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Efficacy and Safety of Lung Recruitment Maneuvers using ultrasound in patients with Acute Respiratory Distress Syndrome

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Abstract

Aim of the study: To assess different lung recruitment maneuvers (LRMs) via lung ultrasound score (LUSS).

Subjects and Methods: We divided 53 patients with respiratory distress syndrome (ARDS) who met inclusion criteria into two groups: Group A: sustained inflation (SI) manoeuvre. Group B: staircase recruitment manoeuvre (SRM). Lung ultrasound aeration score (LUSS), respiratory physiological parameters (PaO2/FiO2 ratio, Dynamic compliance) and hemodynamic changes were collected at four time periods.

Results: PaO2/FiO2 ratio and dynamic compliance significantly increased immediately after and 12 hours after lung recruitment maneuvers (LRM) when compared with basal state that were significantly more in group B (SRM) than in group A (SI) .Both groups showed a significant decrease in LUSS immediately after and 12h after LRM. We noted more significant decrease in LUSS in group B (SRM) than group A (SI). Also, we noted temporary decrease in the Mean arterial pressure (MAP) after LRM and that decrease was more in group B (SRM) than group A (SI). Group B (SRM) had a significant pneumothorax complication compared to group A (SI). There were no statistically difference in both groups regarding length of ICU stays, days of mechanical ventilation (MV) or mortality.

Conclusions: Staircase recruitment maneuver (SRM) can improve oxygenation and dynamic compliance more than sustained inflation (SI) in ARDS patients but has more adverse effects on hemodynamics and barotrauma.

Keywords: Lung Recruitment Maneuver (LRM); Lung Ultrasound Score (LUSS); Sustained Inflation (SI); Staircase Recruitment Maneuver (SRM); Acute Respiratory Distress Syndrome (ARDS).

1. Introduction

Positive pressure ventilation is a non-physiological procedure that saves lives but is not void of serious adverse effect. Lung protective ventilation goals to limiting ventilation induced lung injury (VILI) by reducing tidal volume as well as driving pressure [1,2].

Such strategy decreases the effect of the VILI mediators: tidal over distension (alveoli that accept volume and pressure that exceed the elastic limit) and tidal recruitment (the repeating opening and closing of collapsed alveoli during mechanical ventilation) [3–5].

The open lung concept is additional ventilator approach complementary with the idea of protective ventilation [4–6]. Lanchmann was the first who proposed the open lung strategy combing a lung recruitment manoeuvre (LRM) with an adequate level of PEEP [6].

Lung Recruitment manoeuvres (LRMs) aim to reduce lung atelectasis by brief controlled increase of airway pressure whereas PEEP maintains the lung open afterward. It improves gas exchange and lung mechanics as well as minimize VILI [3–5,7].

2. Subjects and methods

2.1.Subjects

This prospective randomized controlled trial (RCT) was performed at Intensive Care Unit (ICU) at Fayoum University after receiving the approval of the Institutional Ethics Committee (Number:M599).

Inclusion criteria

We included patients who

- met the diagnosis of ARDS, based on the Berlin definition and Kigali modification [8].
- received endotracheal intubation and mechanical ventilation.

Exclusion criteria

We excluded patients who are

- hemodynamically unstable.
- Pregnancy
- severe chronic obstructive pulmonary disease.

- patients with subcutaneous emphysema
- morbid obesity.
- deformed chest wall that were unfit for pulmonary ultrasound.

2.2. Study design

We divided the selected patients into two groups. Group A: we applied lung recruitment using sustained inflation (SI) maneuver (a transient riase of plateau pressure using pressure support mode. The pressure support was set to zero and the PEEP was elevated to 40 cmH2O for 40 seconds and had PEEP afterward as previously determined by FiO2/PEEP combination.)[9] and Group B: underwent staircase recruitment maneuver (SRM) (Using pressure support mode, the high pressure was set to 15 cmH2O directly above PEEP, which was elevated in a stepwise manner to 20, then to 30 and then to 40 cmH2O every two minutes, reaching a max peak pressure of 55 cmH2O. At that time, PEEP is titrated at 3 minute intervals to 25, then to 22.5, then to 20, then to 17.5 or then an absolute minimum 15 cmH2O until SaO2 decreased ≥ 1% from maximum saturation. This was defined as the "derecruitment point". PEEP was then raised to 40 cmH2O for one-minute duration then returned to 2.5cmH2O above the derecruitment point (which was defined as optimal PEEP). LRMs was stopped if patient became bradycardia or tachycardia (< 60 or > 140 beats per minute respectively), develops arrhythmia, hemodynamic instability (systolic blood pressure (SBP) < 80 mmHg or SaO2 < 85%.) [10,11].

Lung ultrasound aeration score (LUSS) and respiratory physiological parameters (ABG, PaO2/FiO2 ratio, Dynamic compliance) were collected at four time periods (before LRM, immediate after LRM, 12h after LRM and at weaning).

2.3. Statistical Methods

We used Statistical Package for the Social Science (SPSS) version 22 (SPSS-22, IBM, Chicago, USA) for analyzing the data.

3. Results

The allocation of patients is shown in the CONSORT (Consolidated Standards of Reporting Trials) flow diagram (**Figure 1**).

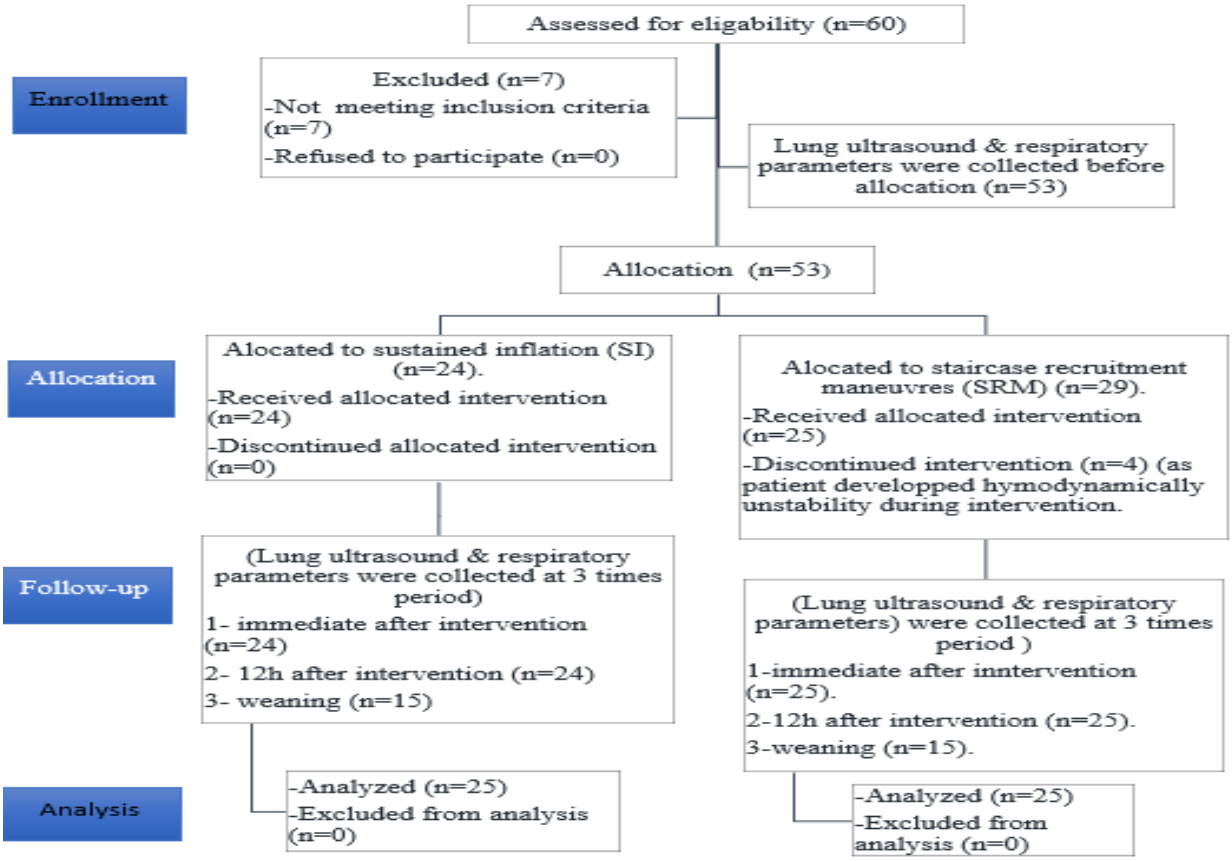

Figure 1: Consort diagram.

The baseline socio-demographic data, cause of ARDS, LUSS, PaO2/ FiO2 ratio, dynamic compliance and hemodynamics before LRM were comparable in both groups (**Table 1**).

Table 1: Baseline characteristics of both groups.

		Sustain inflation (SI)		Staircase Recruitment Maneuver (SRM)		P-value
		Mean	**SD**	**Mean**	**SD**	
Age		48.6	13.0	52.8	16.2	0.307
		N	%	N	%	
Sex	Female	17	70.8%	16	64 %	0.867
	Male	7	29.2%	9	36 %	
Cause of ARDS						

Pneumonia	11	45.8%	19	55.8%	0.317
Sepsis	7	29.2%	6	17.6%	0.226
Alveolar hemorrhage	4	16.7%	6	17.6%	1.000
COVID	1	4.2%	3	8.8 %	0.844
Major surgery	1	4.2%	0	0.0%	0.222
	Mean	SD	Mean	SD	
LUSS	15.2	16	16.1	5.9	0.635
PaO2/ FiO2 ratio	133.4	62	129.8	59.9	0.662
dynamic compliance	39.2	16.6	36.6	15.2	0.052
MAP	91.8	14.2	85.6	12.9	0.098

Both groups showed a significant increase in PaO2/ FiO2 ratio and dynamic compliance immediately after LRM then decreased 12h after LRM but still statistically significant when compared with basal state before LRM (**Tables 2, 3 &Figures 2, 3**).

Table 2: PaO2/ FiO2 ratio before recruitment, immediate and 12h after recruitment.

	Before LRM		**Immediate after LRM**		***P-value***
	Mean	**SD**	**Mean**	**SD**	
Group A (SI)	133.4	62	157.2	66.7	<0.005*
Group B (SRM)	129.8	59.9	171.2	61.5	<0.001*
	Immediate after LRM		**12h after LRM**		***P-value***
	Mean	SD	Mean	SD	
Group A (SI)	157.2	66.7	151.5	68.3	0.082
Group B (SRM)	171.2	61.5	163.9	61.9	0.070
	Before LRM		12h after LRM		P-value
	Mean	SD	Mean	SD	
Group A (SI)	133.4	62	151.5	68.3	0.005*
Group B (SRM)	129.8	59.9	163.9	61.9	0.003*

Table 3: Dynamic compliance ratio before recruitment, immediate and 12h after recruitment in both groups.

	Before LRM		**Immediate after LRM**		**P-value**
	Mean	**SD**	**Mean**	**SD**	
Group A (SI)	39.2	16.6	52.7	16.2	0.038*

Group B (SRM)	36.6	15.2	63.3	13.8	<0.001*
	Immediate after LRM		12h after LRM		P-value
	Mean	SD	Mean	SD	
Group A (SI)	52.7	16.2	48.5	17.2	0.827
Group B (SRM)	63.3	13.8	60.5	14	0.598
	Before LRM		12h after LRM		P-value
	Mean	SD	Mean	SD	
Group A (SI)	39.2	16.6	48.5	17.2	0.004*
Group B (SRM)	36.6	15.2	60.5	14	<0.001*

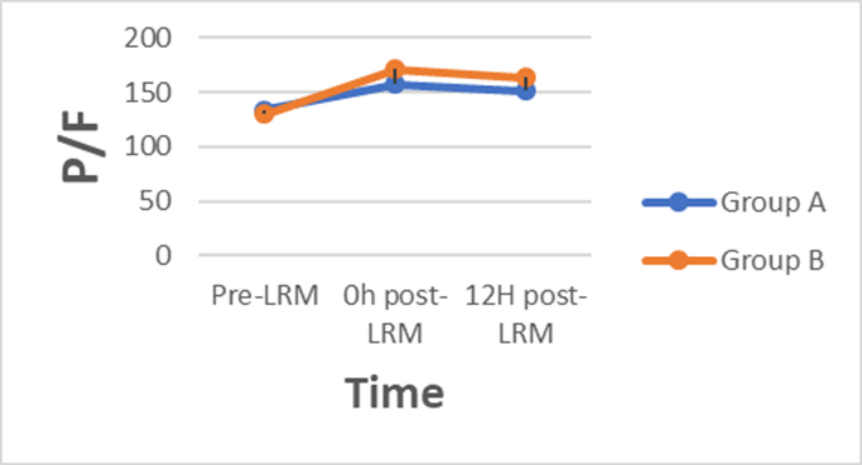

Figure 2: Comparison of PaO2/ FiO2 ratio variable before LRM, 0h post and 12h post LRM in both groups.

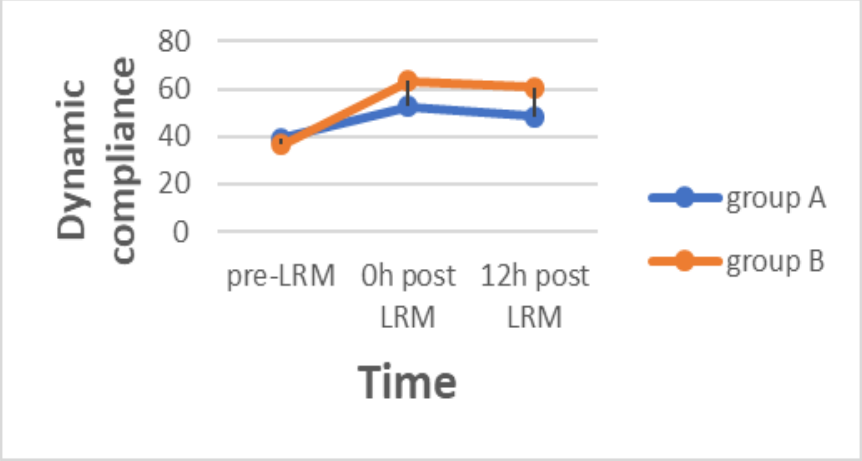

Figure 3: Comparison of dynamic compliance variable before LRM, 0h post and 12h post LRM in both groups.

This improvement was significant higher in SRM group compared to SI group (**Table** 4,5).

Table 4: Comparison of PaO2/ FiO2 ratio variable before LRM, 0h post and 12h post LRM in both groups.

	Sustain inflation (SI)		**Staircase Recruitment Maneuver (SRM)**		**P-value**
	Mean	**SD**	**Mean**	**SD**	
Before recruitment	133.4	62	129.8	59.9	0.662
Immediate After recruitment	157.2	66.7	171.2	61.5	0.045*
12h after recruitment	151.5	68.3	163.9	61.9	0.049*
Weaning	325.3	39.8	305.8	24.4	0.072

**Significant*

Table 5: Comparison of Dynamic compliance (DC) variable before LRM, 0h post and 12h post LRM in both groups.

	Sustain inflation (SI)		**Staircase Recruitment Maneuver (SRM)**		**P-value**
	Mean	**SD**	**Mean**	**SD**	
Before recruitment	39.2	16.6	36.6	15.2	0.052
Immediate after recruitment	52.7	16.2	63.3	13.8	0.032*
12h after recruitment	48.5	17.2	60.5	14	0.044*

**Significant*

In contrast, both groups showed a significant reduction in LUSS immediately after LRM then increased 12h after LRM but still statistically significant when compared with basal state before LRM (**Table** 6 **figure** 4). This observation was significantly higher in SRM group (**Table** 7).

Table 6: LUSS before recruitment, immediate and 12h after recruitment in both groups.

	Before LRM		**Immediate after LRM**		**P-value**
	Mean	**SD**	**Mean**	**SD**	
Group A (SI)	15.2	6	12.1	5.7	0.004*
Group B (SRM)	16.1	5.9	10.3	4.4	<0.001*
	Immediate after LRM		12h after LRM		P-value
	Mean	SD		SD	
Group A (SI)	12.1	5.7	12.9	5.8	0.307

Group B (SRM)	10.3	4.4	11.3	4.5	0.283
	Before LRM		12h after LRM		P-value
	Mean	SD	Mean	SD	
Group A (SI)	15.2	6	12.9	5.8	0.005*
Group B (SRM)	16.1	5.9	11.3	4.5	<0.001*

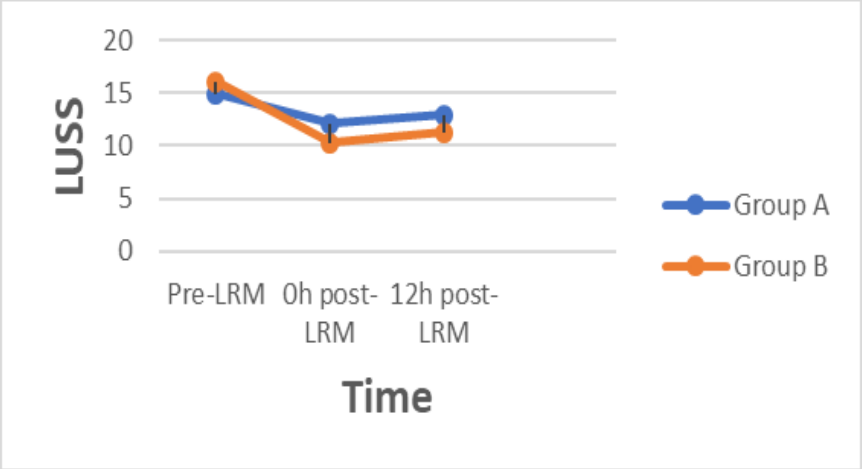

Figure 4: Comparison of LUSS variable before LRM, 0h post and 12h post LRM in both groups

Table 7: Comparison of LUSS before LRM, 0h post and 12h post LRM in both groups.

	Sustain inflation (SI)		**Staircase Recruitment Maneuver (SRM)**		**P-value**
	Mean	**SD**	**Mean**	**SD**	
Before recruitment	15.2	6	16.1	5.9	0.635
Immediate after recruitment	12.1	5.7	10.3	4.4	0.040*
12 h after recruitment	12.9	5.8	11.3	4.5	0.049*
Weaning LUSS	4.8	2.1	5.1	1.7	0.943

**Significant*

There was statistically significance difference in two groups regarding pneumothorax complication that was more in SRM group (5 out of 25,20%) than in SI group (0 out of 24,0%) (P-value 0. 002). We noted no statistically significance difference in the two groups regarding days of MV, length of ICU stays, mortality or weaning (**Table** 8, **Figure** 5).

Table 8: Outcomes in both groups.

		Sustain inflation (SI)		Staircase Recruitment Maneuver (SRM)		P-value
		Mean	**SD**	**Mean**	**SD**	
Days of MV		8.1	3.1	7.9	2.6	0.082
Length of ICU stay		15	5.5	12.7	4.2	0.073
		N	%	N	%	
Mortality	No	15	62.5 %	15	60 %	0.057
	Yes	9	37.5 %	10	40 %	
Complication	No	24	100 %	20	80.0%	0.002*
	Yes	0	0 %	5	20.0%	
Weaning	No	7	29.1%	8	32 %	0.072
	Yes	17	70.8%	17	68 %	

*Significant

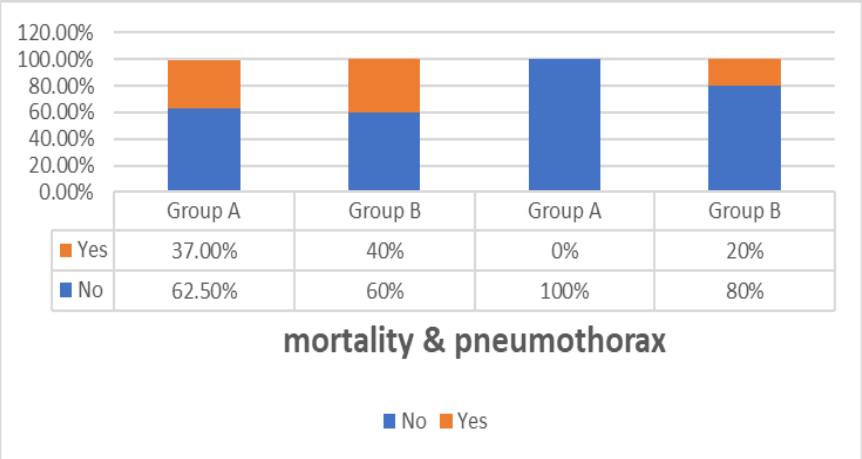

Figure 4: Bar chart showing pneumothorax complication and weaning in both groups.

The mean arterial pressure (MAP) was 91.8±14.2 and 85.6±12.9, respectively, before LRM in SI and SRM. Later, it significantly decreased to 83.8±12.8 and 75.4±14.7, respectively. The decrease in MAP was statistically significant more in SRM group than SI group. Twelve hours after LRM, MAP increased to 89.4±10.9 and 83.1±13.8, respectively, in SRM and SI groups respectively with no statistically difference when compared with basal state (**Table** 9,10, **Figure** 5).

Table 9: MAP before recruitment, immediate and 12h after recruitment in group.

	Before LRM		**Immediate after LRM**		**P-value**
	Mean	**SD**	**Mean**	**SD**	
Group A (SI)	91.8	14.2	83.8	12.8	<0.001*
Group B (SRM)	85.6	12.9	75.4	14.7	<0.001*
	Immediate after LRM		12h after LRM		P-value

	Mean	SD		SD	
Group A (SI)	83.8	12.8	89.4	10.9	0.051*
Group B (SRM)	75.4	14.7	83.1	13.8	0.031*
	Before LRM		12h after LRM		P-value
	Mean	SD	Mean	SD	
Group A (SI)	91.8	14.2	89.4	10.9	0.231
Group B (SRM)	85.6	12.9	83.1	13.8	0.214

Table 10: Comparison of MAP before LRM, 0h post and 12h post LRM in both groups.

	Sustain inflation (SI)		**Staircase Recruitment Maneuver (SRM)**		**P-value**
	Mean	**SD**	**Mean**	**SD**	
Before recruitment	91.8	14.2	85.6	12.9	0.098
Immediate after recruitment	83.8	12.8	75.4	14.7	0.039*
12h after recruitment	89.4	10.9	83.1	13.8	0.083

**Significant*

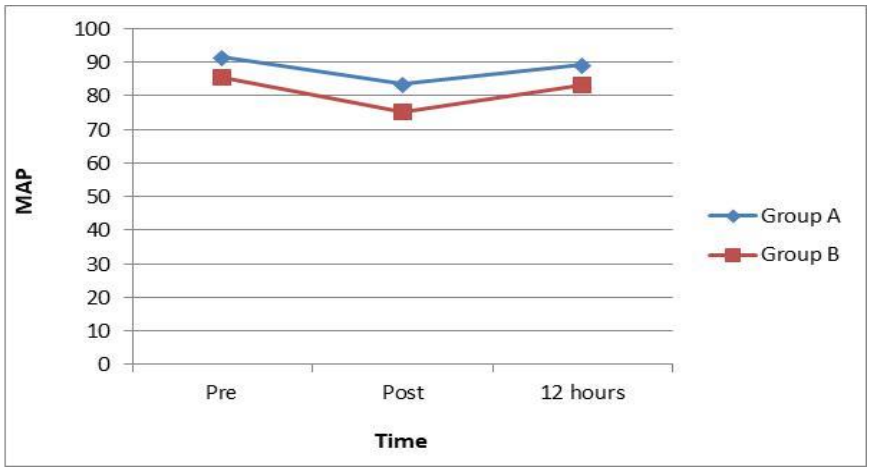

Figure 5: Comparison of MAP variable before LRM, 0h post and 12h post LRM in both groups

4. Discussion

Some studies observed that the change in aeration could be detected bedside by lung ultrasound before the changes in PaO2/FiO2 [12]. Furthermore, LUSS is an efficient measurement tool that could be used to monitor aeration frequently and assess re-aeration while applying LRM (e.g., lower lung ultrasound score indicates

positive re-aeration and higher or equivalent lung ultrasound score indicates negative re-aeration) [13]. This correlation was already found in COVID-19 and non COVID-19 patients [14], also the correlation between lung ultrasound and lung aeration during LRM and proning position is well recognized [15].

We observed dynamic changes in oxygenation index and ultrasound scoring system among ARDS patients before and 0 h ,12 h after lung recruitment. Over this period, we found that LRM in both groups was accompanied with a significant raise in Pao2/Fio2 ratio, dynamic compliance and decreased LUS score compared with basal state.

That matches the study conducted by Stefanidis et al. (2011) who reported that LUSS in non-aerated zones in dependent lung regions were significantly decreased when PEEP increased from 5 to 10 to 15 cm H_2O. These changes were connected with a significant improve in arterial oxygenation [16]. Also, match study done by Mohamed et al (2022). who reported improve in PaO2/FiO2 ratio and decrease in LUS after sustained inflation recruitment in 40 ARDS patients [17]. Grasso et al., Tang et al., Radwan et al. and Li et al. reported same results [9, 19, 20].

We found also in our study that PaO2/FiO2 ratio 12h after LRM reduced compared with PaO2/FiO2 ratio immediately after LRM but significantly higher when compared with the basal state before LRM.

In our study, we also found that the improving in PaO2/FiO2 ratio and the decrease in LUSS after LRM was more significant in SRM group than in SI group and this could be referred to the application of higher pressure in SRM group.

Zhao et al. proposed that patients` arterial oxygen partial pressure and PaO2/FiO2 ratio enhanced significantly after LRMs [21], on the other hand, Yun et al. reported, during recruitment not all cases with optimally recruited lung zone showed a significant increase in oxygenation, which was measured by electrical impedance tomography [22].

These contrasting outcomes could be explained by many reasons including the huge variety of individual lung physiological characteristics and the details

of recruitment maneuvers used in these studies.

Concerns regarding the potential hazards of hemodynamic deterioration while applying LRMs have been voiced [24]. Our data display that, applying of LRMs caused a substantial reduction in MAP and increase in heart rate and that returned close to the basal level at 12h after LRMs.

That matches the study conducted by Tang et al. [20] ,Gasso et al. [9] and Radwan et al. [18]. On the other hand, Brower et al. and Oczenski et al. both found no significant alteration in HR and MAP after LRM when compared to non-LRM group [24] LRMs increase afterload due to increase lung volume that could explain their effect on mean arterial pressure and cardiac output through [25,26].

Of note, SRM was discontinued in four patients due to development of hemodynamical instability. Their mean P/F ratio before starting SRM was less than 82 ± 23. This wasn't noted to any patient in SI group.

A significant difference regarding MAP was noted between both groups. SRM group showed a statistically significant reduction in MAP than SI group.

Our explanation is that in SRM group, we applied higher opening pressure alas well as higher optimal PEEP that potentially raise transalveolar pressure which reduce venous return causing more reduce in MAP than in SI group.

In our study, pneumothorax developed in 20% (5 patient out of 25) in SRM group where no one was affected in SI group highlighting a considerable advantage in SI over SRM in our study.

In a multicenter RCT of 767 patients with acute lung injury (ALI) conducted by Mercat et al in 37 ICUs in France compared the outcome of rising alveolar pressure via PEEP while minimizing hyperinflation to limit alveolar distension. This study revealed that 6.8% of recruited patient had pneumothorax [27].

Deaths in our study were with percent 40 % (10 patient out of 25) in SRM group while were with percent 37.5 % (9 patients out 24) in SI group with total 38.8 % of all participants in our study (19 patients out 49) whereas mortality before

hospital discharge percent was 35.4% in the study done by Mercat et al. [27].

In our study, mortality was comparable in both group with statistically insignificant difference (37.5% in SI group and 38.8% in SRM group).

We included moderate to severe ARDS patients in our both groups (PaO2/FiO2 ratio 133.4 ±62SD, 129.8 ±59.9SD respectively). This may explain the high mortality rate in our study.

We did not confirm lung collapse using CT chest. Hyperinflation could not be readily discriminated from normal lung and this factor is possibly the essential limitation of this technique

5. Conclusion

Transthoracic LUS is a feasible and free of radiation tool used to assess lung aeration bedside. The score of LUS could be used to estimate re-aeration after LRMs. Staircase recruitment maneuver (SRM) can improve oxygenation and dynamic compliance more than sustained inflation (SI) in ARDS patients but has more adverse effects on hemodynamics and barotrauma. Both has no effect on mortality, days of MV or length of ICU stay.

Ethical approval: This RCT was conducted at ICU at Fayoum University after approval by the Institutional Ethics Committee (Number:M599).

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Conflicts of Interest: None declared

AI declaration statement: None declared.

Authors' contributions: AAM: Protocol/project development, Data collection and management, manuscript writing/editing. **OMM:** Protocol/project development, Data analysis, manuscript writing, and editing. **DME:** Data management, Manuscript writing/editing. **AFE:** Data management, manuscript writing/editing. All authors have read and approved the manuscript.

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