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Assessment of Lung Recruitment Maneuvers Using Lung Ultrasound in Comparison with Oxygenation Index in Patients with ARDS

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ABSTRACT

Background: Acute Respiratory Distress Syndrome (ARDS) presents a significant challenge in critical care, with lung recruitment manoeuvres (RMs) being a pivotal treatment strategy. Lung Ultrasound (LUS) and the Oxygenation Index (OI) are two methods used to assess the efficacy of RMs, but their comparative utility remains underexplored.

Objective: To evaluate the role of LUS in the assessment of lung RMs in comparison with OI in mechanically ventilated ARDS patients.

Methods: In a prospective non-randomized interventional study, 48 ARDS patients undergoing mechanical ventilation were divided into two groups: the LUS group (n=27) and the OI group (n=21). LUS was performed using a curvilinear probe, and OI was determined through arterial blood gases analysis.

Results: The LUS group showed a significant improvement in PFR from 99.37 ± 63.96 to 176.07 ± 77.24 ($p<0.05$) after RMs, while the OI group exhibited an increase from 116.29 ± 66.69 to 197.14 ± 76.03 ($p<0.05$). Both groups demonstrated significant increases in lung compliance post-RMs, with no significant difference between them ($p=0.999$ before RMs and $p=0.875$ after RMs). The optimal PEEP was slightly higher in the LUS group (17.78 ± 2.25 cmH_2O) compared to the OI group (17.29 ± 2.22 cmH_2O), though not statistically significant ($p=0.056$).

Conclusion: Both LUS and OI are effective in assessing the efficacy of lung RMs in ARDS patients, with no significant difference in the improvement of peak flow rate (PFR), lung compliance, and optimal PEEP settings. LUS offers a non-invasive and readily available alternative to OI.

Keywords: Lung recruitment manoeuvres, Lung ultrasound, Oxygenation index, Acute respiratory distress syndrome.

INTRODUCTION

Acute respiratory distress syndrome (ARDS) is a critical condition marked by extreme hypoxemia resulting from failure in pulmonary gas exchange, identified initially in the 1960s [1]. ARDS leads to a reduction in functional lung capacity as numerous lung units are poorly aerated or not aerated at all, due to their collapse, fluid accumulation, or consolidation. Despite advancements in treatment, the mortality rate associated with ARDS remains alarmingly high, ranging between 30% and 40% [2].

Lung recruitment manoeuvres (RMs), which involve temporarily increasing lung volume through sustained high airway pressures, along with the implementation of high levels of positive end-expiratory pressure (PEEP) as part of an 'open lung approach,' are recommended to restore lung volume and minimize the repetitive opening and closing of small airways, thus reducing lung strain and the risk of atelectrauma [3, 4].

To assess the effectiveness of PEEP in enhancing pulmonary recruitment, various techniques including computed tomography (CT), static pressure-volume (P-V) curve analysis, and the oxygenation index method are utilized, although each has its limitations [5]. The oxygenation index (OI) integrates the concentration of inspired oxygen, partial pressure of arterial oxygen, and airway pressures to quantify the extent of the shunt effect contributing to arterial hypoxemia and the decline in lung compliance due to alveolar flooding [6]. In contrast, the Lung Ultrasound Score (LUS) provides a non-intrusive, dependable, and easily replicable means of evaluating lung reaeration directly at the patient's bedside [7, 8].

Recent guidelines and expert consensus have underscored the utility of LUS, especially in emergency and intensive care settings [9]. Hence, this study aimed to compare the effectiveness of LUS against OI in evaluating lung RMs among ARDS patients.

PATIENTS AND METHODS

In this prospective, non-randomized, interventional study, we enrolled 48 adult patients of both genders who were receiving mechanical ventilation due to ARDS from September 2022 to December 2023 at Benha University Hospitals.

Exclusion criteria: Individuals younger than 18, those on mechanical ventilation without experiencing lung collapse or the need for lung RMs, those with hemodynamic instability, recent cardiac arrest survivors, pregnant individuals, those with elevated intracranial pressure, and those who had undergone thoracic surgery.

The participants were allocated into two distinct cohorts: Group A, consisted of 27 patients who underwent LUS evaluations using a curved probe, while group B, comprised 21 patients who were assessed using the OI method.

Upon enrolment, we collected comprehensive demographic data (age, gender, weight, height, and BMI) and a full medical history (current health status, smoking habits, cardiac conditions, chronic pulmonary

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diseases, diabetes, hypertension, COPD, and steroid usage). Within the first 24 hours of admission, each patient underwent a thorough clinical examination that included general and targeted chest assessments (notably respiratory rate, oxygen desaturation, and the presence of rales upon auscultation), a complete suite of laboratory tests (CBC, liver and kidney function tests, serum electrolyte levels, arterial blood gases, and C-reactive protein), and radiological imaging (standard chest X-rays, CT scans, and echocardiography), in addition to chest and lung ultrasonography.

Lung Ultrasonography: All patients underwent a baseline LUS immediately after ARDS diagnosis and again during or after lung RMs. This was performed using a curvilinear array 4 to 5 MHz transducer of LOGIQ F8 Expert (GE Medical Systems, China). Examinations were conducted in the supine position with lung presets, covered all intercostal spaces across anterior, lateral, and posterior regions of both lungs. Results, including mechanical ventilation parameters and SaO_2 levels, were documented to quantify changes in lung aeration.

Lung recruitment method: In mechanically ventilated patients with tracheal intubation, lung recruitment was achieved using pressure-controlled ventilation. An arterial line monitored blood pressure and gas levels. Patients received full sedation with propofol or midazolam, and neuromuscular blockers as needed. Positioned supine, the incremental PEEP method was applied, starting with pressure assist/control ventilation at 35 cmH_2O and 100% FiO_2 for 15 minutes, followed by blood gas and lung ultrasound analysis. PEEP was then progressively increased by 5 cmH_2O intervals, assessed through ultrasound and blood gas analysis, until optimal lung recruitment was determined by ultrasound scoring. The final PEEP was set at 2 cmH_2O above the detected closing pressure for continued ventilation.

In Group A (LUS group), LUS scans were initially performed using a curvilinear probe focused on the most atelectatic lung areas. RMs began by identifying the airway pressure level where lung re-aeration patterns (condensation to normal lung imagery) emerged, determining the lung's opening pressure. Following recruitment, a PEEP trial was conducted to ascertain the closing pressure, marked by a transition from normal to B1–B2 patterns and consolidation, setting the final PEEP at 2 cmH_2O above this closing pressure for ongoing ventilation. Conversely, **Group B (oxygenation index group)** systematically increased PEEP from 25 cmH_2O up to 35 cmH_2O in 30-second intervals, followed by decrements of 1 cmH_2O until a drop in PaO_2 was observed. This process was repeated, and PEEP was set at 2 cm H_2O above the identified value to maintain optimal lung recruitment.

Observation index:
Continuous vital and respiratory function monitoring was achieved using the Nihon Kohden Bedside Monitor BSM-3552 for tracking electrocardiogram data, heart rate, blood pressures (systolic, diastolic, and mean arterial), and oxygen saturation levels. Additionally, ventilator parameters such as PEEP, tidal volume, peak and plateau airway pressures, mean airway pressure, and dynamic lung compliance were observed using the ventilator's monitoring system. To assess pulmonary gas exchange, arterial blood samples were analyzed using a GEM Premier 3000 blood gas analyzer, measuring pH, PaO_2, $PaCO_2$, and arterial oxygen saturation to compute the OI.

Ethical considerations: The study was done after being accepted by The Research Ethics Committee, Benha University (Approval Code: Ms 13-9-2022). All patients provided written informed consents prior to their enrolment. The consent form explicitly outlined their agreement to participate in the study and for the publication of data, ensuring protection of their confidentiality and privacy. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical analysis

The statistical evaluation was conducted using SPSS version 28 (IBM Inc., Armonk, NY, USA). For quantitative data, means and standard deviations (SD) were calculated and differences between groups were assessed using the unpaired Student's t-test. Qualitative data were expressed in terms of frequencies and percentages and analyzed using the Chi-square test as needed. A P value $\leq$ 0.05 in a two-tailed test was deemed to indicate statistical significance.

RESULTS

Regarding demographic data (Age and sex), comorbidities (Smoking, HTN, DM, COPD, and steroid) and cause of MV (Hypoxia, resp. distress, hemodynamic instability), laboratory data (Hb, WBCS, urea, creatinine, AST, ALT, and CRP) except platelets differed significantly (P= 0.032) (Table 1).

Table (1): Comparison of the studied groups regarding demographic data, comorbidities, and cause of MV

		Group A (n=27)		Group B (n=21)		P value
Demographic data						
		Mean	**SD**	**Mean**	**SD**	
Age (years)		54.44	12.469	62.71	19.10	0.077
Sex	**Male**	15(55.5%)		12(57.1%)		0.912
	Female	12(44.5%)		9(42.9%)		
Comorbidities						
Smoking		15(55.5%)		12(57.1%)		0.912
HTN		18(66.6%)		15(71.4%)		0.724
DM		15(55.5%)		9(42.8%)		0.383
COPD		12(44.5%)		9(42.8%)		0.912
Steroid		17(62.9%)		9(42.8%)		0.165
Cause of MV						
Hypoxia		16(59.3%)		9(42.8%)		0.309
Respiratory distress		6(22.2%)		9(42.8%)		
Hemodynamic instability		5(18.5%)		3(14.3%)		
Laboratory investigations						
Hb (g/dL)		10.65	2.61	11.31	2.58	0.388
WBCS (cells/mcl)		15.53	8.56	13.54	6.43	0.379
Platelets (/mcl)		206962.96	110936.73	274142.86	95833.33	**0.032***
Urea (mg/dl)		70.63	57.92	62.43	46.65	0.600
Creatinine (mg/dl)		1.48	1.31	1.18	.61	0.334
AST (u/l)		70.04	91.34	57.43	29.79	0.547
ALT (u/l)		99.81	228.05	80.29	87.77	0.712
CRP (mg\l)		40.41	34.29	32.57	29.18	0.407

Data are presented as mean ± SD or number (%), HTN: Hypertension, DM: Diabetes mellites, COPD: Chronic obstructive pulmonary disease, HR: Heart Rate, MAP: Mean arterial pressure, RM: Recruitment manoeuvers, HB: hemoglobin, WBCS: white blood cells, AST: Aspartate aminotransferase, ALT: Alanine transaminase, CRP: C reactive protein.

Regarding hemodynamics parameters, there were a higher significant difference in group A than in group B regarding MAP before and after RM (P= 0.036, 0.001, respectively) while no significant differences were reported concerning HR before and after RM between both groups (Figure 1).

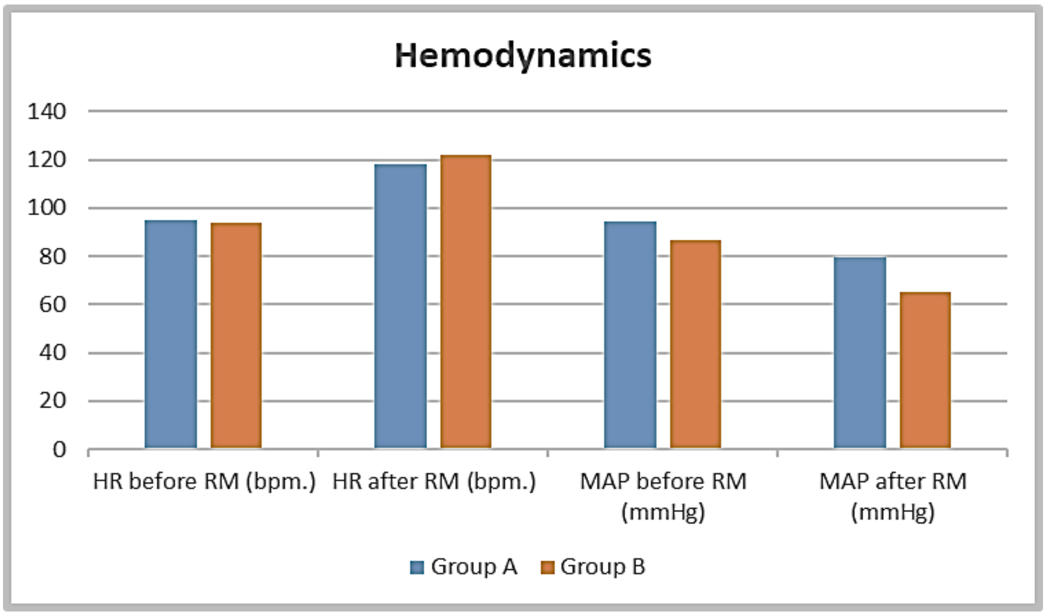

Figure (1): Hemodynamics parameters of the studied groups

There were lower significant differences in group A than in group B regarding tricuspid annular plane systolic excursion (TABSE) before RM (P= 0.011), while there were no significant differences regarding TABSE after RM (Figure 2).

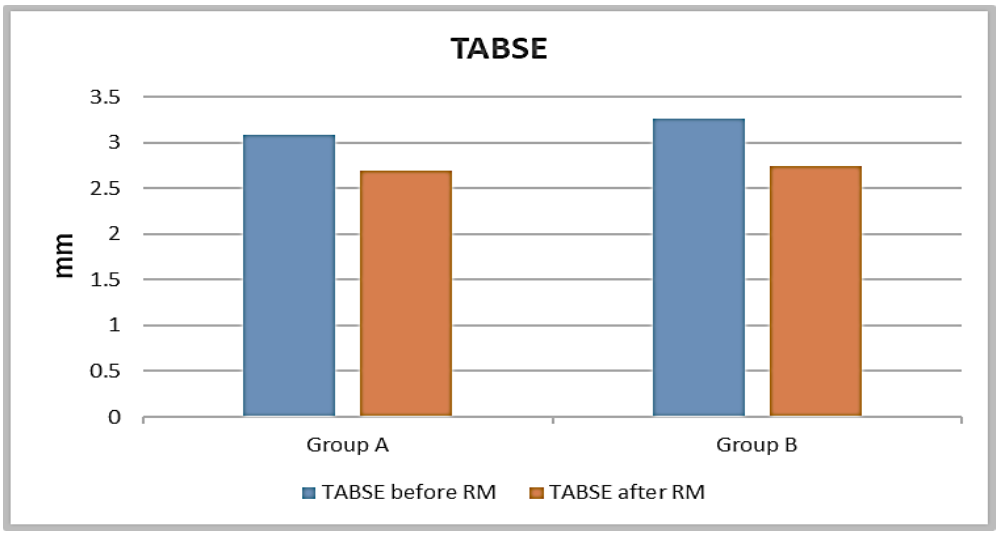

Figure (2): TABSE of the studied group.

Regarding the PFR and lung compliance, both of group A and group B experienced significant increases in PFR and lung compliance following lung RMs. Specifically, group A's mean PFR improved from 99.37 ± 63.96 to 176.07 ± 77.24, while group B's mean PFR rose from 116.29 ± 66.69 to 197.14 ± 76.03. Similarly, lung compliance in group A increased from 23.58 ± 3.31 to 34.22 ± 2.64, and in group B from 23.58 ± 1.27 to 34.34 ± 2.38. No significant differences were observed between the groups in terms of PFR and lung compliance improvements, with p-values of 0.377 and 0.350 for PFR before and after recruitment respectively, and 0.999 and 0.875 for compliance. In terms of opening pressure and optimal PEEP, group A demonstrated a mean opening pressure of 36.52 ± 3.28 and an optimal PEEP of 17.78 ± 2.25, whereas group B showed a mean opening pressure of 35.86 ± 5.18 and an optimal PEEP of 17.29 ± 2.22. A marginal but statistically significant difference was observed regarding the optimal pressure between the groups (p-value 0.056). Additionally, the OI in group B before and after recruitment maneuvers was 14.43 ± 5.13 and 12.43 ± 5.528 ml/cmH_2O respectively, with Group A's re-aeration score noted at 10.37 ± 3.07 (Table 2).

Table (2): PaO_2\FIO_2 ratio, dynamic compliance, OI before and after RM, opening pressure, closing pressure, optimal PEEP, and re-aeration score of both groups

	Group A (n=27)		**Group B (n=21)**		**P value**
	Mean	**SD**	**Mean**	**SD**	
PaO_2\FIO_2 ratio before RM (mmHg)	99.37	63.96	116.29	66.69	0.377
PaO_2\FIO_2 ratio after RM (mmHg)	176.07	77.24	197.14	76.03	0.350
Opening pressure (cmH_2O)	36.52	3.28	35.86	5.18	0.613
Closing pressure (cmH_2O)	15.78	2.25	15.29	3.22	0.556
Optimal PEEP (cmH2O)	17.78	2.25	17.29	3.22	0.056
Dynamic Compliance before RM (ml/cmH_2O)	23.58	3.31	23.58	1.27	0.999
Dynamic Compliance after RM (ml/cmH_2O)	34.22	2.64	34.34	2.38	0.875
OI before RM (ml/cmH_2O)	---	---	14.43	5.13	---
OI after RM (ml/cmH_2O)	---	---	12.43	5.528	---
Re-aeration score	10.37	3.07	---	---	---

Data are presented as mean ± SD. PEEP; Positive end-expiratory pressure, RM: Recruitment maneuvers, OI: oxygenation index.

Mortality, and complication (pneumothorax) were insignificantly different between both groups. (Figure 3)

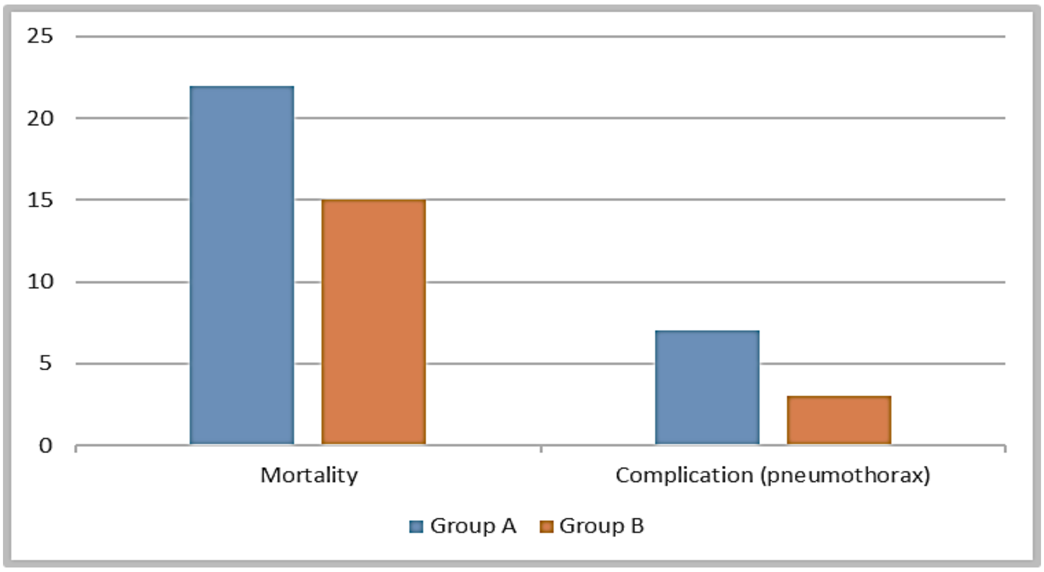

Figure (3): Mortality and complication (pneumothorax) of the studied groups.

DISCUSSION

Using mechanical ventilation with low tidal volume and high PEEP is a standard approach to enhance oxygenation in ARDS patients. Yet, individuals not responding to this regimen often require repeated lung RMs utilizing higher pressures to effectively open collapsed alveoli [10].

This study observed that the participant groups were comparable across socio-demographic parameters such as age, sex, comorbidities, and reasons for mechanical ventilation (MV). Similarly, **Radwan *et al.*** found no significant differences between the groups in terms of these variables [11].

Regarding hemodynamic responses, this investigation revealed no significant differences in heart rate (HR) before and after RMs across the groups, whereas the mean arterial pressure (MAP) was notably lower in group B than in group A both before and after RMs. This aligns with **Tang *et al.*** [12] findings, which indicated a significant increase in HR and a decrease in MAP following lung recruitment due to the derecruited alveoli's reaeration by intentionally raising transalveolar pressure temporarily. The decrease in MAP, especially noted in our study's LUS group, was attributed to the higher opening pressures and optimal PEEP used, which increased transalveolar pressure more significantly, thus reducing venous return and further lowering MAP.

In this study, both groups exhibited similar levels of AST, ALT, and CRP, but a notable difference was observed in platelet counts, with significantly lower levels in group A than in group B. This finding aligns with **Radwan *et al.*** [11] who found no significant differences between groups in terms of initial lab data including hemoglobin, white blood cells, platelets, and levels of creatinine and electrolytes.

Differences emerged in the study regarding the PaO_2/FiO_2 ratio, opening and closing pressures, optimal PEEP, and dynamic compliance before and after lung recruitment, with a marked significant difference in optimal pressure ($p < 0.001$) between the groups. **Radwan *et al.*** [11] highlighted a significant change in the PFR percent before and 12 hours after lung recruitment. However, no significant differences were noted in compliance percent changes before and after recruitment in either group. This could be attributed to the application of optimal PEEP, determined by LUS to be 2 cmH_2O above the closing pressure, ensuring alveoli remained open post-recruitment.

Chiumello *et al.* [13] observed a significant improvement in the PaO_2/FiO_2 ratio from 101.95 ± 42.4 before lung recruitment maneuvers (RM) to 149.33 ± 50.4 afterwards ($p \leq 0.001$), which further increased to 212.6 ± 92 after 12 hours ($p < 0.001$). A strong inverse correlation was noted between LUS and PaO_2/FiO_2 before and after RM, indicating that as PaO_2/FiO_2 increased, LUS scores decreased. **Lu *et al.*** [14] in their study on 50 patients exposed to paraquat demonstrated that those who developed ARDS showed a lower PaO_2/FiO_2 ($p = 0.001$) and higher LUS ($p = 0.001$) compared to those without ARDS, especially between days 3 to 7, suggesting a direct relationship between a drop in PaO_2/FiO_2 and an increase in LUS. **Hodgson *et al.*** [15] conducted a randomized study on 20 ARDS patients, comparing PEEP titration with ARDSnet control ventilation strategies and noted significant improvements in the treatment group in both PaO_2/FiO_2 ($p = 0.005$) and static lung compliance ($p < 0.001$) over seven days.

In this study, Tricuspid Annular Plane Systolic Excursion (TAPSE) before RM was significantly lower in group A than in group B, but differences after RM were not significant between groups. **Mohamed and Abo Hamila** [16] found a significant reduction in LUS from 25.3 ± 6.3 before RM to 17.4 ± 6.5 after RM ($p \leq 0.001$), which further decreased to 15.38 ± 8.62 after 12 hours ($p \leq 0.001$). **Longo *et al.*** [17] demonstrated that atelectasis post-Cardiopulmonary bypass (CPB) adversely affects right ventricular function, which can be mitigated by lung recruitment using 10 cmH_2O of PEEP, significantly enhancing RV function as measured by TAPSE compared to the baseline.

In the present study, it was found that about 22 (81.5%) patients died in group A and 15 (71.4%) patients died in group B. Complication (pneumothorax) were occurred in 7 (25.9%) in group A and 3 (14.2%) in group B. Mortality and complication (pneumothorax) were insignificantly different between both groups.

Mohamed and Abo Hamila [16] showed no statistically significant difference between the two groups. Patients included in the study were segregated according to outcome into 23 survivors (57.5%) and 17 (42.5%) non survivors.

LIMITATIONS

Small sample size, single centre study, and research was limited at this point.

CONCLUSION

LUS proves to be a valuable tool for assessing and facilitating alveolar recruitment in patients with ARDS. It surpasses the maximum oxygenation-guided approach by attaining higher opening pressures, achieving superior lung aeration enhancement, and significantly minimizing lung heterogeneity in ARDS cases. Utilizing bedside ultrasonography offers considerable benefits in monitoring lung aeration and the effectiveness of RMs in cases with ARDS.

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