ORIGINAL ARTICLE

PREDICTING POST-EXTUBATION RESPIRATORY FAILURE AFTER MYOCARDIAL INFARCTION USING THE RAPID SHALLOW BREATHING INDEX AND LUNG ULTRASOUND SCORE

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Background: The Rapid Shallow Breathing Index (RSBI) has been hypothesized to have discriminating power for categorizing patients at higher risk of post-extubation respiratory failure (RF). Hence aim of this study was to determine the predictive value of RSBI for post-extubation RF in patients after acute myocardial infarction (AMI). **Methods:** Consecutive, intubated patients admitted post-revascularization were included. RSBI and lung ultrasound score (LUS) were measured and post-extubation RF within 48 hours was recorded. **Results:** RF was observed in 36.3% (78/215) patients. For the prediction of RF, RSBI and LUS had area under the curve of 0.670 and 0.635, respectively. The sensitivity, specificity, negative predictive value, and positive predictive value of RSBI >50.5 were 75.6%, 54.7%, 79.8%, and 48.8% respectively, while, the accuracy measures for the combination of RSBI with LUS >1.5 were 44.9%, 84.7%, 73.0%, and 62.5% respectively. **Conclusion:** Combined RSBI and LUS measured during spontaneous breathing trial in patients after an AMI, have high predictive abilities for identifying post-extubation RF.

Keywords: Acute myocardial infarction; Extubation; Noninvasive ventilation

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INTRODUCTION

Fifty-seven (57%) percent of patients after an acute myocardial infarction (AMI) may develop respiratory failure due to either cardiogenic pulmonary oedema or increased work of breathing due to a poor cardiac reserve.[1] Non-invasive ventilation has been well described to reduce the risk and complications associated with post-extubation failure. In patients with chronic obstructive pulmonary disease (COPD) exacerbation, early post-extubation non-invasive ventilation (NIV) decreases mortality rates, duration of invasive ventilation, length of intensive care unit (ICU) and hospital stay and ventilator associated pneumonia.[2–8] In patients with acute hypoxemic respiratory failure (ARF), NIV after planned extubation is more effective in preventing re-intubation and decreases hospital mortality compared to oxygen alone.[9–16] The ratio of respiratory rate (f) to the tidal volume (VT), known as the Rapid Shallow Breathing Index (RSBI), is an important variable for the assessment of a patient's readiness for extubation during liberation from ventilator. It was developed by Tobin and Yang to help clinical decision making for extubation of critically ill patients.[17,18] Utility of the RSBI as a liberating tool has been assessed by various studies, and the cutoff value of 105 remains the most widely used value in intubated patients.[17,18] There is clinical evidence supporting the role of RSBI to help predict the need for NIV in patients with COPD exacerbations.[18,19] It has also been observed as a strong predictor of NIV failure in patients with ARF.[17–19] There is very limited data available about the use of post-extubation NIV for respiratory failure (RF) in patient with acute myocardial infarction (AMI). There are also no risk stratification tools available to guide the clinician as to which patient may need or benefit from early NIV for RF after extubation. We hypothesized, that as the RSBI can identify patient readiness for extubation, in the same way, it can also be used to predict which patient might need NIV for RF post-extubation. Timely NIV may prevent re-intubation and decrease duration of CCU stay. The aim of this study was to determine the predictive value of RSBI for predicting post-extubation RF in patients with AMI. A secondary objective was to determine relationships of hemodynamic, metabolic, ultrasonographic variables with post-extubation RF.

MATERIAL AND METHODS

This prospective, observational single-center study included consecutive adult patients who presented with acute myocardial infarction (AMI). Patients included required invasive mechanical ventilation post angiography/angioplasty, admitted in the coronary care unit of a tertiary care cardiac center. Period of study was between November 2020 and May 2021. This protocol was reviewed and approved by the Ethical Review Committee. Verbal consent for participation and publication was obtained from the patients' attendants or legal caretaker. Inclusion criteria was consecutive, adult patients (≥18 years) with AMI and requiring mechanical ventilation for >24 hours. Patients placed on NIV for post extubation stridor or patients with "do not intubate" and/or "do not resuscitate" order at the time of extubation were excluded. Acute myocardial infaction was diagnosed as per the 4th universal definition of MI.[20] RSBI was calculated as a ratio of respiratory frequency (f) divided by the tidal volume (VT).[17]

Respiratory failure (RF) was defined as presence of at least one of the following criteria;

1) PaO2<60 mmHg on room air, saturation <90% on room air, decrease in PaO2 >30 mmHg from baseline if the patients were on oxygen or an increase in the FiO2 requirement.
2) PH <7.30 and PaCO2 >45 mmHg.
3) A > 4 point increase (more negative) in the base deficit over a one hour observation period from the baseline level.
4) Tachypnoea (respiratory rate >30) or respiratory distress (using accessory muscles of respiration).

After 24 hours of invasive mechanical ventilation, patients were evaluated daily. Liberation from ventilator was considered based on patients' haemodynamics, metabolic profile, ventilator requirements, and clinical condition. Specific criteria under consideration were divided into clinical and lab parameters. Clinical criteria included absence of arrhythmias, declining vasopressors (Noradrenaline dose of ≤0.1 µg/kg/min) and less secretions, atelectasis, bronchospasm with a normal cough and gag reflex and a GCS ≥10. Lab parameters included improving hypoxemia defined as oxygen saturation (SaO_2) of ≥90% on fraction inspired oxygen (FiO_2) ≤40%, normal electrolytes, haemoglobin level ≥ 8 g/dl, RSBI < 105 and absence of any respiratory infection.[18] The liberation protocol was based on a gradual reduction of pressure-support ventilation mode (PSV) to obtain an expiratory tidal volume of 8 ml/kg.

When the patient was considered ready for extubation, a spontaneous breathing trial was carried out on PSV of 5 cm H_2O, positive end expiratory pressure (PEEP) 5 cm H_2O, $SaO_2 \geq 90\%$, $FiO_2 < 40\%$, and f/TV < 105. RSBI was assessed at 3 levels of PEEP and pressure support (PS); PEEP of 5 cm and PS of 5 cm of H_2O (5, 5), PEEP of 0 cm H_2O and PS of 5 cm H_2O (0, 5), and PEEP of 0 cm H_2O and PS of 0 cm H_2O (0, 0). RSBI was calculated as a ratio of frequency (f) divided by the tidal volume (VT). We used a protocolised approach whereby during spontaneous breathing trial (SBT), RSBI was calculated serially at varying levels of support. This attempts to identify underlying valvular and myocardium dysfunction at different levels of pressure support. The patient is rested for a minimum of 30 minutes to prevent exhaustion by weaning efforts, Additional pre and post SBT hemodynamic and metabolic parameters were recorded; heart rate (HR), systolic blood pressure (SBP), pH, base excess (BE), arterio-venous carbon dioxide (CO2) gap, mixed venous oxygen concentration (ScvO2), and PaCO2. Pre and post SBT lung ultrasound was performed in all the patients and the Lung Ultrasound Score was calculated as described by Soummer *et al*.[21] Four ultrasound aeration patterns were defined and were assessed in each intercostal space. Normal aeration (N); characterized by the presence of lung sliding with horizontal "A lines" and, 1 or 2 isolated vertical "B lines". Moderate loss of lung aeration (B1 line); characterized either by multiple well-defined and regularly spaced 7-mm apart "B1 lines", issued from the pleural line and corresponding to interstitial oedema. Severe loss of lung aeration (B2 line); characterized by multiple coalescent vertical B2 lines issued from the pleural line and corresponding to alveolar oedema. Complete loss of lung aeration (C) resulting in lung consolidation and characterized by the presence of a tissue pattern containing either hyperechoic punctiform images representative of static air bronchograms, or hyperechoic tubular images, representative of dynamic air bronchograms. For a given region of interest, points were allocated according to the worst ultrasound pattern observed, a score of 0 for N, 1 for B1 lines, 2 for B2 lines, and 3 for C. The total lung ultrasound score was calculated as the sum of the 12 regions examined.[21]

All the patients were kept under continual, routine CCU monitoring. Noninvasive ventilation (NIV) was applied by the assigned ICU physician for the signs of RF as defined above. Sample size for the study was calculated based on the results of the study conducted by Soleimanpour *H et al*.[18] Statistics used for calculation were 43.9% NIV requirement due to RF at 110 cutoff of RSBI with sensitivity and specificity of 94.8% each in predicting NIV requirement, at 95% confidence level with 5% absolute precision. The required sample size for the study was calculated to be n=174 patients. In order to minimize the selection bias and exclusion of patients due to information loss, the calculated sample size was inflated by a factor of 25% (1.25×174=218).

Collected data was analyzed using SPSS version 21.0. Descriptive statistics were computed for the study variables. Baseline demographic and clinical characteristics were compared for the patients with and without post-extubation RF by the independent sample t-test or Chi-square tests. Pre and post SBT hemodynamic parameters, metabolic parameters, and LUS were compared within each group by the paired sample t-test, while, pre and post parameters between the groups were compared by the independent sample t-test. A receiver operating characteristic curve (ROC) was constructed to predictive abilities of the RSBI for predicting post extubation RF. Area under the curve (AUC) along with 95% confidence intervals (CI) were obtained for all the classifiers. The optimal cut-off value for RSBI and LUS for prediction of post-extubation RF was obtained using Youden's J statistic and sensitivity, specificity, negative predictive value (NPV), and positive predictive values (PPV) were calculated. In the post-hoc analysis, decision tree analysis was performed taking post-extubation RF as dependent variable and RSBI (0, 0) and post SBT LUS as independent variables. Method of categorization was Chi-square automatic interaction detection (CHAID) and event rate at each subsequent node(s) were computed. Multivariable logistic regression analysis was performed taking post-extubation RF as the dependent variable and clinically significant variables as independent variables including age ≥65 years, female gender, chronic kidney disease, coronary artery disease, hypertension, COPD, diabetes mellitus, mitral regurgitation (moderate to severe), biventricular dysfunction, ejection fraction ≤ 30%.). Apart from RSBI (0, 0) ≥51 and LUS (post SBT) ≥2, arrhythmias, use of vasopressors, CPR, heart rate (post SBT) ≥100 bpm, base excess (post SBT) were also noted. Backward conditional method was used for model selection with probability of stepwise entry as 0.05 and removal as 0.10 and results for the logistic regression analysis are reported by computing odds ratios (OR) and 95% confidence intervals (CI). Throughout the analysis a *p*-value ≤0.05 was taken as criteria for statistical significance.

RESULTS

A total of 215 patients were observed during the study period; 69.8% (150) were males and mean age was 60.56 ± 11.37 years. Hypertension was observed in 70.2% (151) followed by diabetes 50.7% (109). Fifty-one (23.7%) had moderate to severe mitral regurgitation, 5.6% (12) of the patients had a normal ejection fraction (>45%) at baseline with LV dysfunction in 92.1% (198). RV dysfunction in 20.5% (44) and biventricular dysfunction 18.1% (39) patients. Forty-six (21.4%) patients had arrhythmias and vasopressors were administered in 41.4% (89). Forty-two (19.5%) patients were post CPR. At the time of inclusion, 82.3% (177) of the patients had leukocytosis, 17.2% (37) had fever, and 57.7% (124) had an abnormal chest X-ray.

Baseline and clinical characteristics of patients stratified by post-extubation RF are presented in Table 1.

Post-extubation RF was observed in 36.3% (78) patients. Patients who developed RF had higher rate of moderate to severe MR (32.1% vs. 19.0%; *p*=0.030) and low oxygen saturation (96.18±10.81% vs. 98.55±1.95%; *p*=0.013) compared to those who did not have post-extubation RF. Among haemodynamic parameters, a significant positive association of heart rate (HR) was observed with post-extubation RF. Between the group comparison of pre-SBT HR was 100.1±19.4 vs. 94.31±13.99; *p*=0.004 for the patients with and without post-extubation RF, respectively. Similarly, between the group comparison of post-SBT HR was 99.04±14.59 vs. 95.63±14.13; *p*=0.032 for the patients with and without post-extubation RF, respectively (Table-2). Among metabolic parameters, base excess (BE) had significant association with post-extubation RF. Between the group comparison of pre-SBT BE was 0.53±3.67 vs. -0.37±3.76; *p*=0.015 for the patients with and without post-extubation RF, respectively. Similarly, between the group comparison of post-SBT BE was 0.78±3.77 vs. -0.22±3.14; *p*=0.008 for the patients with and without post-extubation RF, respectively (Table-2). The mean RSBI at all three levels of peep and pressure support were significantly higher among patients with post-extubation RF as compared to patients without post-extubation RF. Mean RSBI at peep 0 and pressure support of 0 was 61.01±17.24 vs. 51.68±14.22; *p*<0.001 for with and without post-extubation RF respectively.

Lung ultrasound scores (LUS) obtained at the beginning and end of spontaneous breathing trials (5,5) were significantly different between patients with and without post-extubation RF; pre-SBT mean LUS was 2±2.61 vs. 0.86±1.56; *p*<0.001 (between the group comparison) and post-SBT LUS was 2.5±2.84 vs. 1.24±2.02; *p*<0.001 (between the group comparison), respectively (Table2). The receiver operating characteristic (ROC) analysis for the risk stratification of post-extubation RF with pre and post SBT change in various hemodynamic and metabolic parameters, lung ultrasound score, and RSBI are presented in Figure 1. RSBI at all three levels of PEEP and pressure support and post weaning change in LUS showed a significant discriminating power amongst all other parameters (Figure-1). The AUC for post SBT LUS was 0.635 [95% CI; 0.555 to 0.715], similarly, the AUC of RSBI at PEEP and pressure support of (5, 5), (0, 5), and (0, 0) were 0.624 [95% CI; 0.546 to 0.702], 0.637 [95% CI; 0.559 to 0.716], and 0.670 [95% CI; 0.594 to 0.746] respectively. The optimal cut-off value for the end SBT LUS was ≥2 and the cut-off value for RSBI at PEEP and pressure support of (0, 0) was found to be ≥51. The sensitivity, specificity, NPV, and PPV for in individual as well as combined discriminating criteria are provided in Table-3.

In the post-hoc analysis, the discriminating power of the combination of the two criteria, i.e., LUS ≥1.5 and RSBI (0,0) >50.5, is presented in Figure 2B, the combination has a sensitivity of 44.9% [95% CI; 33.6–56.6%], specificity of 84.7% [95% CI; 77.5–90.3%], NPV of 73.0% [95% CI; 68.6–76.9%], and PPV of 62.5% [95% CI; 51.2–72.6%]. The decision tree analysis for post-extubation RF deduced same cut-off values for RSBI (0, 0) and LUS. The event rate for the patients with LUS >1.5 and RSBI (0, 0) >50.5 was found to be 62.5% (35/56) (Node 4 in Figure 2B) as against 36.9% (24/65) in patients group where RSBI > 50.5 but LUS ≤1.5 (Node 3 in Figure 2B) and 20.2% (19/94) in patients group where RSBI ≤50.5 (Node 1 in Figure 2B). In a subgroup analysis of patients with RSBI ≤ 50.5 {measured during a spontaneous breathing trial with PEEP 0, PSV 0}, patients with post-extubation RF had significantly higher pre-existing CAD, 36.8% (7/19) vs. 13.3% (10/75); *p*=0.017 and pre and post SBT LUS scores; 1.89±3.09 vs. 0.85±1.47; *p*=0.035 and 2.47±3.12 vs. 1.2±1.99; *p*= 0.030 respectively.

Table-1: Baseline and clinical characteristics of patients stratified by post-extubation respiratory failure

Characteristics	Total	Post-extubation Respiratory Failure		p-value
		No	Yes	
Total (N)	**215**	**137 (63.7%)**	**78 (36.3%)**	-
Gender				
Male	69.8% (150)	72.3% (99)	65.4% (51)	0.291
Female	30.2% (65)	27.7% (38)	34.6% (27)	
Age (years)	60.56 ± 11.37	59.99 ± 11.14	61.58 ± 11.75	0.325
22 to 50 years	19.1% (41)	21.2% (29)	15.4% (12)	0.570
51 to 65 years	50.7% (109)	48.9% (67)	53.8% (42)	
> 65 years	30.2% (65)	29.9% (41)	30.8% (24)	
Co-morbid conditions				
Chronic kidney disease	8.4% (18)	8.8% (12)	7.7% (6)	0.786
Coronary artery disease	17.7% (38)	16.1% (22)	20.5% (16)	0.410
Hypertensive	70.2% (151)	67.2% (92)	75.6% (59)	0.191
COPD	14% (30)	13.9% (19)	14.1% (11)	0.962
Diabetes mellitus	50.7% (109)	46.7% (64)	57.7% (45)	0.122
Mitral regurgitation	23.7% (51)	19% (26)	32.1% (25)	0.03*
Ejection Fraction				
20 to 30%	44.2% (95)	44.5% (61)	43.6% (34)	0.96
30 to 45%	50.2% (108)	49.6% (68)	51.3% (40)	
>45%	5.6% (12)	5.8% (8)	5.1% (4)	
Ventricular septal rupture	1.9% (4)	2.2% (3)	1.3% (1)	0.636
LV Dysfunction	92.1% (198)	92.7% (127)	91% (71)	0.662
RV Dysfunction	20.5% (44)	18.2% (25)	24.4% (19)	0.286
LV Dimension: Systolic	36.06 ± 7.37	35.94 ± 7.7	36.27 ± 6.81	0.755
LV Dimension: Diastolic	46.73 ± 7.31	46.77 ± 7.04	46.64 ± 7.8	0.899
RV Dimension	20.44 ± 3.81	20.12 ± 3.41	21 ± 4.39	0.105
Biventricular Dysfunction	18.1% (39)	15.3% (21)	23.1% (18)	0.156
Arrhythmias	21.4% (46)	19.7% (27)	24.4% (19)	0.424
Vasopressors	41.4% (89)	38% (52)	47.4% (37)	0.175
P/F Ratio	340.19 ± 108.1	345.5 ± 111.36	330.86 ± 102.17	0.341
≤300	47% (101)	47.4% (65)	46.2% (36)	0.855
>300	53% (114)	52.6% (72)	53.8% (42)	
Initial elective intubation	80.9% (174)	79.6% (109)	83.3% (65)	0.499
Post CPR	19.5% (42)	20.4% (28)	17.9% (14)	0.658
Secretions	96.3% (207)	95.6% (131)	97.4% (76)	0.499
1	81.2% (168)	84.7% (111)	75% (57)	0.116
2	16.9% (35)	14.5% (19)	21.1% (16)	
3	1.9% (4)	0.8% (1)	3.9% (3)	
Cough Reflex	100% (240)	100% (150)	100% (90)	-
Gag Reflex	100% (240)	100% (150)	100% (90)	-
Cuff Leak	99.5% (214)	99.3% (136)	100% (78)	0.449
Sepsis				
Fever	17.2% (37)	15.3% (21)	20.5% (16)	0.333
Leukopenia	0.9% (2)	0% (0)	2.6% (2)	0.060
Leukocytosis	82.3% (177)	83.2% (114)	80.8% (63)	0.652
CXR abnormality	57.7% (124)	54% (74)	64.1% (50)	0.150
PSV	14.47 ± 2.43	14.42 ± 2.35	14.55 ± 2.57	0.696
PEEP	5 ± 0	5 ± 0	5 ± 0	-
Oxygen Saturation (SO_2)	97.69 ± 6.77	98.55 ± 1.95	96.18 ± 10.81	0.013*
FiO_2	40.13 ± 7.64	39.38 ± 3.06	41.44 ± 11.96	0.058

COPD = chronic obstructive pulmonary disease, LV = left ventricle, RV= right ventricle, CPR = cardiopulmonary resuscitation, CXR = chest X-ray, PSV = pressure support ventilation, PEEP = positive end expiratory pressure, FiO2 = fraction inspired oxygen. *significant at 5%

Table-2: Lung ultrasound score, haemodynamic, and metabolic parameters of the patients stratified by post-extubation respiratory failure

Characteristics	Total	Post-extubation Respiratory Failure		^P-value
		No	Yes	
Total (N)	**215**	**137 (63.7%)**	**78 (36.3%)**	-
Ultrasound Lung Score Before SBT				
B1 lines	33% (71)	26.3% (36)	44.9% (35)	0.010*
B2 lines	5.1% (11)	3.6% (5)	7.7% (6)	
Consolidation	0.5% (1)	0.7% (1)	0% (0)	
Normal	61.4% (132)	69.3% (95)	47.4% (37)	
Ultrasound Lung Score at End of SBT				
B1 lines	37.7% (81)	32.1% (44)	47.4% (37)	0.018*
B2 lines	6.5% (14)	4.4% (6)	10.3% (8)	
Consolidation	0.5% (1)	0.7% (1)	0% (0)	
Normal	55.3% (119)	62.8% (86)	42.3% (33)	
Lung Ultrasound Score (LUS) at PEEP, PSV (5,5)				
Pre-SBT	1.27 ± 2.08	0.86 ± 1.56	2 ± 2.61	<0.001*
Post- SBT	1.7 ± 2.42	1.24 ± 2.02	2.5 ± 2.84	<0.001*
Δ LUS	0.42 ± 1.02	0.38 ± 1.03	0.5 ± 0.99	0.063
˜P-value	<0.001*	<0.001*	<0.001*	-
Heart rate (HR)				
Pre- SBT	96.41 ± 16.36	94.31 ± 13.99	100.1 ± 19.4	0.004*
Post- SBT	96.87 ± 14.36	95.63 ± 14.13	99.04 ± 14.59	0.032*
%Δ HR	1.14 ± 9.65	1.68 ± 8.11	0.19 ± 11.88	0.351
˜P-value	0.233	0.010*	0.821	-
Systolic blood pressure (SBP)				
Pre- SBT	124.34 ± 18.3	125.04 ± 19.05	123.1 ± 16.95	0.277
Post- SBT	123.31 ± 17.27	123.4 ± 17.98	123.15 ± 16.06	0.787
%Δ SBP	0 ± 12.13	-0.48 ± 12.17	0.86 ± 12.08	0.361
˜P-value	0.303	0.156	0.861	-
pH				
Pre- SBT	7.44 ± 0.06	7.44 ± 0.06	7.44 ± 0.06	0.382
Post- SBT	7.4 ± 0.34	7.41 ± 0.34	7.38 ± 0.35	0.444
Δ PH	-0.04 ± 0.34	-0.02 ± 0.34	-0.06 ± 0.34	0.349
˜P-value	0.062	0.365	0.061	-
Base Excess (BE)				
Pre- SBT	-0.05 ± 3.75	-0.37 ± 3.76	0.53 ± 3.67	0.015*
Post- SBT	0.14 ± 3.41	-0.22 ± 3.14	0.78 ± 3.77	0.008*
Δ BE	0.19 ± 2.3	0.15 ± 2.36	0.25 ± 2.21	0.980
˜P-value	0.600	0.675	0.754	-
Carbon Dioxide (CO_2) gap				
Pre- SBT	8.92 ± 4.47	8.88 ± 4.96	8.98 ± 3.89	0.624
Post- SBT	8.54 ± 4.25	8.82 ± 5.17	8.22 ± 2.81	0.322
Δ CO2 gap	-0.72 ± 4.52	-0.52 ± 5.27	-0.97 ± 3.48	0.296
˜P-value	0.058	0.585	0.011*	-
Mixed Venous Oxygen Concentration (ScvO2)				
Pre- SBT	66.42 ± 11.01	66.59 ± 12.61	66.23 ± 8.93	0.396
Post- SBT	67.36 ± 9.95	67.02 ± 11.04	67.75 ± 8.59	0.937
Δ $ScvO_2$	0.93 ± 9.79	0.42 ± 9.91	1.53 ± 9.7	0.284
˜P-value	0.128	0.739	0.064	-
Carbon Dioxide (CO_2)				
Pre- SBT	34.73 ± 5.52	34.24 ± 5.73	35.59 ± 5.03	0.081
Post- SBT	37.54 ± 6.49	37.13 ± 6.47	38.23 ± 6.5	0.082
Δ CO_2	2.84 ± 6.46	2.95 ± 6.64	2.64 ± 6.15	0.813
˜P-value	<0.001*	<0.001*	<0.001*	-
Glasgow Coma Scale (GCS)				
Pre- SBT	10.01 ± 0.36	9.99 ± 0.09	10.04 ± 0.59	0.382
Post- SBT	10.01 ± 0.36	9.99 ± 0.09	10.04 ± 0.59	0.382
Rapid Shallow Breathing Index (RSBI)				
RSBI at Peep 5 and Pressure Support 5	42.71 ± 15.29	40.13 ± 13.35	47.23 ± 17.4	<0.001*
RSBI at Peep 0 and Pressure Support 5	48.13 ± 15.68	45.11 ± 13.1	53.42 ± 18.32	<0.001*
RSBI at Peep 0 and Pressure Support 0	55.07 ± 15.99	51.68 ± 14.22	61.01 ± 17.24	<0.001*
****Reason of post-extubation respiratory failure**				
Hypoxemic respiratory failure	74.4% (58)	0% (0)	74.4% (58)	-
Hypercarbic respiratory failure	9% (7)	0% (0)	9% (7)	-
Any type of shock	1.3% (1)	0% (0)	1.3% (1)	-
Work of breathing	96.2% (75)	0% (0)	96.2% (75)	-
Outcomes				
Days in CCU	2.67 ± 1.31	2.18 ± 0.86	3.55 ± 1.49	<0.001*
Re-intubation	4.7% (10)	1.5% (2)	10.3% (8)	0.003*
Mortality in CCU	3.7% (8)	0.7% (1)	9% (7)	0.002*

Δ = absolute difference, %Δ = percentage difference, CCU = coronary care unit, SBT= spontaneous breathing trial
*significant at 5%, ^between the groups, ˜within the groups. **Multiple options possible and percentage are computed based on patients with post-extubation respiratory failure

Table-3: Accuracy assessment of rapid shallow breathing index and lung ultrasound score-based criteria for predicting post extubation respiratory failure

Measure	Criteria 1		Criteria 2		Criteria 3	
	Statistics	95% CI	Statistics	95% CI	Statistics	95% CI
Sensitivity	75.6%	64.6% to 84.7%	57.7%	46.0% to 68.8%	44.9%	33.6% to 56.6%
Specificity	54.7%	46.0% to 63.3%	67.2%	58.6% to 74.9%	84.7%	77.5% to 90.3%
PPV	48.8%	43.2% to 54.3%	50.0%	42.4% to 57.6%	62.5%	51.2% to 72.6%
NPV	79.8%	72.2% to 85.7%	73.6%	67.7% to 78.8%	73.0%	68.6% to 76.9%
Accuracy	62.3%	55.5% to 68.8%	63.7%	56.9% to 70.2%	70.2%	63.6% to 76.3%

CI = confidence interval, NPV = negative predictive value, PPV = positive predictive values, RSBI (0, 0) = rapid shallow breathing index at peep 0 and pressure support of 0, LUS = lung ultrasound score. Criteria 1 = RSBI (0, 0) ≥ 51. Criteria 2 = End weaning LUS ≥ 2. Criteria 3 = LUS ≥ 2 and RSBI (0, 0) ≥ 51

Table-4: Predictors of post-extubation respiratory failure

Parameters	Initial Solution		Final Solution	
	OR [95% CI]	P-value	OR [95% CI]	*p*-value
Age ≥ 65 years	1.13 [0.57 -2.24]	0.730	-	-
Female gender	1.17 [0.58 -2.38]	0.664	-	-
Chronic kidney disease	1.17 [0.37 -3.72]	0.784	-	-
Coronary artery disease	1.02 [0.42 -2.5]	0.958	-	-
Hypertensive	1.76 [0.84 -3.68]	0.136	-	-
COPD	1.31 [0.49 -3.46]	0.590	-	-
Diabetes mellitus	1.38 [0.72 -2.64]	0.328	-	-
Mitral regurgitation	1.95 [0.91 -4.19]	0.085	1.96 [0.97 -3.95]	0.062
Biventricular Dysfunction	1.73 [0.75 -4.02]	0.200	-	-
Ejection fraction ≤ 30%	0.87 [0.46 -1.68]	0.686	-	-
Arrhythmias	1.56 [0.7 -3.49]	0.275	-	-
Vasopressors use	1.45 [0.75 -2.83]	0.272	-	-
CPR	0.53 [0.22 -1.24]	0.142	-	-
Heart rate (post SBT) ≥100 bpm	0.92 [0.49 -1.73]	0.795	-	-
Base Excess (post SBT)	1.11 [0.59 -2.11]	0.742	-	-
RSBI (0,0) ≥ 51	4.32 [2.14 -8.71]	<0.001*	3.86 [2.03 -7.35]	<0.001*
LUS (post SBT) ≥ 2	2.81 [1.42 -5.55]	0.003*	2.42 [1.32 -4.46]	0.004*

OR = odds ratio, CI= confidence interval, COPD = chronic obstructive pulmonary disease, CPR = cardiopulmonary resuscitation, RSBI (0, 0) = rapid shallow breathing index at peep 0 and pressure support of 0, LUS = lung ultrasound score, SBT= spontaneous breathing trial. *significant at 5%

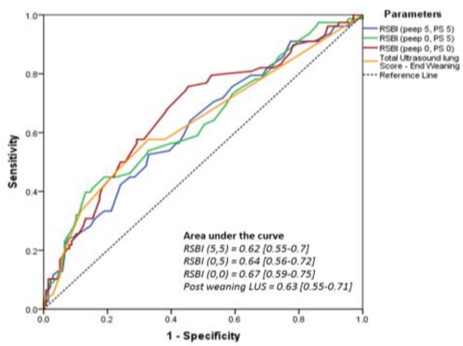

Figure-1: The receiver operating characteristic curve (ROC) analysis for prediction of post-extubation respiratory failure with lung ultrasound score and RSBI

RSBI = rapid shallow breathing index, LUS = lung ultrasound score, PEEP = positive end-expiratory pressure, PS = pressure support

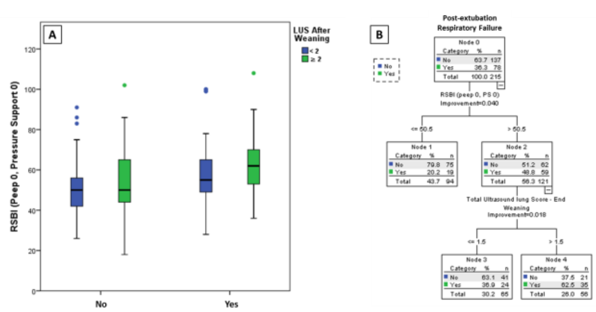

Figure-2: Combined discriminating power of end weaning lung ultrasound score and RSBI at peep and support of (0, 0)

RSBI = rapid shallow breathing index, LUS = lung ultrasound score

On multivariable logistic regression RSBI (0,0) ≥51, and post SBT LUS ≥2 were found to be independent predictors of post-extubation RF with odds ratios of 3.86 [2.03–7.35], and 2.42 [1.32–4.46] respectively.

DISCUSSION

This study shows that in patients intubated with an acute coronary syndrome, the RSBI measured during a spontaneous breathing trial has high predictive abilities for respiratory failure after extubation. This predictive accuracy was found to be consistent across varied levels of pressure support during the liberation process. We also found that an increase in the Lung Ultrasound Score during a spontaneous breathing trial is similarly predictive. The combination of RSBI and an increase in the LUS were additive.

Post- extubation pulmonary oedema has been reported in 44–87% patients with cardiovascular morbidity.[22,23] Respiratory muscle strength was assessed by Terzi et al in 130 patients after at least 72 hours of endotracheal mechanical ventilation (MV), where they described the Forced Vital Capacity as a useful measure (AUC 0.76).[24] However dynamic parameters that assess cardiorespiratory endurance may be of particular value in patients with variable cardiac reserve.

The RSBI as a predictor of deterioration has been evaluated previously for COPD and hypoxic respiratory failures. Frutos-Vivar *et al*., in a multicenter study of 900 intubated patients, 103 with cardiac dysfunction, reported that 13.4% patients failed extubation. An RSBI of > 57 breaths/L/min and positive fluid balance (OR, 3.0; 95% CI, 1.8–4.8) were identified as significant risk factors for failure.[25] Capucci *et al* in the Multisensor Chronic Evaluations in Ambulatory Heart Failure Patients Study (MultiSENSE) enrolled 528 patients implanted with cardiac resynchronization therapy defibrillators and observed a significant increase (6.0%) in RSBI before clinically apparent respiratory failure.[26] In an another study on post cardiac surgery patients by Takaki S *et al*.[27], the anthropometric parameter, such as body weight and body mass index, adjusted RSBI has been reported to have higher sensitivity and specificity for prediction of extubation failure as compared to non-adjusted RSBI. However, this study only included uncomplicated cardiac surgery patients with low risk of extubation failure, while, our study which was exclusively done in acute MI post-PCI patients at higher risk of extubation failure showed a comparable RSBI cut-off values.

Regarding the utility of RSBI as a predictor for advanced respiratory support; Soleimanpour *et al*.[18] in a study of 98 patients with acute hypercapnic respiratory failure due to COPD, showed that an RSBI of 110 had a sensitivity and specificity of 94.8% each in predicting the ultimate need for noninvasive respiratory support. Berg KM *et al*.[19] showed in 101 patients with acute respiratory failure, an RSBI of >105 was associated with significant increase in the risk of intubation (adjusted OR = 3.7) and in-hospital mortality (adjusted OR = 4.5). In our study of cardiac failure and pulmonary oedema patients, we demonstrated that the RSBI can similarly use to predict deterioration. Utility of RSBI as main criteria for weaning in post cardiac surgery patients was reported to be associated with a lower extubation times without any significant increase in re-intubation rate.[28] In addition to RSBI as an important variable for the assessment of a patient's readiness for extubation,[28] our study has found it as a significant predictor of post extubation respiratory failure.

The lung ultrasound is increasingly used as a bedside tool to identify increased extravascular lung water. Alexis Ferré et al found that among the 33 cases with spontaneous breathing trials failure, lung ultrasound diagnosed pulmonary edema with a sensitivity of 88% (64–98) and a specificity of 88% (62–98) with AUC of 0.91 (0.75–0.98).[29] Similarly, Maria Chiara Scali et al. in a prospective study found severe stress B-lines as independent predictors of death and nonfatal myocardial infarction with hazard ratio of 3.544 [95% CI: 1.466 to 8.687].[30] Soummer A *et al*.[21] reported that in a cohort of 100 critically ill, mechanically ventilated patients, a LUS of more than 17 after a spontaneous breathing trial was found to be highly predictive of post extubation distress with a positive likelihood ratio of 11.8. In our study, the combination of LUS with RSBI had significant clinical utility in determining post-extubation respiratory failure.

Mitral regurgitation (MR) may become clinically significant after the cardio protective effects of mechanical ventilation are removed. This can then lead to cardiogenic pulmonary oedema and respiratory failure. Our study showed that patients with MR are around two times (adjusted OR=1.96) at higher risk of developing post-extubation RF. Continuous positive airway pressure and bi-level airway pressure (BiPAP) application to patients with cardiogenic pulmonary oedema due to MR are well described.[31]

The strengths of our study are that we assessed dynamic variables at the bedside that would be useful in prognosticating this select group of reperfused patients after an acute MI. We found very few studies that have looked at predictors of extubation failure in this group of patients. Limitations may include a possible bias due to inter-physician variability that may have affected weaning and extubation practice, however, the bedside ICU team was blinded to the results of the RSBI and lung ultrasound scores and we consider that this may not be an important factor. Other limitations are the single center and relatively smaller sample size. Secondly, as this study was carried out during the pandemic, there is a possibility that patients admitted might comprise a different spectrum than usually encountered. None of the patients included in this study had COVID-19 and the Emergency department services remained unaltered, we therefore do not consider this to be a major problem.

From our study we can predict the value of RSBI for Respiratory failure. By knowing the cut-off value, we can apply NIV post extubation as this will help in reducing reintubation rate, number of days in CCU and also decrease the risk of acquiring nosocomial infections. The protocolised manner of liberation process will also help in identifying patients at risk of respiratory failure of cardiovascular origin and optimizing them before extubation will also help in reducing the reintubation rates. We found cut-off value of >2 LUS score in our study for predicting respiratory failure post extubation which is very low from other lung ultrasound studies. We presume that the reason for this low LUS score value is that our study population was properly revascularized, were diuresed before SBT and their heart failure was optimized before extubation. Therefore, we recommend lung ultrasound in every cardiovascular patient before liberation from ventilator to identify respiratory failure.

CONCLUSION

Our results support the bedside usage of RSBI and LUS obtained pre and post spontaneous breathing trials to predict post-extubation respiratory failure in acute MI patients. In clinical practice ICU physicians can consider an RSBI ($\geq$ 51 at PEEP of 0 and pressure support of 0) along with LUS ($\geq$ 2 absolute increase post- SBT) as a discriminant cut-off. Patients with mitral regurgitation and a prior history of CAD are at higher risk, regardless of RSBI assessment. Combined RSBI and LUS have additive predictive abilities.

AUTHORS' CONTRIBUTION

MIA, JA, MK, and NS contributed to the concept and design of study, MIA, MU, and KB contributed to the collection, analysis and interpretation of data, HM, MIA, MU, KB, and MK contributed to the drafting of the manuscript, and JA and NS critically analyzed for content. All authors have read and approved the manuscript.

REFERENCES

1. Vallabhajosyula S, Kashani K, Dunlay SM, Vallabhajosyula S, Vallabhajosyula S, Sundaragiri PR, *et al*. Acute respiratory failure and mechanical ventilation in cardiogenic shock complicating acute myocardial infarction in the USA, 2000–2014. Ann Intensive Care 2019;9(1):96.
2. Keenan SP, Sinuff T, Burns KE, Muscedere J, Kutsogiannis J, Mehta S, *et al*. Clinical practice guidelines for the use of noninvasive positive-pressure ventilation and noninvasive continuous positive airway pressure in the acute care setting. CMAJ 2011;183(3):E195–214.
3. Burns KE, Adhikari NK, Keenan SP, Mead MO. Noninvasive positive pressure ventilation as a weaning strategy for intubated adults with respiratory failure. Cochrane Database Syst Rev 2010;4:CD004127.
4. Burns KE, Adhikari NK, Keenan SP, Mead M. Use of noninvasive ventilation to wean critically ill adults off invasive ventilation: meta-analysis and systematic review. BMJ 2009;338:b1574.
5. Antonelli M, Bello G. Noninvasive mechanical ventilation during the weaning process: facilitative, curative or preventive. Crit Care 2008;12(2):136.
6. Nava S, Hill N. Non-invasive ventilation in acute respiratory failure. Lancet 2009;374(9685):250–9.
7. Nava S, Ambrosino N, Clini E, Prato M, Orlando G, Vitacca M, *et al*. Noninvasive mechanical ventilation in the weaning of patients with respiratory failure due to chronic obstructive pulmonary disease: a randomized, controlled trial. Ann Intern Med 1998;128(9):721–8.
8. Ferrer M, Sellarés J, Valencia M, Carrillo A, Gonzalez G, Badia JR, *et al*. Non-invasive ventilation after extubation in hypercapnic patients with chronic respiratory disorders: randomised controlled trial. Lancet 2009;374(9695):1082–8.
9. Ferrer M, Esquinas A, Arancibia F, Bauer TT, Gonzalez G, Carrillo A, *et al*. Noninvasive ventilation during persistent weaning failure: a randomized controlled trial. Am J Respir Crit Care Med 2003;168(1):70–6.
10. Chen J, Qiu D, Tao D. Time for extubation and sequential noninvasive mechanical ventilation in COPD patients with exacerbated respiratory failure who received invasive ventilation. Zhonghua Jie He Hu Xi Za Zhi 2001;24(2):99–100.
11. Hill NS, Lin D, Levy M. Noninvasive positive pressure ventilation (NPPV) to facilitate extubation after acute respiratory failure: a feasibility study. Am J Respir Crit Care Med 2000;161(3):A263.
12. Girault C, Daudenthun I, Chevron V, Tamion F, Leroy J, Bonmarchand G. Noninvasive ventilation as a systematic extubation and weaning technique in acute-on-chronic respiratory failure: a prospective, randomized controlled study. Am J Respir Crit Care Med 1999;160(1):86–92.
13. Trevisan CE, Vieira SR, Research Group in Mechanical Ventilation Weaning. Noninvasive mechanical ventilation may be useful in treating patients who fail weaning from invasive mechanical ventilation: a randomized clinical trial. Crit Care 2008;12(12):R51.
14. Rabie GM, Mohamed AZ, Mohamed RN. Noninvasive ventilation in the weaning of patients with acute-on-chronic respiratory failure due to COPD. Chest 2004;126(4):755.
15. Wang C, Zhang Q, Cao Z. Pulmonary infection control window in the treatment of severe respiratory failure of chronic obstructive pulmonary diseases: a prospective, randomized controlled, multi-centre study. Chin Med J (Engl) 2005;118(19):1589–94.
16. Ornico SR, Lobo SM, Sanches HS, Deberaldini M, Tófoli LT, Vidal AM, *et al*. Noninvasive ventilation immediately after extubation improves weaning outcome after acute respiratory failure: a randomized controlled trial. Crit Care 2013;17(2):R39.

17. Yang KL, Tobin MJ. A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation. N Engl J Med 1991;324(21):1445–50.
18. Soleimanpour H, Taghizadieh A, Salimi R, Golzari SE, Mahmoodpoor A, Safari S, *et al*. Rapid shallow breathing index survey, a predictor of non-invasive ventilation necessity in patients with chronic obstructive pulmonary disease exacerbation: An analytical descriptive prospective study. Iran Red Crescent Med J 2014;16(2):e13326.
19. Berg KM, Lang GR, Salciccioli JD, Bak E, Cocchi MN, Gautam S, *et al*. The rapid shallow breathing index as a predictor of failure of noninvasive ventilation for patients with acute respiratory failure. Respir Care 2012;57(10):1548–54.
20. Thygesen K, Alpert JS, Jaffe AS, Chaitman BR, Bax JJ, Morrow DA, *et al*. Fourth universal definition of myocardial infarction (2018). J Am Coll Cardiol 2018;72(18):2231–64.
21. Soummer A, Perbet S, Brisson H, Arbelot C, Constantin JM, Lu Q, *et al*. Lung Ultrasound Study Group. Ultrasound assessment of lung aeration loss during a successful weaning trial predicts postextubation distress. Crit Care Med 2012;40(7):2064–72.
22. Caille V, Amiel JB, Charron C, Belliard G, Vieillard-Baron A, Vignon P. Echocardiography: a help in the weaning process. Crit Care 2010;14(3):R120.
23. Cabello B, Thille AW, Roche-Campo F, Brochard L, Gómez FJ, Mancebo J. Physiological comparison of three spontaneous breathing trials in difficult-to-wean patients. Intensive Care Med 2010;36(7):1171–9.
24. Terzi N, Lofaso F, Masson R, Beuret P, Normand H, Dumanowski E, *et al*. Physiological predictors of respiratory and cough assistance needs after extubation. Ann Intensive Care 2018;8(1):18.
25. Frutos-Vivar F, Ferguson ND, Esteban A, Epstein SK, Arabi Y, Apezteguía C, *et al*. Risk factors for extubation failure in patients following a successful spontaneous breathing trial. Chest 2006;130(6):1664–71.
26. Capucci A, Molon G, Gold MR, Zhang Y, Sweeney R, Averina V, *et al*. Rapid shallow breathing worsens prior to heart failure decompensation. J Card Fail 2014;20(8):S14.
27. Takaki S, Kadiman SB, Tahir SS, Ariff MH, Kurahashi K, Goto T. Modified rapid shallow breathing index adjusted with anthropometric parameters increases predictive power for extubation failure compared with the unmodified index in postcardiac surgery patients. J Cardiothorac Vasc Anesth 2015;29(1):64–8.
28. Oribabor CE, Mansuroglu N, Khusid F, Patten A, Suleiman M, Primiano J, *et al*. Low extubation times in cardiac surgery patients using the rapid shallow breathing index. Chest 2005;128(4):S273.
29. Ferré A, Guillot M, Lichtenstein D, Mezière G, Richard C, Teboul JL, *et al*. Lung ultrasound allows the diagnosis of weaning-induced pulmonary oedema. Intensive Care Med 2019;45(5):601–8.
30. Scali MC, Zagatina A, Ciampi Q, Cortigiani L, D'Andrea A, Daros CB, *et al*. Lung ultrasound and pulmonary congestion during stress echocardiography. JACC Cardiovasc Imaging 2020;13(10):2085–95.
31. Bellone A, Barbieri A, Ricci C, Iori E, Donateo M, Massobrio M, *et al*. Acute effects of non-invasive ventilatory support on functional mitral regurgitation in patients with exacerbation of congestive heart failure. Intensive Care Med 2002;28(9):1348–50.

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