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Use of Lung Ultrasound to predict the effectiveness of Non-invasive ventilation in patients with Acute Hypoxemic Respiratory Failure

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Abstract

Acute hypoxemic respiratory failure (AHRF) is a common cause of ICU admission. Non-invasive mechanical ventilation (NIV) is an important tool in treatment of AHRF. Traditionally lung imaging in critically ill is performed either by bedside chest radiography or computed tomography. Bedside lung ultrasound (LUS) is increasingly used for evaluation of critically ill patients with different lung and pleural pathologies. Our study was designed to determine the role of LUS in predicting success or failure of NIV as a treatment of AHRF due to cardiac etiology. The study was conducted on 50 adult critically ill patients of both gender. LUS was performed just before or at the start of NIV, at 5 minutes, and after 60 minutes of its application. Lung ultrasound reareation score (LUS-ReS) was then calculated through the change of the lung ultrasound pattern at these time intervals. LUS-ReS was then compared to the outcome. The sensitivity and specificity of the LUS-ReS to assess the success of NIV at T_0/T_5, T_5/T_{60} and T_0/T_{60} were 89.66% - 75%, 86.21% - 87.5 %, and 93.1 % - 93.75 % respectively. It provided a useful, available, fast and non-invasive tool in predicting the outcome of NIV as a treatment of AHRF.

Keywords: Chest ultrasonography, lung ultrasound reareation score, non-invasive ventilation, hypoxemic respiratory failure.

Introduction

Respiratory failure is defined as inadequate gas exchange due to malfunction of the respiratory system. Hypoxemic respiratory failure is defined by arterial Oxygen saturation <90% while receiving an inspired Oxygen fraction >0.6 with normal or low PaCO2 (<45 mmHg)(1).Hypoxemia results from ventilation-perfusion mismatch and intrapulmonary shunting resulting from airspace filling or collapse(2).

Non-invasive positive pressure ventilation (NIPPV) is a safe and effective tool to improve gas exchange in selected patients with acute hypoxemic respiratory failure (AHRF) of varied etiology. Early application of NIPPV in AHRF patients (due to cardiogenic pulmonary edema or severe community-acquired pneumonia) who are not yet meeting the criteria for invasive mechanical ventilation is associated with a significant reduction in the morbidity and mortality associated with invasive mechanical ventilation(3-5).

In patients with severe AHRF meeting the criteria for mechanical ventilation via a face mask or an endotracheal tube, mechanical ventilation delivered via a face mask was found to be equally effective to conventional ventilation in improving gas exchange(6, 7).

Outcome predictors are important to identify patients who are less likely to improve with noninvasive ventilation, thus requiring closer observation and a readily available means of intubation[8, 9].

Ultrasound is becoming an essential part of the chest imaging in the ICU as it is portable, has no risk of ionizing radiation, has real-time imaging, and has the ability to perform dynamic imaging. It is relatively cheap and is readily available at the bedside making it easier and faster to get an ultrasound imaging than a chest X-ray[10].

A range of frequencies (4 to 12MHz) can be used to visualize the lungs. High frequencies are useful to look at the periphery of the lung with a high resolution as studying the pleural line and analyzing it. Lower frequencies help with the imaging of deeper lung tissues, e.g.as in cases with lung consolidation[11].

In the supine position, the anterior and lateral lung areas can be easily scanned. Six regions, delineated by the anterior and posterior axillary lines should be systematically examined: upper and lower parts of the anterior, lateral and posterior chest wall [11].

Patients and Methods

Design: a prospective observational study conducted on fifty adult critically ill patients, according to sample size calculation.

Setting: Critical Care Medicine Department of Alexandria Main University Hospital. The study was approved by the medical ethics committee of Alexandria faculty of Medicine. An informed consent from patients' next of kin was taken before enrollment into the study. Included patients were adults with acute hypoxemic respiratory failure due to cardiac origin and are fulfilling the criteria for need of NIPPV application.

Exclusion Criteria:

1. Impaired consciousness or agitated patients.
2. pH < 7.1.
3. Hemodynamic instability (MAP <60 mmHg).
4. Facial surgery, trauma, or deformity.
5. Recent chest trauma or deformity.

Demographic data, past history, clinical examination, preliminary diagnosis, lab investigations, and CXR were all done for the selected patients. Routine ICU monitoring including pulse oximetry and chest ECG leads were done. Lung ultrasound (LUS) was done 3 times for each patient before or just after application of non-invasive ventilation (T_0), after 5 minutes from the start of application of non-invasive ventilation (T_5) and after 60 minutes of its application (T_{60}).

Ultrasound scan was performed in six regions for each hemi-thorax. LUS patterns were defined as: consolidation (C); multiple coalescent B-lines (B+); multiple irregularly spaced B-lines (B) and normal areation (A). A LUS reareation score (ReS) was calculated detecting changes in the US pattern when comparing T_0 to T_5, T_5 to T_{60} and T_0 to T_{60} assessments. Outcome was defined as NIV success or failure requiring invasive ventilation within 6 hours. LUS-ReS were then compared to the outcome to detect its effectiveness in prediction of NIV failure or success.

Data were fed to the computer using IBM SPSS software package version 20.0.Quantitative data were described using mean and standard deviation for normally distributed data. For normally distributed data, comparison between two independent populations were done using independent t-test. ROC analysis was used to predict the sensitivity, specificity and accuracy of the score in predicting mortality.

Results

The study was carried out on both gender, 22 male and 23 female patients. The mean age of the patients was 60.12±1years. Five patients were excluded from the study due to meeting one or more of the termination criteria; (respiratory rate >35 cycle/minute, inability to tolerate the interface, heart rate increasing >30 % from the starting rate or exceeds 150 bpm., new arrhythmias or deterioration of level of consciousness).

The remaining 45 patients were categorized into two groups according to the fate of NIPPV trial. Mean LUS-ReS (SD) at T5 to T60 was -1.75 (± 3.34) in the failure group and 5.55 (± 3.68) in the success group (*P* =<0.001). Mean LUS-ReS (SD) at T0 to T60 was -1.75 (± 3.92) in the failure group and 13.62 (± 4.34) in the success group (*P* =<0.001), (table 1). It was found that there was a significant negative correlation between reareation score and change in heart rate, respiratory rate and mean atrial blood pressure at different periods of follow up (table 2).

Table (1): comparison between LUS-ReS in both studied groups at different time intervals.

Reareation Score	Outcome		p
	Success of NIPPV (n = 29)	Intubation within 6 hours(n = 16)	
$T_{(0/5)}$			
Min. – Max.	2.0 – 19.0	-6.0 – 5.0	<0.001*
Mean ± SD.	8.07 ± 4.11	0.0 ± 3.25	
$T_{(5/60)}$			
Min. – Max.	0.0 – 14.0	-8.0 – 3.0	<0.001*
Mean ± SD.	5.55 ± 3.68	-1.75 ± 3.34	
$T_{(0/60)}$			
Min. – Max.	3.0 – 20.0	-9.0 – 6.0	<0.001*
Mean ± SD.	13.62 ± 4.34	-1.75 ± 3.92	

LUS: lung ultrasound score
NIPPV: non-invasive positive pressure ventilation
$T_{(0/5)}$: comparison of LUS on application of NIPPV and after five minutes
$T_{(5/60)}$:comparison of LUS after five and 60 minutes of application of NIPPV
$T_{(0/60)}$: comparison of LUS on and after 60 minutes of application of NIPPV
p: significant if < 0.05

Table (2): Correlation between LUS-ReSand vital signs in studied patients.

	LUS-ReS	
	r_s	P
Change in heart rate (beats/min)		
$T_{(0/5)}$	-0.325*	0.029
$T_{(5/60)}$	-0.575*	0.001
$T_{(0/60)}$	-0.694*	0.001
Change in respiratory rate (cycles/min)		
$T_{(0/5)}$	-0.376*	0.011
$T_{(5/60)}$	-0.598*	0.001
$T_{(0/60)}$	-0.577*	0.001
Change in MAP (mmHg)		
$T_{(0/5)}$	-0.384*	0.009
$T_{(5/60)}$	-0.625*	0.001
$T_{(0/60)}$	-0.616*	0.001

LUS: lung ultrasound score
NIPPV: non-invasive positive pressure ventilation
$T_{(0/5)}$: comparison of LUS on application of NIPPV and after five minutes
$T_{(5/60)}$:comparison of LUS after five and 60 minutes of application of NIPPV
$T_{(0/60)}$: comparison of LUS on and after 60 minutes of application of NIPPV
MAP: mean arterial blood pressure
p: significant if < 0.05

ROC curves were obtained for the three LUS-ReS at T0 to T5 (AUC 0.942), T5 to T60 (AUC 0.935) and T0 to T60 (AUC 0.991). A LUS-ReS (T0to T5) cut-off value of 3 could predict NIV effectiveness, with a sensitivity of 89.66% and a specificity of 75%.LUS-ReS (T5 to T60) with a cut-off value of 1 could also predict NIV success.LUS-ReS (T0 to T60) at a cut-off value of 3could predict NIV effectiveness, with a sensitivity of 93.1% and a specificity of 93.75% (table 3, Fig. 1).

Table (3): Correlation between LUS-ReS and NIPPV fate.

Reareation Score	AUC	P	95% C.I		Cut off	Sensitivity	Specificity	PPV	NPV
			LL	UL					
T_0/T_5	0.942	<0.001*	0.877	1.0	>3	89.66	75.0	86.7	80.0
T_5/T_{60}	0.935	<0.001*	0.870	1.0	>1	86.21	87.50	92.6	77.8
T_0/T_{60}	0.991	<0.001*	0.974	1.0	>3	93.10	93.75	96.4	88.2

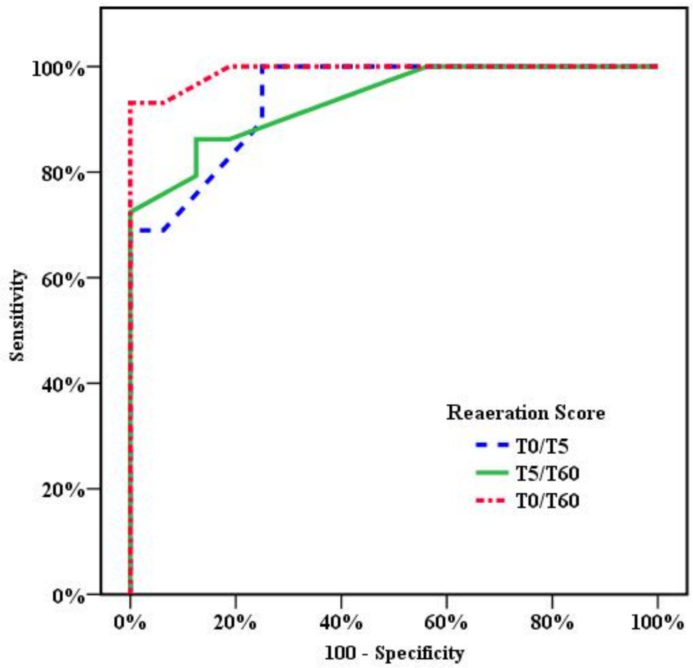

Figure (1): ROC curve for LUS-ReSto predict NIPPV success.

Discussion

Avoidance of invasive ventilation drawbacks in ICU with special attention to high incidence of VAP and heavy sedation was a big concern in the field of critical care medicine. Encouraging application of NIPPV whenever possible is one of the tools to guard against the previously mentioned obstacles in various types of respiratory failure. There is a growing evidence concerning the role of Bedside lung ultrasound (LUS) in critically ill for evaluation of different lung and pleural pathologies. The present study was designed to augment the use of VIPPV in selected cases of AHRF with evaluation of its success using the bedside lung ultrasound as a non-invasive available tool.

Our study was matched with a study published by L.Nobile et al[12].Its aim was to evaluate the lung ultrasound (LUS) reareation score (ReS) as a predictive tool for non-invasive ventilation (NIV) efficacy in general wards for acute respiratory failure (ARF) treatment. Its population number was only sixteen patients of acute hypoxemic respiratory failure.

In the present study there was statistically strong correlation between the LUS ReS and the outcome as patients with high LUS ReS showed better outcome indicating that the LUS ReS is a useful predictive tool for the success or failure of NIV in AHRF patients with cardiac origin. These results were compared with the study published by L.Nobile et al., which showed that LUS ReS T0/T5 AUC was 0.72, LUS ReS T0/T60 AUC 0.83. The cut-off point was 0 with a sensitivity of 91 % and a specificity of 80 % [13].

In our study the mean LUS ReS T0/T5 was 8.07 ± 4.11 in the success group while was 0 ± 3.25 in the failure group with P=<0.001 while in the study of L.Nobile et al. was 2.5 ± 2.5 in the success group and 0 ± 3.1 in the failure group with a p: 0.15[13].

LUS ReS T0/T60 in our study had a mean of 13.62 ± 4.34 in the success group and -1.75 ± 3.92 in the failure group with a p = <0.001while the other study showed LUS ReS mean 4.2 ± 3.4 in the success group and – 1.2 ± 3.9 in the failure group with P = 0.03[13].

Many studies used LUS and reareation score to determine lung recruitment. One of them was the study published by Bouhemad B. et al.[14] in 2011 which was performed on 30 patients and used lung reareation score to estimate PEEP induced lung recruitment in patients with acute respiratory distress syndrome (ARDS) and comparing it with the well known pressure-volume (PV) curve method. The results showed highly significant correlation between the LUS ReS and the PEEP-induced lung recruitment measured by PV curves (Rho = 0.88; P < 0.0001). Also the study revealed statistically significant correlation between LUS ReS and PEEP induced increase in PaO2 (Rho = 0.63; P < 0.05). Caution should be taken as LUS ReS can't detect hyperinflation [14].

Another study was performed also in critical care department in Alexandria main university hospital by Mabrouk et al[15] to use LUS loss of aeration score in 50 mechanically ventilated patients after spontaneous breathing trial (SBT) to predict failure or success of extubation. The conclusion was that LUS can accurately detect areation changes in SBT and detect the outcome with strong relation between loss of areation and failure of weaning (AUC 0.955 , P= <0.001) [15].

Another study was published in 2010 by Bouhemad B. et al[16] for Ultrasound assessment of antibiotic-induced pulmonary reareation in ventilator-associated pneumonia. LUS ReS was compared with CT, CXR before and after 7 days in 30 mechanically ventilated patients to assess improvement of VAP and antibiotic responsiveness. A highly significant correlation was found between computed tomography and ultrasound lung reareation (Rho = 0.85, p < .0001). Chest radiography was inaccurate in predicting lung reareation[16].

Another larger study with similar objectives was performed in our department of critical care in Alexandria main university hospital by El-Moursi Amr et al [17]showed also significant correlation between LUS ReS and CT in assessment of lung reaeration after antibiotic therapy (p=<0.001) [17].

The present study had some limitations; there is no studies documenting what level of professionalism is necessary for a reliable U/S diagnosis, interpretation of US signs is operator dependent unlike that of CXR & CT images, and the difficulty to use thoracic US in obese patients. The outcome in the present study was defined over a short time period as NIPPV success if the patient didn't need intubation after 6 hours of the start of NIPPV treatment.

Conclusion

LUS-ReS could be a useful tool in predicting NIPPV effectiveness for treatment of AHRF secondary to cardiac etiology.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of this paper.

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