Original Research Article

Combined Effect of Expiratory Rib Cage Compression Technique and Intercostal Stretch Technique on Static Lung Compliance and Hemodynamic Parameters in Mechanically Ventilated Patients

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ABSTRACT

Background: Expiratory Rib Cage Compression (ERCC) and Intercostal Stretch Technique (ICT) are commonly used in chest physiotherapy to clear secretions in mechanically ventilated patients but there is scarcity of evidence supporting combined effects of these techniques. The present study tested hypothesis that whether there is a significant difference between combined effects of ERCC and ICT compared to ERCC alone on static lung compliance and hemodynamic parameters in mechanically ventilated patients.

Methods: Prospective crossover study conducted on fifty mechanically ventilated patients with mean days of mechanical ventilation= 14.2 ± 3.14 and mean age 46.66 ± 15.7 years. All participants were given both interventions- ERCC+ICT (Group-A) and ERCC (Group-B) on same day with a 3-hour washout period. Outcome measures included static lung compliance (C_{ST}), oxygen saturation (SpO_2), hemodynamic (SBP, DBP, HR) and ABG parameters (pH, pCO2, paO2 and P/F ratio) recorded at time intervals: - before (PRE), POST-1 (after 0 min), POST-2 (after 30 min.) and POST-3 (after 60 min.).

Results: One-way ANOVA and Cohen's D effect size showed that C_{ST} and SpO_2 mean values improved in both treatment groups ($p<0.01$) with significantly higher ($p< 0.05$) increase in C_{ST} and SpO_2 mean values in Group-A as compared to Group-B using t-test. ICC recorded at various time intervals for hemodynamic and ABG parameters was found to be highly statistically significant for both groups ($p<0.01$), with higher ICC coefficients for Group-A than Group-B.

Conclusion: ERCC+ICT improves C_{ST} and SpO_2 in mechanically ventilated patients with stabilizing effect on hemodynamic and ABG parameters compared to ERCC alone.

Keywords: Expiratory rib cage compression, intercostal stretch, ICU physiotherapy, lung compliance, mechanical ventilation.

INTRODUCTION

Critically ill patients in the Intensive Care Unit (ICU) often require mechanical ventilation due to respiratory failure.[1] Mechanically ventilated patients have increased airway secretions due to constant positive pressure ventilation and Secretions tend to accumulate in dependent regions of the lungs due to reduced mucociliary clearance, impaired cough reflex, and lack of

mobility which often leads to atelectasis and pulmonary collapse.[2,3] Bronchial hygiene technique namely manually assisted cough (MAC) also known as quad cough or manual chest compression or "squeezing" or expiratory rib cage compression (ERCC) is known to improve respiratory mechanics by secretion clearance.[4,5] ERCC techniques consists of application of manual thoracic compression during exhalation followed by a rapid release during inspiration and aims to increase expiratory flow and stretch intercostal muscles.[6]

Proprioceptive neuromuscular facilitation (PNF) is a form of stretching in which a muscle is alternately stretched passively and contracted. PNF is also known to improve lung functions.[7] Neuro-facilitatory technique, namely Intercostal Stretch technique (ICT), is known to help in both inspiration and forced expiration.[7] ERCC and ICT techniques have similar physiological basis as both help to increase expiratory flow.[4,7] However, some studies have reported that ICT improves chest expansion, supporting its role in enhancing lung function.[8] Experimental study have also demonstrated the effectiveness of ERCC in improving gas exchange, especially in conditions such as atelectasis.[9] hence ERCC technique can be considered safe and efficacious, particularly during the immediate postoperative period.[10] Also, ERCC has benefit over manual hyperinflation as no special equipment is needed for performing it and has low risk of barotrauma.[2] Additionally, it has been reported that ERCC significantly improves oxygenation, ventilation, and secretion clearance in mechanically ventilated patients.[11] Similarly, ICT has been shown to enhance pulmonary function parameters in healthy individuals, supporting its potential clinical utility.[12]

Previous studies have extensively explored the impact of ICT.[7,8] The effects of ERCC have also been examined.[2,4] However, research involving ERCC has been limited by small sample sizes[3,9,10] and heterogeneous respiratory pathophysiologies among patients requiring mechanical ventilation.[10] Moreover, static lung compliance has not been utilized as an outcome parameter in most studies assessing ERCC.[3,13,14] Additionally, the combined effects of ERCC and ICT have not been investigated.[4,7,14] Therefore, the present tested the hypothesis that whether there is a significant difference between the combined application of ERCC and ICT compared to ERCC alone on static lung compliance and hemodynamic parameters in mechanically ventilated patients.

MATERIAL AND METHODS

Study design: This was an experimental - crossover study conducted on mechanically ventilated patients, between August 2023 and July 2024. Ethical approval was obtained from the Institutional Biomedical Research Ethics Committee, Rohtak, India (Letter No. BREC/23/309, dated July 20, 2023). The study was also registered with the Clinical Trials Registry – India (CTRI) under registration number CTRI/2024/01/061618, approved on January 19, 2024.

Sample size:
Based on the study by Payal Gupta et al. (2014), the sample size was calculated. Taking the standard deviation and mean difference from the previous study, the calculated sample size (N) was 26.86. Considering possible dropouts and exclusions, a total of 50 subjects were included in the present study to ensure adequate statistical power and reliability of results.

Participants
A total of fifty patients, aged 18–65 years, who were hemodynamically stable and had been on mechanical ventilation for 10–20 days with PEEP values between 5–7 mmH2O, admitted to the Intensive Care Unit, Department of Anesthesiology, Pt. B. D. Sharma PGIMS, Rohtak, India was enrolled in study. Patients with contraindications such as rib fractures, chest trauma, or recent surgeries were excluded from the study

(Figure 1). A signed informed consent was taken from the participant's attendant.

Randomization

Each participant received both interventions—ERCC combined with ICT (Treatment A) and ERCC alone (Treatment B)—on the same day, with a 3-hour washout period between treatments. The order of treatment (A/B) to be given to each participant was decided on the basis of a computer-generated randomization list with a 1:1 allocation ratio.

Outcome measures

Static lung compliance (Cstat): - static lung compliance was recorded by direct display from the monitor of Hamilton medical ventilator and an inspiratory pause or an inspiratory hold maneuver is not needed.

Saturation of oxygen (SpO2): The measurement of SpO_2 was done by pulse oximeter probe and readings were recorded which displayed on the display monitor

Respiratory Rate, heart rate, systolic blood pressure, diastolic blood pressure: The measurement of these parameters were done through the chest electrode, automated non-invasive blood pressure system, readings were recorded which displayed on the display monitor.

Arterial blood gas (ABG) analysis parameters: Parameters such as pH, PCO_2, PaO_2, PaO_2/FiO_2 ratio were measured by arterial blood sample drawn from patient's artery for arterial blood gas analysis.

Baseline (PRE) and post-intervention measurements, POST 1 (0 min.), POST 2 (30 min.), POST 3 (60 min.) were taken for outcome measures including Static lung compliance (Cstat), Saturation of oxygen (SpO2), Respiratory Rate (RR) and hemodynamic parameters including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP). Measurements of Arterial blood gas analysis parameters including pH, PCO2, PaO2 and P/F ratio were taken 5 minutes before and after 30 minutes of either of the two interventions and were, labelled as "PRE - ABG" and "POST-ABG".

- **Treatment Procedure:** In Treatment A (ERCC combined with ICT) the patients were placed in a semi-recumbent or supine position with the head elevated to 30–45 degrees. The physiotherapist stood beside the patient, positioned hands laterally on the lower rib cage. A gentle but firm bilateral compression was applied during the expiratory phase of the ventilator cycle, synchronized with the patient's breathing. Both the techniques were applied for 10 breaths, constituting one session. Conventional chest physiotherapy including chest percussion and mechanical chest vibration was also administered.

In Treatment B(ERCC) the patients were also in the same semi-recumbent or supine position with the head elevated to 30–45 degrees. The physiotherapist placed both hands on the lateral aspect of the thorax over the intercostal spaces. During end-expiration, a gentle upward and outward stretch was applied along the intercostal space, maintained for 2–3 seconds. The technique was applied on 3rd and 4th intercostal spaces for 10 breaths. This was followed by standard chest physiotherapy, similar to Group A. Both protocols were carried out on the same day on the same subjects, with a 3-hour washout interval between treatments. In the event of any adverse event, procedures followed the ICMR's SAE (Serious Adverse Event) guidelines.

Statistical Analysis

Data was expressed as mean ± S.D. To assess potential demographic bias, age differences across gender, airway type, and ventilator mode were evaluated using independent t-tests and one-way ANOVA. Within-group comparison was done using one-way ANOVA and Cohen's d effect size for variables including Cstat (ml/cmH2O) and SpO2. Between -group comparison, was done using independent t-test. Between-group mean differences for variable Cstat were further evaluated using Bland–Altman plots. Reliability testing was done using Intraclass

Correlation Coefficient (ICC) for parameters including SBP, DBP, heart rate, respiratory rate, pH, $PaCO_2$, PaO_2, and P/F ratio. Data analysis was conducted using SPSS software version 30.0 with significance level set at $p < 0.05$.

RESULTS

A total of 50 mechanically ventilated patients aged 18–65 years (mean age 46.66 ± 15.7 years) were included (Figure 1). Demographic data of study participants is given in Table 1. No significant differences were found in age distribution across gender, airway type, or ventilator mode (Table 2; all $p > 0.05$), confirming demographic comparability between participants. One – way ANOVA analysis revealed that compared to baseline (PRE) there was highly significant improvement ($p < 0.01$) in static lung compliance (C_{ST}) within both groups at POST-1, POST-2 and POST-3-time intervals (Table 3). However, the percentage change C_{ST} in mean values compared to baseline was higher in Group-A (ERCC + ICT) compared to Group-B(ERCC). Also, 'Large' Cohen's D effect size was observed for change in C_{ST} mean values in Group-A (ERCC + ICT) compared to 'Medium' Cohen's D effect size for change in C_{ST} in mean values in Group-B (ERCC). Independent 't-test' revealed that there was significant difference ($p < 0.05$) between the C_{ST} mean values observed in Group-A and Group-B at POST-1, POST-2 and POST-3-time intervals. Bland-altman plots indicated that mean difference for change in C_{ST} in mean values at POST-1, POST-2 and POST-3-time intervals, obtained with treatment given in Group-A was significantly higher ($p < 0.05$) compared to change in C_{ST} mean values obtained with treatment given in Group-B (Fig. 2A, 2B and 2C). Also, for SpO_2 mean values, within group analysis using one-way ANOVA showed that compared to baseline (PRE) there was highly significant improvement ($p < 0.01$) in SpO_2 within both groups at POST-1, POST-2 and POST-3-time intervals (Table 4) accompanied with 'Large' Cohen's D effect size observed for change in SpO_2

mean values. Independent 't-test' revealed that there was highly significant difference ($p < 0.01$) between the SpO_2 mean values observed in Group-A and Group-B at POST-1, POST-2 and POST-3-time intervals with higher increase in oxygenation mean values in Group-A compared to Group-B. The measure of the statistical agreement/Intra class correlation (ICC) between various hemodynamic (Table 5) and ABG parameters (Table 6) recorded at various time intervals both in Group-A and Group-B was found to be highly statistically significant ($p < 0.01$), indicating that both ERCC+ICT in combination and ERCC when given alone are consistent in their effect of these parameters. But the ICC coefficients were higher for Group-A > Group-B; indicating that combined effect stabilizes hemodynamic parameters more compared to solo technique.

DISCUSSION

This study aimed to assess and compare the effects of ERCC and ICT on respiratory and hemodynamic parameters in mechanically ventilated patients. Results clearly demonstrate that the combined effects of ERCC with ICT improves static lung compliance, oxygenation, and respiratory rate.

Static lung compliance significantly improved in both groups post-intervention, with greater improvements in Group A (ERCC + ICT). These findings are consistent with the work of Guimarães et al. (2014)[9], who reported that ERCC significantly enhances lung compliance in mechanically ventilated subjects by improving alveolar recruitment and decreasing airway resistance. Similarly, Ashwini et al., (2017)[8] also supported this finding by reporting that ICT activates mechanoreceptors, which may increase inspiratory muscle activation and enhance chest wall mobility. The enhanced compliance observed in Group A suggests that multimodal interventions may effectively reduce alveolar collapse, improve tidal volume distribution, and optimize ventilation mechanics.
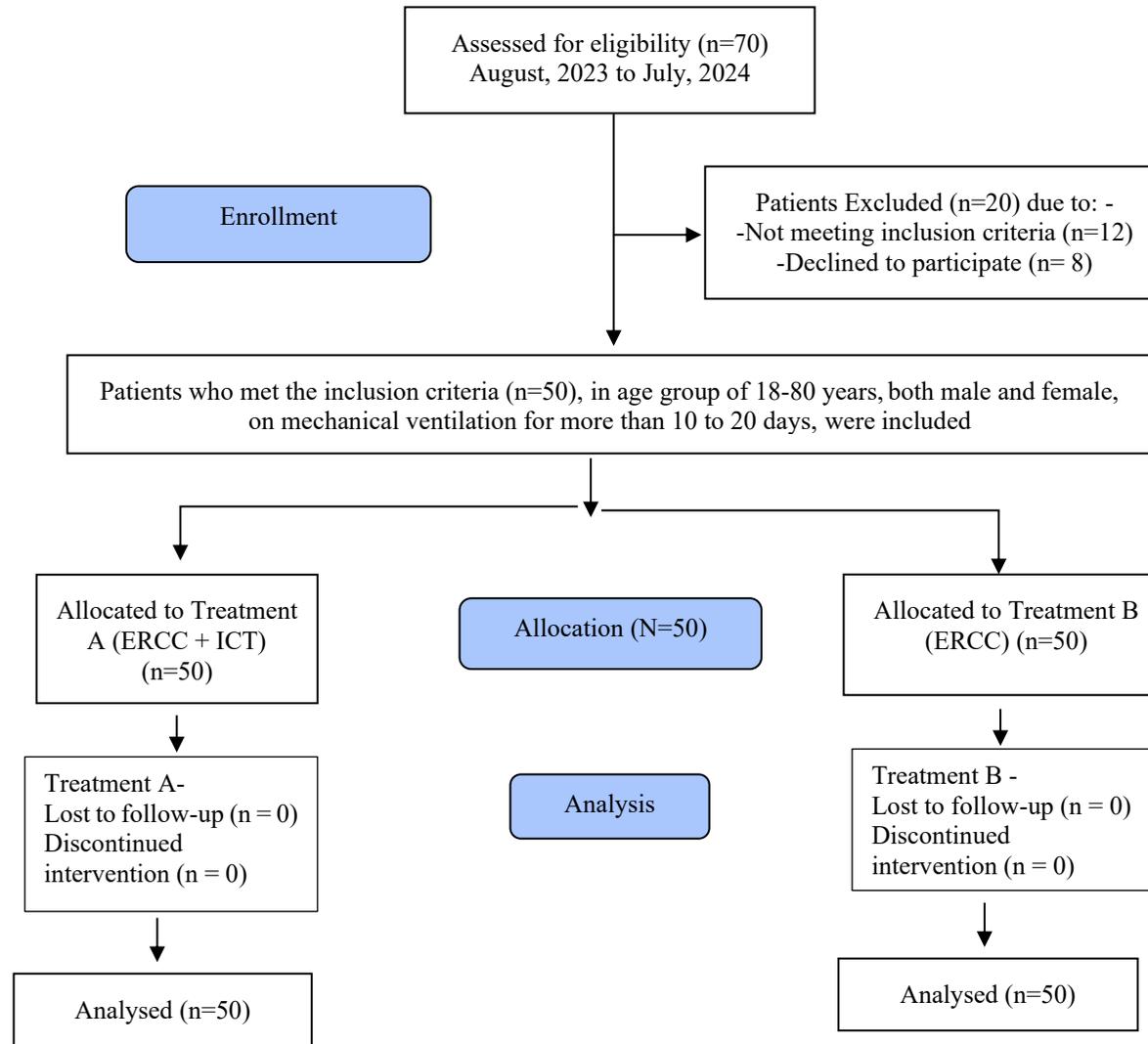
Figure 1: CONSORT (Consolidated standards of Reporting Trails) flow diagram of study participants from enrolment to analysis

Table 1: Gender Distribution of the Study Population (N = 50) and clinical Characteristics of the Study Population

Gender	Category	Frequency (n)	Percentage (%)
	Male	28	56%
	Female	22	44%
Variable	Category	Frequency (n)	Percentage (%)
Diagnosis	Respiratory	50	100%
Ventilation mode	VC-AC	26	52%
	VC-SIMV	14	28%
	SPN-CPAP	12	24%
	VC-CMV	3	6%
	VC-BIPAP	1	2%
Airway type	Endotracheal Tube (ET)	42	84%
	Tracheostomy Tube (TT)	8	16%
No. Of days on ventilator	10 to 20 days	Mean value	Standard deviation
		14.2	3.14

VC-AC: Volume-Controlled Assist Control; VC-SIMV: Volume-Controlled Synchronized Intermittent Mandatory Ventilation; SPN-CPAP: Spontaneous Continuous Positive Airway Pressure; VC-CMV: Volume-Controlled Continuous Mandatory Ventilation; VC-BIPAP: Volume-Controlled Bilevel Positive Airway Pressure.

Table 2: Age Comparison Across participants with different demographic characteristics

Comparison	Groups compared	Test type	Mean age (years)	P-value
Age by gender	Male (47.12) vs Female (44.67)	Independent t-test	t = 0.575	0.568; NS
Age by airway type	ET (45.33) vs TT (48.13)	Independent t-test	t = -0.527	0.601; NS
Age by ventilator mode	VC-AC (47.31), VC-SIMV (44.29), SPN-CPAP (50.17), VC-CMV (39.33), VC-BIPAP (21)	One-way ANOVA	F = 1.46	0.227; NS

NS: - non significant

Table 3: -Comparison of Static lung compliance mean values (C_{ST} ml/cm H_2O) between Treatment -A (ERCC+ICT) and Treatment -B (ERCC)

Variable	Intervention	Time interval (in minutes)				F VALUE; #p VALUE	COHEN'S D EFFECT SIZE
		PRE	POST-1 (After 0 min.)	POST-2 (After 30 min.)	POST-3 (After 60 min.)		
C_{ST} mL/cm H_2O (mean ± S.D.)	Treatment-A (ERCC+ICT)	35.53[a] ± 13.45[a]	52.31[b] ± 18.73 (47.24%)	56.52b[bc] ± 20.89 (59.09%)	60.29[cd] ± 22.16 (69.71%)	14.43; p< 0.01**	0.25; large
	Treatment -B (ERCC)	33.29[a] ± 20.10	43.75[b] ± 22.92 (31.45%)	43.76[b] ± 22.93 (31.45%)	43.76[b] ± 22.92 (31.47%)	73.28; p< 0.01**	0.04; medium
	t- value	0.65	2.04	2.91	3.67		
	@ p-value	0.26[NS]	0.02**	0.01**	0.01**		

Values in parenthesis are mean percentage changes from baseline measurements.
*Measurements are statistically significant at p<0.05; ** Highly Significant at p<0.01.
***Means with different superscripts in a column differ significantly (p<0.05). NS= non-significant.
#p value: p values for within group differences evaluated through one-way ANOVA,
@p values for between group differences evaluated through unpaired "t" test

Table 4: Comparison of SpO2 mean values between Treatment -A (ERCC+ICT) and Treatment -B (ERCC)

Variable	Intervention	Time interval (in minutes)				F VALUE; #p VALUE	COHEN'S D EFFECT SIZE
		PRE	POST-1 (After 0 min.)	POST-2 (After 30 min.)	POST-3 (After 60 min.)		
SpO2 (mean ± S.D.)	Treatment-A (ERCC+ICT)	97.56a ± 1.38	99.66b ± 0.60 (2.15%)	99.66b± 0.66 (2.15%)	99.76b ± 0.56 (2.15%)	76.583; p<0.01**	1.17; large
	Treatment-B (ERCC)	97.86^a ± 1.25	99.18^b ± 0.75 (1.34%)	99.22^b ± 0.79 (1.38%)	99.26^b ± 0.76 (1.43%)	28.11; p<0.01**	0.43; large
	t- value	1.14	3.56	3.03	3.79		
	*p-value	2.55^{NS}	0.01**	0.01**	0.01**		

Values in parenthesis are mean percentage changes from baseline measurements.
*Measurements are statistically significant at p<0.05; ** Highly Significant at p<0.01.
***Means with different superscripts in a column differ significantly (p<0.05). NS= non-significant.
#p value: p values for within group differences evaluated through one way ANOVA,
@p values for between group differences evaluated through unpaired "t" test.

Table 5: Comparison of hemodynamic and respiratory parameters recorded at various time intervals with Treatment -A (ERCC+ICT) and Treatment -B (ERCC)

Variable and time interval	Intra-class correlation coefficient (ICC)	ERCC+ICT/ Treatment -A	ERCC/Treatment -B
SBP (PRE-POST 3-time interval)	ICC	0.93	0.9
	95% Confidence interval	0.84-0.97	0.63-0.96
	p value	0.01**	0.01**
DBP (PRE-POST 3-time interval)	ICC	1	0.49
	95% Confidence interval	1-1	0.35-0.63
	p value	0.01**	0.01**
HR (PRE-POST 3-time interval)	ICC	0.98	0.91
	95% Confidence interval	0.96-0.99	0.75-0.96
	p value	0.01**	0.01**
RR (PRE-POST 3-time interval)	ICC	0.89	0.83
	95% Confidence interval	0.74-0.88	0.48-0.93
	p value	0.01**	0.01**

Measurements are statistically significant at p<0.05; ** Highly Significant at p<0.01.

Table 6: Comparison of ABG parameters recorded at various time intervals with Treatment -A (ERCC+ICT) and Treatment -B (ERCC)

Variable and time interval	Intra-class correlation coefficient (ICC)	ERCC+ICT/ Treatment -A	ERCC/ Treatment -B
pH (PRE-POST 2-time interval)	ICC	0.95	0.93
	95% Confidence interval	0.92-0.97	0.89-0.96
	p value	0.01**	0.01**
pCO2 (PRE-POST 2-time interval)	ICC	0.97	0.95
	95% Confidence interval	0.90-0.99	0.90-0.98
	p value	0.01**	0.01**
paO2 (PRE-POST 2 time interval)	ICC	0.9	0.92
	95% Confidence interval	0.67-0.96	0.83-0.96
	p value	0.01**	0.01**
P/F ratio (PRE-POST 2-time interval)	ICC	0.96	0.88
	95% Confidence interval	0.87-0.98	0.79-0.93
	p value	0.01**	0.01**

Measurements are statistically significant at p<0.05; ** Highly Significant at p<0.01.
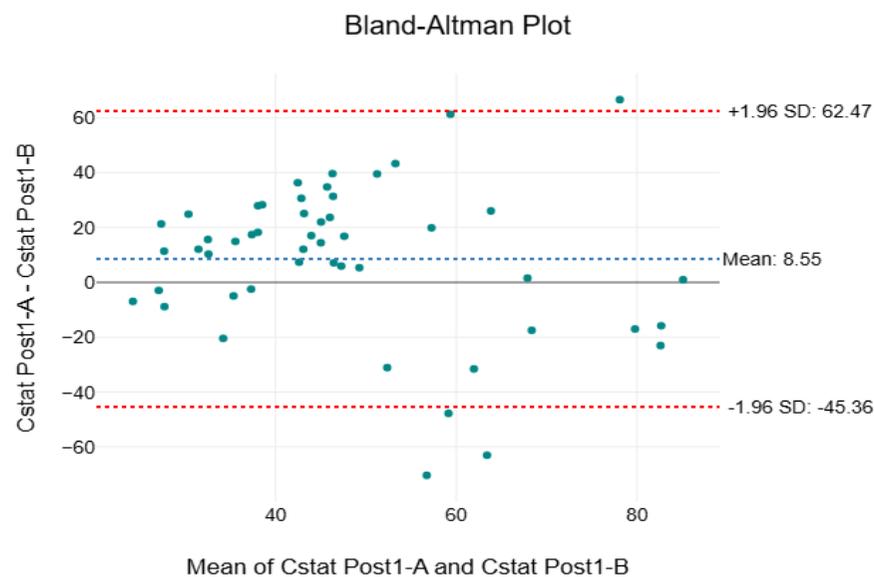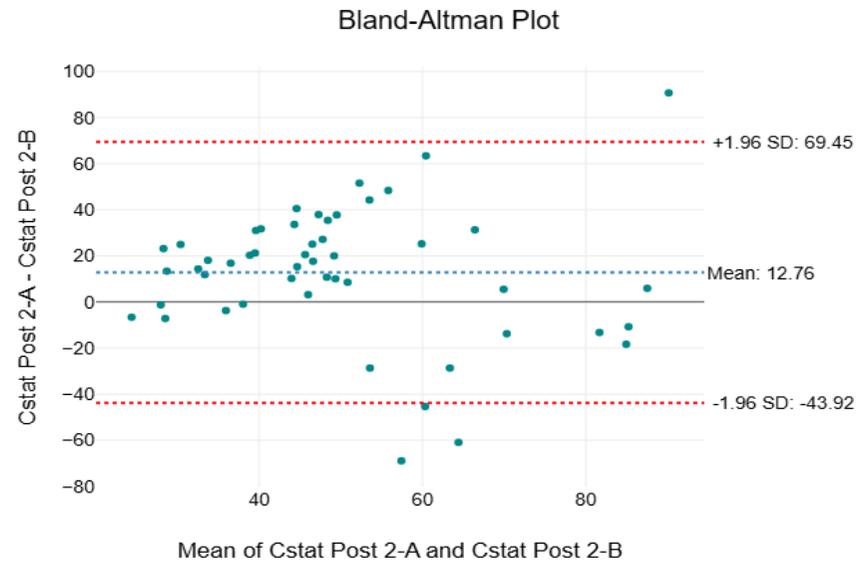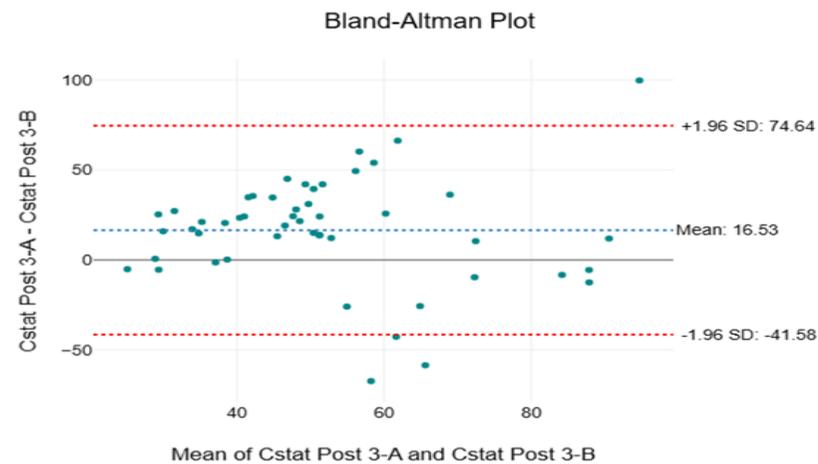

Fig. 2A

Fig. 2B

Fig. 2C

Figure 2 (A-C). Bland-altman plots showing mean difference between Static lung compliance mean values recorded in Treatment-A(ERCC+ICT) and in Treatment–B (ERCC) at POST-1 time interval (Fig. 2A), at POST-2-time interval (Fig. 2B), at POST-3-time interval (Fig. 2C),

Group A demonstrated highly significant improvements in oxygen saturation at all post-intervention time points compared to Group B. This aligns with previous research indicating that ERCC enhances oxygenation by facilitating secretion clearance and improving ventilation-perfusion matching. Unoki et al. (2005)[10] and Yaghoubi et al. (2017)[13] reported improved SpO$_2$ and oxygenation when ERCC was applied prior to suctioning. Also, Gupta et al (2014)[1] reported significant improvements in SpO$_2$ and respiratory rate following ICT supporting the additive effects of ERCC and ICT. This demonstrates that combining mobilization techniques with secretion management can maximize oxygen delivery and reduce hypoxemic episodes.

While heart rate increased significantly post-intervention in Group B, Group A maintained a more stable heart rate, combined ERCC + ICT may promote better autonomic balance or reduced respiratory distress. This is in line with findings by Gupta et al. (2014)[1] and Khalil et al. (2021)[2], who noted that combining ICT with manual techniques can have a stabilizing effect on heart rate and oxygenation.

No significant changes were found in systolic or diastolic blood pressures between or within groups, confirming the hemodynamic safety of ERCC and ICT, corroborating earlier findings by Naue et al. (2014)[12] and Bousarri et al. (2014)[3]. A rise in RR was observed in Group B post-intervention, whereas Group A maintained significantly lower RR values, which may indicate more efficient ventilation mechanics and reduced work of breathing. The outcomes support previous studies suggesting that intercostal stretch and rib cage mobilization reduce respiratory effort in both healthy and ICU patients.

Although PCO$_2$ levels improved significantly within Group B, the between-group differences were not statistically significant. Prior animal studies by Unoki et al. (2004)[6] demonstrated that ERCC combined with suctioning improved gas exchange in atelectatic lungs, but translation to human patients might vary depending on pathology and baseline ventilation settings. Similarly, no significant changes in pH, PaO$_2$, or PaO$_2$/FiO$_2$ ratio were noted between groups, which is comparable to findings by Hosoe et al. (2022)[14], suggesting that the effect of ERCC on gas exchange may be limited in short durations or influenced by lung pathology heterogeneity.

The evidence gathered supports the use of combined ERCC and ICT as a superior modality over ERCC alone. These results agree with the conclusions of several previous studies and reviews[1-14], reinforcing the physiological plausibility and clinical utility of multimodal chest physiotherapy in mechanically ventilated patients.

CONCLUSION
The findings of present study led us to accept the alternate hypothesis that combination of ERCC with ICT is effective in improving respiratory parameters, and maintaining hemodynamic stability in mechanically ventilated patients than ERCC alone. These findings highlight the potential of integrating ERCC and ICT into respiratory care protocols for critically ill patients, offering a viable adjunct to conventional ventilation support that may contribute to better respiratory outcomes and patient comfort in the ICU setting.

Limitations
Participants were not followed for a longer period of time, limiting the ability to assess the long-term effects of the interventions on respiratory outcomes and overall patient recovery.

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