



ORIGINAL ARTICLE

Comparing lung aeration and respiratory effort using two different spontaneous breathing trial: T-piece vs pressure support ventilation



Raquel Bosch-Compte^{a,*}, Francisco José Parrilla^a, Rosana Muñoz-Bermúdez^a, Irene Dot^a, Cristina Climent^a, Joan Ramon Masclans^{a,b}, Judith Marin-Corral^{a,c,1}, Purificación Pérez-Terán^{a,1}

^a Critical Care Department, Hospital del Mar, Critical Illness Research Group (GREPAC), Institut Hospital del Mar d'Investigacions Mèdiques (IMIM), Barcelona, Spain

^b Medicine and Life Sciences Department (MELIS), Universitat Pompeu Fabra (UPF), Barcelona, Spain

^c Division of Pulmonary Diseases & Critical Care Medicine, South Texas Veterans Health Care System and University of Texas Health San Antonio, San Antonio, TX, USA

Received 19 May 2023; accepted 30 June 2023

Available online 3 October 2023

KEYWORDS

Diaphragmatic ultrasound;
Electrical impedance tomography;
Lung aeration;
Lung ultrasound;
Spontaneous breathing trial;
Respiratory effort

Abstract

Objective: To assess the changes in lung aeration and respiratory effort generated by two different spontaneous breathing trial (SBT): T-piece (T-T) vs pressure support ventilation (PSV).

Design: Prospective, interventionist and randomized study.

Setting: Intensive Care Unit (ICU) of Hospital del Mar.

Participants: Forty-three ventilated patients for at least 24 h and considered eligible for an SBT were included in the study between October 2017 and March 2020.

Interventions: 30-min SBT with T-piece (T-T group, 20 patients) or 8-cmH₂O PSV and 5-cmH₂O positive end expiratory pressure (PSV group, 23 patients).

Abbreviations: SBT, spontaneous breathing trial; T-T, T-piece trial; PSV, pressure support ventilation; ICU, Intensive Care Unit; MV, mechanical ventilation; EIT, electrical impedance tomography; LUS, lung ultrasound; DU, diaphragmatic ultrasonography; PEEP, positive end expiratory pressure; RR, respiratory rate; SpO₂, oxygen saturation; FiO₂, inspiratory oxygen fraction; HR, heart rate; SBP, systolic blood pressure; NIRS, non-invasive respiratory support; ARF, acute respiratory failure; BSL, basal; EoSBT, end of spontaneous breathing trial; OTE, one hour after orotracheal extubation; EELI, end-expiratory lung impedance; Δ EELI, EELI variation; $\Delta\%$ EELI, percentage of EELI variation; Δ LUS, LUS variation; $\Delta\%$ LUS, percentage of LUS variation; DE, diaphragm excursion; TF, thickening fraction; T_i, inspiratory time; Δ DE, DE variation; Δ TF, TF variation; Δ TI, TI variation; BMI, body mass index; APACHE II, Acute Physiology and Chronic Health Evaluation II; SOFA, Sequential Organ Failure Assessment; LOS, length of stay; NIV, non-invasive mechanical ventilation; HFNC, high flow nasal cannula; SD, standard deviation; IR, interquartile range; OS, Online Supplement; AU, arbitrary units.

* Corresponding author.

E-mail addresses: Raquelbosch13@gmail.com, rboschc.girona.ics@gencat.cat (R. Bosch-Compte).

¹ Contributed equally to work.

<https://doi.org/10.1016/j.medine.2023.07.010>

2173-5727/© 2023 Elsevier España, S.L.U. and SEMICYUC. All rights reserved.

Main variables of interest: Demographics, clinical data, physiological variables, lung aeration evaluated with electrical impedance tomography (EIT) and lung ultrasound (LUS), and respiratory effort using diaphragmatic ultrasonography (DU) were collected at different timepoints: basal (BSL), end of SBT (EoSBT) and one hour after extubation (OTE).

Results: There were a loss of aeration measured with EIT and LUS in the different study timepoints, without statistical differences from BSL to OTE, between T-T and PSV [LUS: 3 (1, 5.5) AU vs 2 (1, 3) AU; $p=0.088$; EELI: -2516.41 (-5871.88 , 1090.46) AU vs -1992.4 (-3458.76 , -5.07) AU; $p=0.918$]. Percentage of variation between BSL and OTE, was greater when LUS was used compared to EIT (68.1% vs 4.9%, $p\leq 0.001$). Diaphragmatic excursion trend to decrease coinciding with a loss of aeration during extubation.

Conclusion: T-T and PSV as different SBT strategies in ventilated patients do not show differences in aeration loss, nor estimated respiratory effort or tidal volume measured by EIT, LUS and DU.

© 2023 Elsevier España, S.L.U. and SEMICYUC. All rights reserved.

PALABRAS CLAVE

Ecografía
diafragmática;
Tomografía de
impedancia eléctrica;
Aireación pulmonar;
Ecografía pulmonar;
Prueba de respiración
espontánea;
Esfuerzo respiratorio

Comparación de la aireación pulmonar y el esfuerzo respiratorio utilizando dos pruebas de respiración espontánea diferentes: tubo en T vs ventilación con presión de soporte

Resumen

Objetivo: Evaluar los cambios de aireación pulmonar y esfuerzo respiratorio generados por dos pruebas de respiración espontánea (PRE) diferentes: tubo en T (T-T) frente a ventilación con presión soporte (PS).

Diseño: Estudio prospectivo, intervencionista y aleatorizado.

Ámbito: Unidad de Cuidados Intensivos (UCI) del Hospital del Mar.

Participantes: Cuarenta y tres pacientes ventilados durante al menos 24 horas y considerados elegibles para una PRE fueron incluidos en el estudio entre octubre de 2017 y marzo de 2020.

Intervenciones: PRE de 30 minutos con T-T (20 pacientes) o PS de 8 cmH₂O y presión positiva al final de la espiración de 5 cmH₂O (23 pacientes).

Variables de interés principales: Datos demográficos, clínicos, variables fisiológicas, aireación pulmonar evaluada con tomografía de impedancia eléctrica (EIT) y ecografía pulmonar (LUS) y esfuerzo respiratorio mediante ultrasonografía diafragmática (DU) en diferentes momentos: basal (BSL), final de SBT (EoSBT) y una hora post-extubación (OTE).

Resultados: Hubo pérdida de aireación medida con EIT y LUS en los diferentes tiempos de estudio, sin diferencias estadísticas de BSL a OTE, entre T-T y PS [LUS: 3 (1, 5.5) AU vs 2 (1, 3) AU; $p=0.088$; EELI: -2516.41 (-5871.88 , 1090.46) AU vs -1992.4 (-3458.76 , -5.07) AU; $p=0.918$]. El porcentaje de variación entre BSL y OTE fue mayor cuando se utilizó LUS en comparación con EIT (68.1% vs 4.9%, $p\leq 0,001$). La excursión diafragmática tiende a disminuir coincidiendo con una pérdida de aireación durante la extubación.

Conclusiones: T-T y PS como estrategias de PRE en pacientes ventilados no muestran diferencias en la pérdida de aireación, ni en el esfuerzo respiratorio estimado ni en el volumen corriente medido por EIT, LUS y DU.

© 2023 Elsevier España, S.L.U. y SEMICYUC. Todos los derechos reservados.

Introduction

The weaning process consists in liberate patients from mechanical ventilation (MV) removing the endotracheal tube after well tolerate spontaneous breathing.^{1,2} To determine the optimal moment for extubation remains a challenge, so current guidelines recommend the implementation of a spontaneous breathing trial (SBT) as a tool to predict weaning outcome.²⁻⁴ However, 10%–25% of patients who

are extubated following a successful SBT need to be reintubated, which is associated with higher mortality.^{5,6} The T-piece trial (T-T) and low level of pressure support ventilation (PSV) are the most common modes of SBT used in clinical practice but there is still no consensus on which of them are associated with better outcomes.^{1,4,7,8} While some studies suggested that PSV is related to a higher proportion of successful extubation, some meta-analysis advocate for the T-T method.^{3,7,9,10} Recently, Li et al., have also published a meta-analysis suggesting comparable predictive

power of successful extubation between them in critically ill patients.¹¹

Since loss of aeration and diaphragm dysfunction have been related to weaning failure, they should be taken into account when evaluating an extubation attempt.^{12–21} Some authors evaluated the utility of electrical impedance tomography (EIT) to predict SBT failure during the weaning process.^{12–14} Specifically, EIT showed a significant decrease in tidal variation of impedance and end-expiratory lung volume after ventilator disconnection during a SBT.^{12,13} In this regard, SBT failure compared to success was characterized by a greater lung de-recruitment and more inhomogeneity of ventilation distribution measured by EIT.¹⁴ Transthoracic lung ultrasound (LUS) is also a non-invasive, radiation-free, bedside tool, that allows to detect the amount of lung aeration loss or derecruitment of the lung during the SBT and could be an accurate predictor of weaning failure.^{15,16,22} Different studies agree that there is a greater lung derecruitment evaluated by LUS in patients who develop weaning failure after successfully pass the SBT (both T-T and PSV), in comparison with other who are successfully weaned.^{16–18,23} Moreover, current literature have suggested that diaphragmatic ultrasonography (DU) could be an accurate tool to identify diaphragmatic dysfunction, to monitor respiratory work-load and, also, to predict extubation failure during weaning from MV and SBT.^{20,21,24}

However, heterogeneous results have been published and there are no recommendations on which SBT to use based on patient characteristics to achieve better outcomes. Nevertheless, differences in aeration between different SBT have not been compared, so further investigation is needed to determine the best approach. In that sense, we hypothesized that both SBT, T-T and PSV, could generate different changes in aeration and respiratory drive which could be related to differences in successful extubation rates. Therefore, this study aimed to evaluate the changes in lung aeration evaluated with EIT and LUS, and respiratory effort estimation using DU, generated by two different SBT (T-T vs PSV).

Materials and methods

Study design

This is a prospective, interventionist and randomized single center study, conducted at the Critical Care Department of the Hospital del Mar in Barcelona, between October 2017 and March 2020. It was designed and conducted in accordance with the amended Declaration of Helsinki and approved by the Institutional Review Board of the PSMAR (Hospital del Mar, Barcelona, Spain, number 2015/6444/I). Informed consent was obtained from each patient or next of kin.

Patients and selection criteria

All patients admitted to the Intensive Care Unit (ICU) undergoing MV for at least 24h who were considered eligible for an SBT were included in the study. SBT eligibility criteria are detailed in the Online Supplement and were based on previous literature.² The exclusion criteria were age

<18 years, pregnancy, neuromuscular disease, presence of tracheostomy and patients with surgical incisions likely to interfere with ultrasound or impedance examination.

Study groups and definitions

Enrolled patients were randomized in a 1:1 ratio by using closed-envelope technique to the following groups: (1) T-T: 30-min SBT with T-piece, or (2) PSV: 30-min SBT with 8-cmH₂O PSV and 5-cmH₂O positive end expiratory pressure (PEEP). Oxygenation parameters remained unchanged from the mechanical ventilation period before the SBT and during the 30 min of trial in both groups. The intervention was not blinded for the investigators or attending physicians. Since one of the objectives was to assess the impact of both SBT strategies in aeration changes and outcomes after extubation, patients who failed in the SBT were excluded. In this regard, SBT failure was considered when during the trial appeared at least one of the follows as described before²: agitation, anxiety or depressed mental status, diaphoresis, cyanosis, respiratory rate (RR) greater than 35 breaths/min, use of accessory muscles, dyspnea, persistent decrease in oxygen saturation (SpO₂) by pulse oximetry <90% with inspiratory oxygen fraction (FiO₂) ≥ 0.5, heart rate (HR) above 140 beats/min or greater than a 20% increase from baseline, systolic blood pressure (SBP) lower than 90 mmHg or higher than 180 mmHg, or development of arrhythmia. Failure in extubation was considered when reintubation or the use of any kind of non-invasive respiratory support (NIRS) after the extubation process due to acute respiratory failure (ARF) was needed within the first 48 h after extubation.^{2,25,26} Those decisions were left to the attending physicians who were blinded to the ultrasonographic neither EIT results. Patients who required reintubation in the first 24 h for other reason than respiratory failure (e.g. surgical intervention) were also excluded.

Study protocol

Online Supplement (OS) Fig. 1 shows the study protocol followed in all the patients included in both groups. Experimental procedures as electrical impedance (EIT) and ultrasonography (LUS and DU measures) were performed at inclusion before randomization (Basal or BSL) and one hour after orotracheal extubation (OTE). In the T-T group in which intrathoracic pressures changed by protocol during the SBT, they were also performed at the end of the 30 min SBT (EoSBT), just before the extubation process. In the PSV group, these measurements were not repeated during the SBT since it was assumed no aeration changes when PEEP was maintained.

Electrical impedance tomography measurements (EIT)

EIT was performed using the Swisstom BB₂® device (Swisstom, Landquart, Switzerland). The inner surface of the belt containing 32 electrodes (SensorBelt®, Swisstom, Landquart, Switzerland) was placed along the sixth intercostal space around the chest. EIT data were continuously

recorded and analysed offline using Swisstom's EIT Data Analyser (ibeX 1.1, Swisstom, Landquart, Switzerland). EIT-derived parameters as end-expiratory lung impedance (EELI) and EELI variation (Δ EELI) were measured following previous literature.^{27,28} EELI variation between the different timepoints (Δ EELI or delta) was also recorded and calculated as the EELI difference between the two analysed timepoints. The percentage of variation ($\Delta\%$ EELI) between two different timepoints was calculated as the Δ EELI divided by the EELI value at the first timepoint and multiplied by 100. Further details are shown in the Online Supplement.

Lung ultrasound measurements (LUS)

LUS was performed by trained operators using the Vivid I[®] ultrasound device (General Electric, Fairfield, CT, USA). Measurements were performed with a 3.5–5MHz convex probe. Four quadrants of each hemithorax were examined (anterior superior, anterior inferior, lateral superior and lateral inferior) and each one was rated according to the aeration pattern evidenced as previously described²²: 0=normal aeration (A lines or <3 B lines); 1=moderate loss of aeration (multiple B lines); 2=severe loss of aeration (confluent B lines); 3=alveolar consolidation (tissue pattern) which correspond to complete loss of aeration. The LUS score was obtained from the sum of all the quadrant rates, ranging from 0 to 24. LUS variation or delta (Δ LUS) between different analysed timepoints was also recorded, as well as percentage of variation ($\Delta\%$ LUS).

Diaphragm ultrasound measurements (DU)

DU was performed by trained operators using the Vivid I[®] ultrasound device (General Electric, Fairfield, CT, USA) while patients were lying in a semi-recumbent position with the head of the bed elevated at an angle between 30° and 45°. The images during forced breaths, sighs and cough were excluded. Images were recorded and analysed later by a trained blind investigator. Diaphragm excursion (DE), thickening fraction (TF) and inspiratory time (T_I) were measured as previously described.^{29,30} Further details are shown in the Online Supplement. Variation of all these parameters between the different timepoints were also recorded again as delta (Δ DE, Δ TF, ΔT_I).

Data collection

At inclusion, the following data were collected for each patient: age, gender, body mass index (BMI), toxic habits, comorbidities, chronic treatment, reason for admission to the ICU and severity scores such as Acute Physiology and Chronic Health Evaluation II score (APACHE II) and Sequential Organ Failure Assessment score (SOFA) at ICU admission. ICU treatment, ICU length of stay (LOS) until SBT, duration of MV and ventilator parameters at inclusion were also recorded. Physiological variables as RR, SBP, HR and SpO₂ were registered at the three timeline points: BSL, EoSBT and OTE (see [supplementary material OS Fig. 1](#)). Need of NIRS as prophylaxis or treatment for ARF at the moment of OTE measurements [non-invasive mechanical ventilation

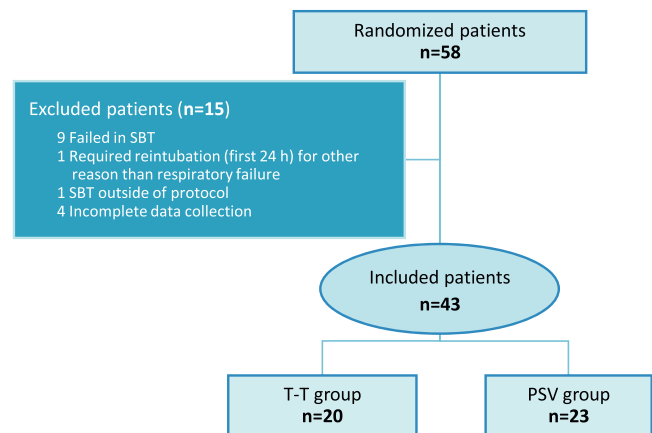


Figure 1 Flow chart of participants.

SBT: spontaneous breathing trial; T-T: T-piece trial; PSV: pressure support ventilation.

(NIV) or high-flow nasal cannula (HFNC)] were also recorded, as well as the need for reintubation. Finally, ICU LOS and ICU mortality were collected.

Statistical analysis

For the baseline descriptive analysis of the two study groups, categorical variables were expressed as frequencies and percentages. Following the results of the Kolmogorov–Smirnov test, continuous variables were expressed as means and standard deviation (SD) when the data followed a normal distribution, or as medians and interquartile range (IR 25, 75%) otherwise. The differences between groups were analysed with the chi-square test for categorical variables and Student's t-test or Mann–Whitney U test for continuous variables. Paired group analysis was used to compare EIT, LUS and DU data between different timepoints. Statistical significance was established at $p \leq 0.05$. Data were analysed using the statistical package for social sciences 19.0 (IBM[®] SPSS Statistics[®], Chicago, IL, USA) for Windows.

Accepting an alpha risk of 0.05 and a beta risk of 0.2 in a two-sided test, 28 subjects are necessary in first group and 28 in the second to recognize as statistically significant a difference greater than or equal to 4 units. The common standard deviation is assumed to be 5. It has been anticipated a drop-out rate of 10%.

Results

A total of 58 patients were enrolled in the study. Among them, 43 were finally included, 20 (46%) being randomized to the T-T group and 23 (53%) to the PSV group ([Fig. 1](#)). [Table 1](#) shows the principal characteristics of included patients. Briefly, there were no differences in demographic variables, comorbidities and chronic treatment as well as, in the reason for ICU admission, severity scores, and treatment received during ICU stay. Furthermore, no differences were found in extubation failure, in the NIRS used after extubation (used in almost 50% of patients in each group), ICU LOS, or in-ICU mortality between groups.

Table 1 Baseline characteristics of included patients regarding the study group.

	T-T n = 20	PSV n = 23	p-Value
Demographics			
Age, years	60 (12)	58 (19)	0.654
Gender (male), n (%)	9 (45.0)	15 (65.2)	0.183
BMI, kg/m ²	23.6 (4.7)	26.3 (7.0)	0.152
Toxic habits, n (%)			
Current or former smoker	15 (75.0)	12 (52.2)	0.122
Current alcoholism	5 (25.0)	4 (17.4)	0.541
Comorbidities, n (%)			
Hypertension	7 (35.0)	8 (34.8)	0.988
Liver disease	5 (25.0)	5 (21.7)	0.801
Diabetes mellitus	4 (20.0)	4 (17.4)	0.826
COPD	5 (25.0)	3 (13.0)	0.315
Obesity	3 (15.0)	4 (17.4)	0.832
Neurological disease	4 (20.0)	3 (13.0)	0.538
Heart failure	1 (5.0)	4 (17.4)	0.206
Endocrinological disease	4 (20.0)	1 (4.3)	0.110
Mental illness	3 (15.0)	2 (8.7)	0.520
Coronary artery disease	2 (10.0)	2 (8.7)	0.883
Chronic kidney disease	0 (0.0)	2 (8.7)	0.177
VIH	2 (10.0)	0 (0.0)	0.120
Asthma	0 (0.0)	1 (4.3)	0.345
Chronic treatment, n (%)			
Corticosteroids	4 (20.0)	4 (17.4)	0.826
Statins	3 (15.0)	5 (21.7)	0.571
Insulin	1 (5.0)	0 (0.0)	0.278
Reason for ICU admission, n (%)			
Neurologic	7 (35.0)	10 (43.5)	0.687
Acute respiratory failure	6 (30.0)	9 (39.1)	
Shock	2 (10.0)	2 (8.7)	
Intoxication	3 (15.0)	1 (4.4)	
Cardiologic	2 (10.0)	1 (4.4)	
Severity scores at admission			
APACHE II score	24 (7)	21 (8)	0.180
SOFA score	6 (4)	6 (3)	0.521
ICU treatment, n (%)			
Corticosteroids	10 (50.0)	13 (56.5)	0.669
Neuromuscular blockers	2 (10.0)	4 (17.4)	0.485
Insulin	2 (10.0)	2 (8.7)	0.883
Patients' evolution			
ICU LOS until SBT, days	7 (4)	9 (6)	0.472
Time from MV starting until SBT, days	6 (3)	8 (5)	0.101
Extubation failure, n (%)			
Reintubation	2 (10.0)	0 (0.0)	0.650
NIRS due to ARF	1 (5.0)	2 (8.7)	
NIRS at OTE measurement, n (%)			
NIV	10 (50.0)	11 (47.8)	0.948
HFNC	2 (10.0)	2 (8.7)	
	8 (40.0)	9 (39.1)	
Outcomes			

Table 1 (Continued)

	T-T n = 20	PSV n = 23	p-Value
ICU LOS, days	14 (10)	12 (7)	0.584
ICU mortality, n (%)	2 (10.0)	2 (8.7)	1.000

Data expressed as frequencies and percentages (n (%)) or mean (SD).

Abbreviations: SBT: spontaneous breathing trial; T-T: T-piece; PSV: pressure support ventilation; BMI: body mass index; COPD: chronic obstructive pulmonary disease; APACHE II: Acute Physiology And Chronic Health Evaluation II; SOFA: Sequential Organ Failure Assessment; ICU: Intensive Care Unit; LOS: length of stay; MV: mechanical ventilation; NIRS: non-invasive respiratory support; ARF: acute respiratory failure; OTE: one hour after orotracheal extubation; NIV: non-invasive mechanical ventilation; HFNC: high-flow nasal cannula; LOS: length of stay.

No differences were found in physiological parameters (RR, SBP, HR and SpO₂) evaluated at any study timepoints between groups (see [supplementary material OS Table 1](#)).

Aeration changes

Aeration changes evidenced by EIT and LUS in the two SBT groups at the different protocol monitoring times are shown in [Fig. 2](#). At baseline, no significant differences were found in EELI nor LUS between PSV and T-T ([Fig. 2A](#)). During the study period in both SBT groups, EELI and LUS score showed a trend to loss of aeration (trend to decrease EELI score and to increase LUS score) from BSL to EoSBT and OTE in PSV and T-T although without differences between them ([Fig. 2A](#)). [Fig. 2B](#) shows the Δ EELI and Δ LUS between the different study timepoints in both study groups, showing in all the cases a loss of aeration. In the T-T group, the greatest aeration loss occurred during the SBT period (EELI and LUS). Only differences between study groups in Δ EELI between EoSBT and OTE were statistically significant, showing higher loss of aeration in PSV compared to T-T [-1992.40 (-3458.76 , -5.07) AU vs 48.09 (-1319.71 , 1084.07) AU, $p = 0.027$] ([Fig. 2B](#)). Percentage of variation calculated between BSL and OTE, was greater when LUS was used ($\Delta\%$ LUS 60.6%) in comparison with EIT ($\Delta\%$ EELI 4.7%), $p \leq 0.001$ ([Fig. 2C](#)).

The subanalysis of aeration by groups of SBT regarding the use of NIRS (NIV or HFNC) at one-hour post-extubation is shown in [supplementary material OS Fig. 2](#). There were no significant differences between groups according to receive NIRS at OTE.

Diaphragmatic ultrasound measures

[Fig. 3](#) shows the data of DU in both study groups at different timepoints (DE, TF and T₁). There were no differences between any of them at baseline, neither in the other timepoints ([Fig. 3A](#)). However, DE tended to decrease during extubation in both SBT groups, coinciding with a loss of aeration. During the weaning process, the decrease trend in DE was greater in the T-T group. Furthermore, there were no differences regarding Δ TF between SBT groups ([Fig. 3B](#)).

Discussion

The main findings of this study are that: 1) there are no differences between PSV and T-T in generating aeration loss

measured by EIT and LUS, and 2) there are no differences between PSV and T-T regarding respiratory effort or tidal volume estimated using TF and DE respectively.

For this study and in order to assess changes in aeration and respiratory drive between two SBT strategies, we used the two previously described with the greatest difference in respiratory effort and degree of demand between them: T-piece and PSV with 5-cmH₂O PEEP.^{7,8,11,31} In addition, we performed the SBT during 30 min since no differences have been found between 30 min and longer duration (120 min) SBT on checking breathing capacity related to successful extubation rates.^{32,33} Supporting that, in our study we observed that using the T-T test for 30 min there was no greater loss of aeration than PSV (measured by EIT and LUS), despite in this group the greatest aeration changes occurred during the SBT itself. Moreover, there were no differences in the estimated tidal volume with DE or estimated respiratory effort with TF, compared to the PSV group.

Different studies have found significant lung derecruitment after an SBT based on both, EIT or LUS as a tool to measure pulmonary aeration. Those studies showed that lung derecruitment is greater among patients who develop weaning failure after successfully pass the SBT, in comparison with patients who are successfully weaned.^{13,14,16,17,23} In the present study, we found a loss of aeration during the weaning process regardless the tool used to evaluate lung derecruitment, or the SBT strategy used. Until now, there is no agreement in the literature regarding superiority of a specific SBT to others in determining extubation failure. Although it has been suggested that SBT with a ventilator support could overestimate patients capability to maintain the cardiorespiratory load after extubation,³⁴ we found no aeration differences between the two SBT during the weaning process. However, while we included a general population, other studies as Cabello et al.⁸ included specific subpopulation of difficult-to-wean subjects with a high prevalence of left ventricular heart failure where ventilator support could have modified cardiovascular and respiratory response in comparison with T-piece. Moreover, our absence of differences in aeration between both SBT groups could also be explained by using a T-T of only 30 min duration, as well as the small sample size.

Analyses at different study timepoints, showed that the greatest aeration loss occurred in the T-T group was during the SBT period. These results are in accordance with previous studies,^{7,25,32} where only 30 min SBT allows discrimination of patients who are probably going to fail without producing a greater loss of aeration and could justify the

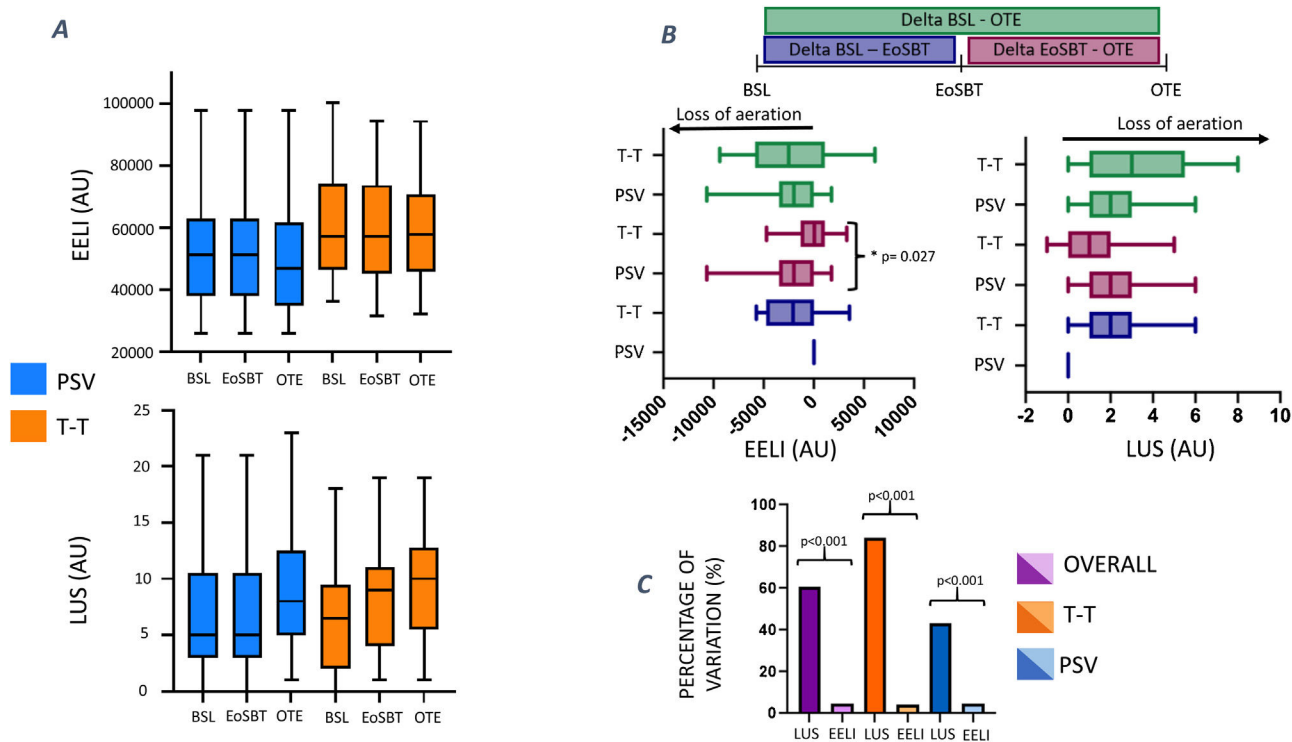


Figure 2 Aeration according to EIT and LUS by SBT (A), aeration changes by SBT (B) and percentage of variation between BSL and OTE of EELI and LUS (C).

PSV: pressure support ventilation; T-T: T-piece trial; EELI: end-expiratory lung impedance; LUS: lung ultrasound; AU: arbitrary units; BSL: basal; EoSBT: end of spontaneous breathing trial; OTE: one hour after orotracheal extubation.

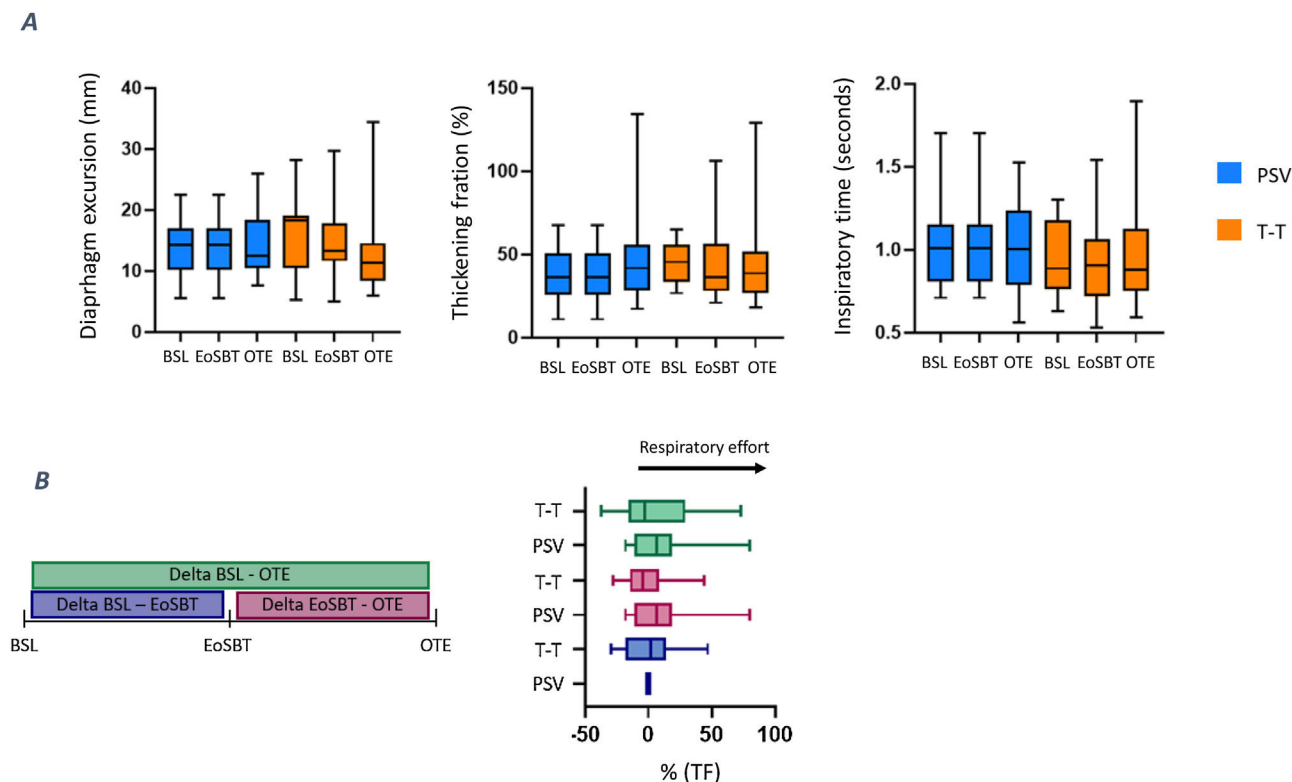


Figure 3 Diaphragm ultrasound measurements by SBT groups (A) and delta diaphragm thickening fraction by SBT (B).

PSV: pressure support ventilation; T-T: T-piece trial; BSL: basal; EoSBT: end of spontaneous breathing trial; OTE: one hour after orotracheal extubation; TF: diaphragm thickening fraction.

benefit of a rest period with reconnection to the MV after a successful T-T trial before extubation.³⁵ Moreover, we found a higher loss of aeration measured by EELI in PSV compared to T-piece between EoSBT and OTE, probably related with the higher aeration loss during the SBT in the T-T group, as commented. That could also support findings of Subirà et al. who recommended a less demanding ventilation strategy during weaning trial to avoid delay on extubation in patients able to spontaneously breathe without the ventilator, although without assessing pulmonary aeration.⁷

In addition, literature supports both, EIT and LUS, to measure pulmonary aeration. However, they have not been compared between them. Our results showed that between BSL and OTE timepoints, the $\Delta\%$ LUS was greater than $\Delta\%$ EELI which could reflect a higher sensitivity of LUS over EELI in order to detect loss of aeration. This phenomenon could be explained by a greater number of thoracic regions evaluated using LUS.

Current literature suggests that DU could be an accurate tool to identify diaphragmatic contractility in patients under MV to predict extubation failure, to measure loss of aeration through DE changes as an estimator of tidal volume, as well as, to monitor diaphragm effort.^{24,30,36,37} On the one hand, DE performed during an SBT in intubated patients has proven to be useful to predict weaning failure. In this regard, the cut-off ranged from 10 to 14mm during normal spontaneous breathing have been selected to diagnose diaphragmatic dysfunction.^{24,38} On the other hand, TF has shown significant correlation with invasive techniques such as oesophageal and transdiaphragmatic pressure monitoring (the gold-standard to assess inspiratory diaphragmatic effort in mechanical ventilated patients)^{36,39} as well as to predict extubation failure during an SBT (cut-off ranged between 30 and 36%).^{24,37} In this line, Xia et al.⁴⁰ showed that patients with a greater loss of pulmonary aeration, had increased diaphragmatic contractility, indicating an additional respiratory effort to compensate lung volume loss. In our study, there were no differences in respiratory effort between groups, in accordance with no differences in aeration loss. Furthermore, in the present study we observed that when MV were disconnected during the SBT in the T-T group, DE decreased. In fact, excursion is directly proportional to inspired volume in both the supine and sitting position, regardless of whether it depends on the force of the diaphragm contraction by itself or passive displacement by ventilator support pressure.²⁴ Consequently, in our study we observed that DE as an estimator of lung tidal volume, tended to decrease with extubation, suggesting a loss of aeration in both groups.

Our study has several limitations to consider. First, prophylactic use of NIV or HFNC after extubation was not protocolized, but at the discretion of the treating physician. Then, it could have been used associated to patients with more comorbidities and higher risk factors for extubation failure. Therefore, since these are not homogeneous criteria, the results of lung aeration could be influenced by the use of NIRS. However, in our cohort of patients, there were no differences between groups regarding the use of NIRS after extubation and this would not be a confusion factor when comparing both strategies. Second, investigators and attending physicians were not blinded to weaning trial randomization group, but clinicians were blinded to their

results and clinical management was not affected by the result of the techniques. Third, although it was not the aim of this study, the sample size and the study design did not allow conclusions to be drawn on clinically relevant outcomes such as weaning failure, hospital mortality, nor stratify aeration loss according to weaning failure. Besides, due to this study included general ICU patients, the results could not be extrapolated to specific group of patients as difficult weaning population, in whom SBT modality may have more clinical importance. Finally, this is an unicentric study with a limited number of included patients and further studies should be designed to generalize the results.

Conclusions

T-piece and PSV as different strategies to perform SBT do not show differences in aeration loss, nor estimated respiratory effort or tidal volume measured by EIT, LUS and DU. Further studies will be needed to evaluate the impact of those SBT strategies in a higher sample size to generalize these results.

Author's contributions

RBC, JMC and PPT conceived and designed the study.

RBC, RM, ID, CC, JMC and PPT, contributed to patient and data recruitment.

RBC, FJP, JRM, JMC and PPT made important intellectual contributions and actively participated in the interpretation of the data.

RBC wrote the paper.

JMC and PPT done contributions to the writing and conceptual exposition of the results.

All authors contributed to critical examination of the paper for important intellectual content and approval of the final manuscript.

Funding

The authors declare that no funds, grants, or other support were received for this study.

Conflict of interest statements

The authors have no relevant financial or non-financial interests relevant to this article to disclose.

Ethics committee approval

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki, and approved by the Institutional Review Board of the PSMAR (Hospital del Mar, Barcelona, Spain, number 2015/6444/I).

Acknowledgments

Acknowledgments to Marta Gas and all the healthcare personnel (physicians, nurses, auxiliaries and the entire logistical team involved) for their dedication and commitment in helping to collect the data that have made this study

possible. This research will be part of the doctoral thesis of one of the coauthors. We thank the Department of Medicine of the Universitat Autònoma de Barcelona for the logistical support for its development.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.medine.2023.07.010>.

References

- Esteban A, Anzueto A, Frutos F, Brochard L, Stewart TE, Benito S, et al. Characteristics and outcomes in adult patients receiving mechanical ventilation. *JAMA*. 2002;287(3):345–55.
- Boles J, Bion J, Connors A, Herridge M, Marsh B, Melot C, et al. Weaning from mechanical ventilation. *Eur Respir J*. 2007;29(5):1033–56.
- Schmidt GA, Girard TD, Kress JP, Morris PE, Ouellette DR, Alhazzani W, et al. Liberation from mechanical ventilation in critically ill adults: executive summary of an Official American College of Chest Physicians/American Thoracic Society Clinical Practice Guideline. *Chest*. 2017;151(1):160–5. Available from: <https://doi.org/10.1016/j.chest.2016.10.037>
- Zein H, Baratloo A, Negida A, Safari S. Ventilator weaning and spontaneous breathing trials; an educational review. *Emergency*. 2016;4(2):65–71.
- Thille AW, Harrois A, Schortgen F, Brun-Buisson C, Brochard L. Outcomes of extubation failure in medical intensive care unit patients. *Crit Care Med*. 2011;39(12):2612–8.
- Jaber S, Quintard H, Cinotti R, Asehnoune K, Arnal JM, Guitton C, et al. Risk factors and outcomes for airway failure versus non-airway failure in the intensive care unit: a multicenter observational study of 1514 extubation procedures. *Crit Care*. 2018;22(1):1–12.
- Subirà C, Hernández G, Vázquez A, Rodríguez-García R, González-Castro A. Effect of pressure support vs T-piece ventilation strategies during spontaneous breathing trials on successful extubation among patients receiving mechanical ventilation: a randomized clinical trial. *JAMA*. 2019;321(22):2175–82.
- Cabello B, Thille A, 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.
- Thille AW, Coudroy R, Nay MA, Gacouin A, Demoule A, Sonnevile R, et al. Pressure-support ventilation vs T-piece during spontaneous breathing trials before extubation among patients at high risk of extubation failure: a post-hoc analysis of a clinical trial. *Chest*. 2020;158(4):1446–55.
- Burns KEA, Soliman I, Adhikari NKJ, Zwein A, Wong JTY, Gomez-Builes C, et al. Trials directly comparing alternative spontaneous breathing trial techniques: a systematic review and meta-analysis. *Crit Care*. 2017;21(1):1–11.
- Li Y, Li H, Zhang D. Comparison of T-piece and pressure support ventilation as spontaneous breathing trials in critically ill patients: a systematic review and meta-analysis. *Crit Care*. 2020;24(1):1–10.
- Bickenbach J, Czaplik M, Polier M, Marx G, Marx N, Dreher M. Electrical impedance tomography for predicting failure of spontaneous breathing trials in patients with prolonged weaning. *Crit Care*. 2017;21(1):1–8.
- Zhao Z, Peng SY, Chang MY, Hsu YL, Frerichs I, Chang HT, et al. Spontaneous breathing trials after prolonged mechanical ventilation monitored by electrical impedance tomography: an observational study. *Acta Anaesthesiol Scand*. 2017;61(9):1166–75.
- Longhini F, Maugeri J, Andreoni C, Ronco C, Bruni A, Garofalo E, et al. Electrical impedance tomography during spontaneous breathing trials and after extubation in critically ill patients at high risk for extubation failure: a multicenter observational study. *Ann Intensive Care*. 2019;9(1). Available from: <https://doi.org/10.1186/s13613-019-0565-0>
- Soliman SB, Ragab F, Soliman RA, Gaber A, Kamal A. Chest ultrasound in predication of weaning failure. *Open Access Maced J Med Sci*. 2019;7(7):1143–7.
- Sachin S, Chakrabarti D, Gopalakrishna KN, Bharadwaj S. Ultrasonographic evaluation of lung and heart in predicting successful weaning in mechanically ventilated neurosurgical patients. *J Clin Monit Comput*. 2021;35:189–97, <http://dx.doi.org/10.1007/s10877-020-00460-8>.
- Haji K, Haji D, Canty DJ, Royle AG, Green C, Royle CF. The impact of heart, lung and diaphragmatic ultrasound on prediction of failed extubation from mechanical ventilation in critically ill patients: a prospective observational pilot study. *Crit Ultrasound J*. 2018;10(1):1–12. Available from: <https://doi.org/10.1186/s13089-018-0096-1>
- Antonio ACP, Teixeira C, Castro PS, Savi A. Behavior of lung ultrasound findings during spontaneous breathing trial. *Rev Bras Ter Intensiva*. 2017;29(3):279–86.
- Jung B, Moury P, Mahul M, de Jong A, Galia F, Prades A, et al. Diaphragmatic dysfunction in patients with ICU-acquired weakness and its impact on extubation failure. *Intensive Care Med*. 2016;42(5):853–61.
- Li C, Li X, Han H, Cui H, Wang G, Wang Z. Diaphragmatic ultrasonography for predicting ventilator weaning: a meta-analysis. *Medicine (Baltimore)*. 2018;97(22):e10968.
- Abdelwahed WM, Abd Elghafar MS, Amr YM, Alsharif SE-din I, Eltomey MA. Prospective study: Diaphragmatic thickness as a predictor index for weaning from mechanical ventilation. *J Crit Care*. 2019;52:10–5, <http://dx.doi.org/10.1016/j.jcrr.2019.03.006>. ISSN 0883-9441.
- Lichtenstein D. Lung ultrasound in the critically ill. *Curr Opin Crit Care*. 2014;20(3):315–22.
- Soummer A, Arbelot C, Lu Q, Rouby J. Ultrasound assessment of lung aeration loss during a successful weaning trial predicts postextubation distress. *Crit Care Med*. 2012;40(7):2064–72.
- Zambon M, Greco M, Bocchino S, Cabrini L, Beccaria PF, Zangrillo A. Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review. *Intensive Care Med*. 2017;43:29–38.
- Vallverdú L, Calaf N, Subirana M, Net A, Benito S, Mancebo I. Clinical characteristics, respiratory functional parameters, and outcome of a two-hour T-piece trial in patients weaning from mechanical ventilation. *Am J Respir Crit Care Med*. 1998;158(6):1855–62.
- Esteban A, Frutos-Vivar F, Ferguson ND, Arabi Y, Apezteguía C, González M, et al. Noninvasive positive-pressure ventilation for respiratory failure after extubation. *N Engl J Med*. 2004;350(24):2452–60.
- Putensen C, Hentze B, Muenster S, Muders T. Electrical impedance tomography for cardio-pulmonary monitoring. *J Clin Med*. 2019;8(8):1176.
- Pérez-Terán P, Marin-Corral J, Dot I, Sans S, Muñoz-Bermúdez R, Bosch R, et al. Aeration changes induced by high flow nasal cannula are more homogeneous than those generated by non-invasive ventilation in healthy subjects. *J Crit Care*. 2019;53:186–92.
- Goligher EC, Fan E, Herridge MS, Murray A, Vorona S, Brace D, et al. Evolution of diaphragm thickness during mechanical ventilation impact of inspiratory effort. *Am J Respir Crit Care Med*. 2015;192(9):1080–8.

30. Matamis D, Soilemezi E, Tsagourias M, Akoumianaki E, Boroli F, Richard JM. Sonographic evaluation of the diaphragm in critically ill patients. Technique and clinical applications. *Intensive Care Med.* 2013;39:801–10.
31. Godard S, Herry C, Westergaard P, Scales N, Brown SM, Burns K, et al. Practice variation in spontaneous breathing trial performance and reporting. *Can Respir J.* 2016;2016.
32. Esteban A, Alía I, Tobin MJ, Gil A, Gordo F, Vallverdú I, et al. Effect of spontaneous breathing trial duration on outcome of attempts to discontinue mechanical ventilation. *Am J Respir Crit Care Med.* 1999;159(2):512–8.
33. Perren A, Domenighetti G, Mauri S, Genini F, Vizzardì N. Protocol-directed weaning from mechanical ventilation: clinical outcome in patients randomized for a 30-min or 120-min trial with pressure support ventilation. *Intensive Care Med.* 2002;28(8):1058–63.
34. Tobin MJ. Physiologic basis of mechanical ventilation. *Ann Am Thorac Soc.* 2018;15 Suppl 1:S49–52.
35. Fernandez MM, González-Castro A, Magret M, Bouza MT, Ibañez M, García C, et al. Reconnection to mechanical ventilation for 1 h after a successful spontaneous breathing trial reduces re-intubation in critically ill patients: a multicenter randomized controlled trial. *Intensive Care Med.* 2017;43(11):1660–7.
36. Umbrello M, Formenti P, Longhi D, Galimberti A, Piva I, Pezzi A, et al. Diaphragm ultrasound as indicator of respiratory effort in critically ill patients undergoing assisted mechanical ventilation: a pilot clinical study. *Crit Care.* 2015;19:161–71.
37. Ferrari G, De Filippi G, Elia F, Panero F, Volpicelli G, et al. Diaphragm ultrasound as a new index of discontinuation from mechanical ventilation. *Crit Ultrasound J.* 2014;6:8–14.
38. Kim WY, Suh HJ, Hong S, Koh Y, Lim C. Diaphragm dysfunction assessed by ultrasonography: influence on weaning from mechanical ventilation. *Crit Care Med.* 2011;39(12):2627–30.
39. Goligher EC, Lachi F, Detsky ME, Farias P, Murray A, Brace D. Measuring diaphragm thickness with ultrasound in mechanically ventilated patients: feasibility, reproducibility and validity. *Intensive Care Med.* 2015;41:642–9.
40. Xia J, Qian CY, Yang L, Li MJ, Liu XX, Yang T, et al. Influence of lung aeration on diaphragmatic contractility during a spontaneous breathing trial: an ultrasound study. *J Intensive Care.* 2019;7(1):1–11.