inhibitors</b>	19 (33.3)	9 (47.4)	10 (26.3)	0.112
<b>Enteral feeding</b>	52 (98.9)	19 (100)	33 (89.2)	0.288
<b>Corticosteroids</b>	36 (63.2)	13 (68.4)	23 (60.5)	0.56
<b>Neuromuscular blocking agents</b>	44 (77.2)	18 (94.7)	26 (68.4)	<b>0.042</b>
<b>PICU length of hospitalisation (days)</b>	26 (17-47)	28(19-54)	23 (12-47)	0.445
<b>Mortality in PICU</b>	7 (12.3)	3 (15.8)	4 (10.5)	0.675

<sup>a</sup>Data are presented as number (%) or median (interquartile range).

<sup>b</sup>VAP/no VAP were compared using the Pearson's chi-squared test of the Fisher exact test for categorical variables, and the Students's t-test or the Mann-Whitney U test for quantitative variables as appropriate, respectively. VAP = ventilator-associated-pneumonia, PRISM II = PICU admission Pediatric Risk of Mortality scores II, PELOD-2 = PEdiatric Logistic Organ Dysfunction score 2, PICU = pediatric intensive care unit, ARDS = acute respiratory distress syndrome.

For the diagnosis of VAP with the association of LUS and clinical criteria by the CDC score, DAB had a positive predictive value (PPV) of 80 [28.4-99.5] %, a NPV of 96 [93.1-97.9] %. B-lines had a sensitivity of 100 [79.4-100] % and a specificity of 95.5 [92.4-97.6] %.

**Table 2:** Lung ultrasound performances in the diagnosis of ventilator-associated-pneumonia

	Sensitivity <sup>a</sup>	Specificity <sup>a</sup>	PPV <sup>a</sup>	NPV <sup>a</sup>	Correctly classified <sup>a</sup>
DAB	25 [7.3-52.4]	94.1 [90.8-96.5]	19 [5.4-41.9]	95.8 [92.8-97.8]	90.5 [86.7-93.6]
cCDC + DAB	25 [7.3-52.4]	99.7 [98.1-100]	80 [28.4-99.5]	96 [93.1-97.9]	95.7 [92.8-97.7]
SPC	50 [24.7-75.3]	35.2 [29.7-41]	4.1 [1.8-7.9]	92.7 [86.2-96.8]	35.9 [30.6-41.6]
cCDC + SPC	50 [24.7-75.3]	97.2 [94.6-98.8]	50 [24.7-75.3]	97.2 [94.6-98.8]	94.8 [91.6-97]
DAB + SPC	12.5 [1.6-38.3]	95.9 [92.9-97.8]	14.3 [1.8-42.8]	95.2 [92.1-97.4]	91.5 [87.8-94.4]
cCDC + (DAB + SPC)	12.5 [1.6-38.3]	99.7 [98.1-100]	66.7 [9.4-99.2]	95.4 [92.3-97.4]	95.1 [92-97.2]
BL	100 [79.4-100]	9 [5.9-12.9]	5.7 [3.3-9.1]	100 [86.8-100]	13.7 [10.1-18.1]
cCDC + BL	100 [79.4-100]	95.5 [92.4-97.6]	55.2 [35.7-73.6]	100 [98.7-100]	95.7 [92.8-97.7]
CS	68.8 [41.3-89]	44.5 [38.7-50.4]	6.4 [3.2-11.2]	96.3 [91.5-98.8]	45.8 [40.1-51.5]
cCDC + CS	68.8 [41.3-89]	97.6 [95.1-99]	61.1 [35.7-82.7]	98.3 [96-99.4]	96.1 [93.2-98]
PE	37.5 [15.2-64.6]	84.1 [79.4-88.1]	11.5 [4.4-23.4]	96.1 [92.9-98.1]	81.7 [76.9-85.9]
cCDC + PE	37.5 [15.2-64.6]	97.9 [95.5-99.2]	50 [21.1-78.9]	96.6 [93.8-98.4]	94.8 [91.6-97]

<sup>a</sup>Data are given as % and 95% confidence intervals. PPV = predictive positive value, NPV = negative predictive value, cCDC = clinical CDC score, DAB = consolidation with dynamic air bronchogram, SPC = sub-pleural consolidation, BL = B-lines, CS = consolidation without dynamic air bronchogram, PE = pleural effusion.

The diagnostic performances of the combination of LUS and the clinical diagnosis of VAP by CDC score with microbiological confirmation are depicted in Table 3. For the diagnostic of VAP, DAB had 50 [15.7-84.3] % sensitivity. The simultaneous presence of DAB and SPC produced 66.7 [9.4-99.2] % of PPV and 98 [95.7-99.3] % of NPV.

**Table 3:** Lung ultrasound performances in the diagnosis of ventilator-associated-pneumonia with microbiologic confirmation

	Sensitivity <sup>a</sup>	Specificity <sup>a</sup>	PPV <sup>a</sup>	NPV <sup>a</sup>	Correctly classified <sup>a</sup>
DAB	50 [15.7-84.3]	94.3 [91-96.6]	19 [5.4-41.9]	98.6 [96.4-99.6]	93.1 [89.7-95.7]
cCDC + DAB	50 [15.7-84.3]	99.7 [98.1-100]	80 [28.4-99.5]	98.7 [96.6-99.6]	98.4 [96.2-99.5]
SPC	50 [15.7-84.3]	35.6 [30.1-41.3]	2 [0.6-5.1]	96.4 [91-99]	35.9 [30.6-41.6]
cCDC + SPC	50 [15.7-84.3]	96 [93-97.9]	25 [7.3-52.4]	98.6 [96.5-99.6]	94.8 [91.6-97]
DAB + SPC	25 [3.2-65.1]	96 [93.1-97.9]	14.3 [1.8-42.8]	97.9 [95.6-99.2]	94.1 [90.9-96.5]
cCDC + (DAB + SPC)	25 [3.2-65.1]	99.7 [98.1-100]	66.7 [9.4-99.2]	98 [95.7-99.3]	97.7 [95.3-99.1]
BL	100 [63.1-100]	8.7 [5.8-12.5]	2.9 [1.2-5.6]	100 [86.8-100]	11.1 [7.8-15.2]
cCDC + BL	100 [63.1-100]	92.9 [89.4-95.6]	27.6 [12.7-47.2]	100 [98.7-100]	93.1 [89.7-95.7]
CS	50 [15.7-84.3]	43.6 [37.9-49.5]	2.3 [0.6-5.8]	97 [92.5-99.2]	43.8 [38.2-49.6]
cCDC + CS	50 [15.7-84.3]	95.3 [92.2-97.4]	22.2 [6.4-47.6]	98.6 [96.4-99.6]	94.1 [90.8-96.5]
PE	37.5 [8.5-75.5]	83.6 [78.9-87.6]	5.8 [1.2-15.9]	98 [95.5-99.4]	82.4 [77.6-86.5]
cCDC + PE	37.5 [8.5-75.5]	97 [94.3-98.6]	25 [5.5-57.2]	98.3 [96.1-99.4]	95.4 [92.4-97.5]

<sup>a</sup>Data are given as % and 95% confidence intervals. PPV = predictive positive value, NPV = negative predictive value, cCDC = clinical CDC score, DAB = consolidation with dynamic air bronchogram, SPC = sub-pleural consolidation, BL = B-lines, CS = consolidation without dynamic air bronchogram, PE = pleural effusion.

Three patients did not have a LUS on the day of VAP diagnosis. Among the 16 patients with LUS on the day of VAP diagnosis, 16 had BL, 11 had CS without DAB, 8 had SPC, 6 had PE and 4 had DAB.

Concerning inter-observer reproducibility for LUS signs, a low agreement between operators was found for DAB ( $\kappa = 0.4$ ,  $p < 0.001$ ) and for CSP ( $\kappa = 0.3$ ,  $p = 0.002$ ). A moderate agreement was observed for BL ( $\kappa = 0.5$ ,  $p < 0.001$ ), for CS ( $\kappa = 0.52$ ,  $p < 0.001$ ) and for pleural effusion ( $\kappa = 0.48$ ,  $p < 0.001$ ).

Nineteen (33%) patients had a VAP diagnosed with clinical and radiological CDC score 2018 positive. The incidence of VAP was 18 [10.8-28.1] /1000 days of ventilation. Median time between intubation and diagnosis of VAP by CDC score was 9 [4-14] days. Twenty-six percent (5/19) were early VAP ( $< 5$  days), 74% (14/19) were late VAP ( $\geq 5$  days).

Nine out of 19 (47%) patients had a bacteriological confirmation with the CDC 2018 criteria. Three patients had a positive ETA but at an insignificant rate ( $10^4$  CFU/mL). The most frequent bacteriological sampling was ETA (19/20 samples), one patient had a BAL. None had PSB. The most common organism isolated was *Pseudomonas aeruginosa* (3 (15%) patients). *Haemophilus influenzae* and *Klebsiella pneumoniae* were each isolated in 2 (10%) patients. *Staphylococcus aureus*, *Enterobacter cloacae*, *Stenotrophomonas maltophilia* and *Rhinovirus* were each found in 5% of patient. Two ETAs were positive for multiple pathogens.

Concerning the diagnosis delay by LUS, 5/11 patients had SPC and 0/11 had a DAB the day-before VAP diagnosis by the gold-standard.

## **Discussion**

### *Lung ultrasound signs of VAP*

To our knowledge, it is the first study dealing with the LUS diagnosis of VAP in the pediatric population.

The results of this study suggested that DAB was the most accurate sonographic signs for VAP diagnosis in suspected patients. In the literature, DAB is the most specific sign of VAP

in adults(24), as confirmed in our results with a specificity of 94.1 [90.8-96.5] %). However, DAB sensitivity in this case was 25 [7.3-52.4] % which is lower than in previous studies(31). In a prospective study, with the performance of LUS during 5 successive days beginning the first day of intubation, Berlet and *al* (31) found a sensitivity of 92% and a specificity of 65% for DAB or fluid bronchogram. In their study, they did not use radiological diagnostic criteria. In another prospective multicentre study (Italy, France, Canada), Mongodi and *al* (26) analysed 99 adult patients (63 with and 36 without VAP) with a clinical and radiological diagnosis of VAP. In these circumstances, DAB sensitivity was 44% and DAB specificity was 81%. For SPC, sensitivity was 81% and specificity 41%. The specificity was better when sonographic signs were present in different zones (97% for DAB and 56% for SPC). With SPC and DAB combined, PPV was 86%, for which our results showed 14.3 [1.8-42.8] % (26). Berlet and *al* did not use SPC as a sign of VAP because they would have been very common in anterior and lateral areas(31), even if they obtained 81% specificity and 41% sensibility.

Consolidations with static air bronchogram show a loss of pulmonary aeration and may be caused by other etiologies such as atelectasis (32). In our study, CS was a sensitive sign (68.8 [41.3-89] %), but with limited PPV (6.4 [3.5-12] %). B-lines were very common (specificity of 9 [5.9-12.9] %) in intubated patients but combined with clinical CDC criteria (cCDC), they became very specific (95.5 [92.4-97.6] %) for VAP, but the PPV remained moderate (55.2 [35.7-73.6] %). In the literature, BL are rarely included in a diagnostic score, as they are frequently found in both VAP group and non-VAP group(25). In our study, BL were also the most frequent sign found in the day of the clinical and radiological diagnosis of VAP (100% of VAP) before CS (68%).

### *Lung ultrasound scores*

Many non-infectious processes may cause fever and pulmonary infiltration in patients with mechanical ventilatory support, symptoms of VAP are nonspecific (16)(33). Although VAP are a major cause of morbimortality in PICU, the diagnosis is difficult because there is no universally validated score (14). The score most commonly used when writing the protocol, the CDC 2018, has drawbacks, particularly the diagnostic performance of the CXR (34). Levinsky and *al*, studied the inter-observer reproducibility in diagnosis of CAP with CXR. There was a poor interobserver agreement, especially among residents, which may impact major clinical decisions. There is a need to systematically train physicians in CXRs reading (35).

However, there is no diagnostic score including LUS in children presently. In this study, the combined use of cCDC and LUS was more accurate than LUS alone for the diagnosis of

VAP. We showed this in particular for the BL and for the SPC, with an improvement in specificity from 9 to 100% and 35 to 97% respectively. Although its sensitivity was low, DAB coupled with cCDC score had excellent PPV and PNV as well as a specificity close to 100%. Moreover, when microbiological confirmation was additionally performed, the sensitivity of DAB increased by 50 [15.7-84.3] % to 25 [7.3-52.4] %.

In neonatal intensive care unit (NICU), Tusor and *al* (25) used a predictive score including temperature, change in pulmonary secretions, respiratory deterioration, LUS results (consolidation > 0.5cm, pleural effusion, DAB) and results of microbiological sampling on the third day of the infection. It was compared with VAP defined by the “NICU Lucerne score” including clinical criteria, CXR and CRP(36). The new score including LUS had a better sensitivity on first day than the score coupled with the CXR (94% versus 81%).

Several adult studies have suggested combined scores because they have a better accuracy for VAP diagnosis than LUS alone(24)(37). Zagli and *al* (38) created a new score based on Procalcitonin, called chest echography and pulmonary infection Score (CEPPIS) and they had an 80% sensitivity and an 85% specificity. CEPPIS was better in predicting VAP than clinical pulmonary infection score (CPIS) (sensitivity 39.8% and specificity 83.3%). Moreover, Haliloglu and *al* studied their score called the lung ultrasound and pentraxin-3 pulmonary infection score (LUPPIS) including temperature, pentatrix-3, pa02/fi02, tracheal secretions, LUS score (2 areas SPC or 1 with DAB) and tracheal culture. Sensitivity and specificity were better for LUPPIS ( 87.5% and 91.3% respectively) than CPIS (43.8% and 82.6%) (37). Finally, by including the Gram reading in the ultrasound score, Mongodi and *al* obtained a specificity of 97% without waiting for the microbiological culture (26).

#### *Inter-observer agreement*

This current practice study demonstrated operator-dependant variability. DAB had low reproducibility but also low prevalence. The CS had the best inter-observer agreement. It concurs with the meta-analysis of Tsou and *al* (39) which studies the accuracy of LUS diagnosis performed by advanced and novice sonographers for CAP. More experienced sonographers had a better diagnosis accuracy. The literature obtains better results when interpretations are made by experts or well-trained physicians(40). Tusor and *al* found an excellent inter-agreement of 0.89 (95% CI 0.8-0.95) in LUS scoring, the only disagreement was identifying DAB(25). Additional training is required to improve performance, especially for residents who were largely involved in the first interpretation (41).

## *Incidence*

Our rate of pneumonia was 33% and the incidence was 18,0 [10.8-28.1] /1000 days of ventilation. These results are close to the data for developing countries, like India or Egypt(3). Staub and *al's* meta-analysis on the ultrasound diagnosis of adult VAP also found high prevalence (38% to 64%)(24). Although on the same territory, we have a higher incidence than a similar study carried out in adult intensive care unit (ICU) in Saint Pierre, in 2015(27). VAP incidence was 13%, diagnosed with CPIS score. Faced with this high local incidence, we need to improve the “VAP Bundles” of our PICU, which have proven to be effective (42). It includes for example, hand hygiene, head elevation from 30 to 45°, continuous control of tracheal cuff pressure(43), daily evaluation of sedation and no change of the ventilation circuits if not necessary (42).

## *Local ecology*

Concerning the local ecology of VAP, we found the same data as in the literature (3)(44). The majority of the infections were caused by gram-negative. Main pathogen was *Pseudomonas aeruginosa*. They are mainly isolated in late-onset lung disease, unlike *Haemophilus influenzae*, which is more common in early-onset lung disease(44). A retrospective study conducted in our department between 2015 and 2018 found the same distribution. The proportion of gram-positive *cocci* infections, mainly *Staphylococcus aureus*, is higher in Europe and the USA. According to the literature, the rate of viral VAP would be underestimated(44).

## *Limitations*

Our study presented several limitations. The main limitations of our cohort were its relatively small sample size and a low number of VAP analysed. As a result, it was not possible to undertake multivariate analysis adjusting for cofounders. In some cases, we met difficulties to perform LUS, mainly due to the presence of pleural or pericardial drain, sternotomy dressing, study of posterior zones with ECMO, ventilation with high frequency oscillation. LUS was not available in every VAP episode, depending on workload and available medical staff. For consolidations, recruitment manoeuvre, although a dynamic and important element to explore further, was not attempted

Some authors decided to exclude CAP at admission (24). According to the CDC, the CAP had a 7-day infection window period, so we chose to include 10 days after their diagnosis(45). But, LUS signs may persist 14 days after diagnosis(46). Therefore, the



performance of LUS for the diagnosis of VAP may be lower in our study, but not including patients with CAP on admission would not have reflected current practice.

Therefore, substituting LUS for CXR in diagnosis of VAP needs to be explored further with larger studies.

## **Conclusion**

In summary, LUS is an accurate lung-imaging tool to assist VAP diagnosis. Combining ultrasound signs with clinical and microbiological data provides even greater accuracy. Multicenter studies with larger population need to be performed in order to create and validate a predictive VAP score including LUS in PICU.

## **Acknowledgments**

We are grateful for all families and staff on the PICU at Saint Denis University Hospital for supporting the project. Thanks to V.Kyulavki, I. El Ghernougui and A.Burtz for their editorial help.

## **Conflict of interest statement**

All authors have disclosed that they do not have any conflicts of interest.

# Discussion

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The CDC introduced a new algorithm for the surveillance of VAP in 2013, with a pediatric definition in 2015: the Pediatric ventilator-associated-event (Ped-VAE). It includes the positive end-expiratory pressure (PEEP) and the fraction of inspired oxygen (FiO<sub>2</sub>). Thus, the Ped-VAE exclude potentially subjective interpretations of radiographic or clinical findings. According to Peña-Lopez and *al*, the Ped-VAE algorithm had more accuracy in predicting outcomes by characterizing lower oxygenation changes and identifying hypoxaemia severity, a major driver of management (47). But Cirulis and *al* showed that adult VAE criteria with modified pediatric criteria, had good specificity (99%), but low sensitivity (46%) compared to CDC score 2015 in a population of pediatric traumatic brain injury patients(48). Implemented in current form, the VAE criteria would miss a large number of VAP diagnoses, which may result in higher PICU morbidity and mortality (49).

However, there is no diagnostic score including LUS in children presently. In this study, the combined use of cCDC and LUS was more accurate than LUS alone for the diagnosis of VAP. We showed this in particular for the BL and for the SPC, with an improvement in specificity from 9 to 100% and 35 to 97% respectively. Although its sensitivity was low, consolidations with DAB coupled with CDC score had excellent positive and negative predictive values as well as a specificity close to 100%. Moreover, when microbiological confirmation was additionally performed, the sensitivity of DAB rises to 50 [15.7-84.3] % versus 25 [7.3-52.4] %.

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Concerning bacteriological samples, endotracheal cultures are sensitive but not specific(50) and this was the most used technique in our study (19/20 samplings). Positive bacterial cultures of tracheal aspirates increase rapidly after intubation and usually include bacteria considered to be pathogens. Tracheal aspirate cultures do not appear to distinguish between infection and colonization(51). It is rather recommended to carry out protected specimen brush(52). It does not require bronchoscopic technique. Sixteen percent (3/19) of our patients were not on antibiotic therapy when VAP was diagnosed. Three patients with VAP had a bacteremia but not with the same pathogen. Twenty (35%) patients had bacterial resistance, of which 26% (15/57) a multi-resistant-bacteria, 2% (1/57) a methicillin-resistant staphylococcus, and 7% (4/57) an extended-spectrum beta-lactamase. Two ETA were positive to multi-resistant bacteria, *Enterobacter cloacae complex* and *Klebsiella pneumoniae*. They produced extended-spectrum-beta-lactamase.

### *Risk factors of VAP*

About associated-factors of VAP (Table 1), we were surprised to see that length of hospitalisation, duration of intubation and mortality were not associated with VAP, contrary to the literature(3).

The only significant differences between the two groups occurred in three parameters: the use of curares is more frequent in the VAP group (94,7% versus 68,4%;  $p = .042$ ), age ( $p = .015$ ) and sex ( $p = .001$ ). The length of curarization was 11 days [4-16]. Continuous sedation is a risk factor for VAP as it increases the duration of intubation, a paediatric study of 93 patients

in 2012 also defined it as such(30). Reassessing the situation daily is recommended by many organisations(53)(54)(42)(1).The use of nursing protocols known as "Daily sedation interruption" is a reversal of usual sedation practices (55)(6) but it is not used in our PICU.

In contrast of our study, using an endotracheal tube cuff would protect against VAP thanks to a reduction in the passage of secretions in the respiratory tract(1). Genovap recommends a pressure higher than 25cmH<sub>2</sub>O(53). Nesir *and al* noted a decrease in digestive micro-aspirations in the lungs during continuous monitoring of the balloon pressure and a reduction in the number of VAP without an increase in tracheal ischaemia(43). It is recommended in Europe to monitor the pressure at least each 24 hours (42).

We did not find proton pump inhibitors as risk factors for VAP. The SRLF (Société de réanimation en langue française) does not recommend its systematic use(54). The combination of anti-ulcer drugs and enteral nutrition would increase the risk of pneumopathy and death(56).

Length of enteral feeding was 15 [7-27] days and not associated with VAP event. In the literature, opinions are contrasted. It is recommended, in particular by the SRLF, based in particular on the meta-analysis of Doig *and al*, which shows a reduction in mortality and the incidence of VAP thanks to the early introduction of enteral nutrition(57). However, an absence of superiority and inferiority of early versus late enteral nutrition was noted in a 2017 meta-analysis by Reintam *and al*.

None of the patients with a tracheostomy had VAP (p=0,085). Five patients were tracheotomized during the mechanical ventilation. The various authors disagree on its role as a protective factor(58)(59)(60). According to Pena-Lopez *and al*, tracheotomized children are more at risk of VAP, but the effect of preventive measures has a better impact on them.

Supine body position is a risk factor of VAP, but we could not find it. A study published in "Lancet" in 1999 shows that a VAP incidence had a rate of 5% in the "semi-seated" group compared to 23% in the supine group, with a risk of 50% for patients in the supine position with enteral nutrition(61). However, difficulties in maintaining the supine body position at 45° exist(62), it must be higher than 30° to have a reduction in the number of VAP. Frequency of controls are recommended at 3 times a day(53).

## *Limitations*

Our study presented several limitations. The main limitations of our cohort were its relatively small sample size and a low number of VAP analysed. As a result, it was not possible to undertake multivariate analysis adjusting for cofounders. In some cases, we met difficulties to perform LUS, mainly due to the presence of pleural or pericardial drain, sternotomy dressing, study of posterior zones with ECMO, ventilation with high frequency oscillation. LUS was not available in every VAP episode, depending on workload and available medical staff. For consolidations, recruitment manoeuvre, although a dynamic and important element to explore further, was not attempted

Some authors decided to exclude CAP at admission (24). According to the CDC, the CAP had a 7-day infection window period, so we chose to include 10 days after their diagnosis(45). But, LUS signs may persist 14 days after diagnosis(46). Therefore, the performance of LUS for the diagnosis of VAP may be lower in our study, but not including patients with CAP on admission would not have reflected current practice.

Therefore, substituting LUS for CXR in diagnosis of VAP needs to be explored further with larger studies.

# Conclusion

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In summary, LUS is an accurate lung-imaging tool to assist VAP diagnosis. The results of this study suggested that consolidations with dynamic air bronchogram were the most accurate signs for VAP diagnosis in suspected patients. Combining ultrasound signs with clinical and microbiological data provides greater accuracy. The inter-observer reproducibility of the different parameters is average and requires a longer training of the physicians. The high incidence of VAP in our population requires the implementation of VAP bundles. Multicenter studies with larger population need to be performed in order to validate a predictive VAP score including LUS in PICU.



# Serment d'Hippocrate

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“Au moment d’être admise à exercer la médecine, je promets et je jure d’être fidèle aux lois de l’honneur et de la probité.

Mon premier souci sera de rétablir, de préserver ou de promouvoir la santé dans tous ses éléments, physiques et mentaux, individuels et sociaux.

Je respecterai toutes les personnes, leur autonomie et leur volonté, sans aucune discrimination selon leur état ou leurs convictions. J’interviendrai pour les protéger si elles sont affaiblies, vulnérables ou menacées dans leur intégrité ou leur dignité. Même sous la contrainte, je ne ferai pas usage de mes connaissances contre les lois de l’humanité.

J’informerai les patients des décisions envisagées, de leurs raisons et de leurs conséquences. Je ne tromperai jamais leur confiance et n’exploiterai pas le pouvoir hérité des circonstances pour forcer les consciences.

Je donnerai mes soins à l’indigent et à quiconque me les demandera. Je ne me laisserai pas influencer par la soif du gain ou la recherche de la gloire.

Admise dans l’intimité des personnes, je tairai les secrets qui me seront confiés. Reçue à l’intérieur des maisons, je respecterai les secrets des foyers et ma conduite ne servira pas à corrompre les mœurs.

Je ferai tout pour soulager les souffrances. Je ne prolongerai pas abusivement les agonies. Je ne provoquerai jamais la mort délibérément.

Je préserverai l’indépendance nécessaire à l’accomplissement de ma mission. Je n’entreprendrai rien qui dépasse mes compétences. Je les entretiendrai et les perfectionnerai pour assurer au mieux les services qui me seront demandés.

J’apporterai mon aide à mes confrères ainsi qu’à leurs familles dans l’adversité.

Que les hommes et mes confrères m’accordent leur estime si je suis fidèle à mes promesses ; que je sois déshonorée et méprisée si j’y manque.”

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**[Diagnostic échographique des pneumopathies acquises sous ventilation mécanique en réanimation pédiatrique]**

Résumé

**Introduction :** Les pneumopathies acquises sous ventilation mécanique (PAVM) sont une cause fréquente d'infection nosocomiale en réanimation pédiatrique avec majoration de la morbi-mortalité. L'échographie pulmonaire (EP) a prouvé son intérêt dans le diagnostic des pneumopathies communautaires de l'enfant et dans les PAVM de d'adulte. L'objectif de cette étude est d'évaluer les performances de l'EP dans le diagnostic des PAVM en réanimation pédiatrique (RP).

**Méthode :** Étude mono-centrique prospective réalisée en RP au CHU Saint Denis à La Réunion. Tout patient mineur admis en RP, ventilé depuis plus de 48 heures entre le 1<sup>er</sup> Novembre 2018 et le 31 Juillet 2020 a été inclus. Une EP a été réalisée quotidiennement et a été comparée au diagnostic de PAVM par le score clinico-radiologique CDC 2018 identifié comme le gold-standard.

**Résultats :** Cinquante-sept patients ont été inclus avec un âge médian de 8 mois. Dix-neuf patients ont développé une PAVM et parmi eux, 9 (47%) ont eu une confirmation microbiologique. L'incidence était de 18,0 [IC 95% 10,8-28,1] PAVM /1000 jours de ventilation. Le signe le plus spécifique était le bronchogramme aérien dynamique (DAB) (94,1 [90.8-96.5] %). La précision diagnostique a été améliorée par l'association de l'EP avec la clinique : le DAB avait respectivement des valeurs prédictives positives et négatives de 80 [28.4-99.5] %, et 96 [93.1-97.9] % et les lignes B, une sensibilité et spécificité de 100 [79.4-100] % et 95.5 [92.4-97.6] %. La présence simultanée de la clinique, de la culture microbiologique et du DAB associée aux consolidations sous-pleurales avait 66,7 [9.2-99.2] % de valeur prédictive positive et 98 [95.7-99.3] % de valeur prédictive négative.

**Conclusion :** Le DAB est le signe échographique le plus performant pour le diagnostic des PAVM de l'enfant associé à un score clinique et à la culture microbiologique.

**Disciplines :** Pédiatrie, réanimation pédiatrique.

**Mots-clés :** Échographie pulmonaire, pneumopathies acquises sous ventilation mécanique, PAVM, réanimation pédiatrique, bronchogramme aérien dynamique.

**[Lung ultrasound in diagnosis of ventilator-associated-pneumonia in pediatric intensive care unit]**

Abstract

**Backgrounds:** Ventilator-associated-pneumonia (VAP) is a leading cause of nosocomial infections in paediatric intensive care unit (PICU) with increased morbidity and mortality, length of intubation and hospitalisation. Lung ultrasound (LUS) has been successfully applied to diagnose community-acquired-pneumonia in children and VAP in adult and neonatal population. The objective was to evaluate LUS performances in the diagnosis of VAP in a PICU.

**Method:** Monocentric, prospective study between November 1, 2018 and July 31, 2020 in a 12-beds PICU in Saint Denis, La Réunion were included all patients under 18 years old that were admitted to the PICU, mechanically ventilated for more than 48 hours. LUS was performed daily and compared to diagnostic of VAP by the center of disease control (CDC) 2018 score identified as the "gold-standard".

**Measurements and main results:** Fifty-seven patients were included. Median age was 8 [2.7-34.1] months. Nineteen (33%) children developed a VAP, among which 9 (47%) had a microbiological confirmation. The incidence of VAP was 18 (95% CI 10.8-28.1) /1000 days of ventilation. For LUS diagnosis, the most accurate sign was the dynamic air bronchogram (DAB) with 94.1 [90.8-96.5] % specificity. Accuracy was improved with the association of LUS and the clinical score: DAB had a positive and negative predictive value of 80 [28.4-99.5] %, and 96 [93.1-97.9] %, respectively, and the B-lines sensitivity and specificity were 100 [79.4-100] % and 95.5 [92.4-97.6] %. The simultaneous presence of clinical criteria of CDC, DAB, sub-pleural consolidations and microbiological confirmation allowed to achieve 66,7 [9.2-99.2] % positive predictive value and 98 [95.7-99.3] % negative predictive value.

**Conclusion:** DAB was the most accurate sonographic sign to diagnose VAP in suspected patients associated with clinical score and microbiology.

**Discipline:** Pediatrics, PICU

**Keywords:** Lung ultrasonography, LUS, echography, ventilated-associated-pneumonia, VAP, PICU