Scientific Foundation SPIROSKI, Skopje, Republic of Macedonia
Open Access Macedonian Journal of Medical Sciences. 2021 Nov 05; 9(B):1370-1380.
https://doi.org/10.3889/oamjms.2021.7026
eISSN: 1857-9655
Category: *B - Clinical Sciences*
Section: *Intensive care*

Ultrasound-Guided Preload Indices during Different Weaning Protocols of Mechanically Ventilated Patients and its Impact on Weaning Induced Cardiac Dysfunction

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Edited by: Mirko Spiroski
Citation: Zeid D, Ahmed W, Soliman R, Alazab A, Elsawy AS. Ultrasound-Guided Preload Indices during Different Weaning Protocols of Mechanically Ventilated Patients and its Impact on Weaning Induced Cardiac Dysfunction. Open Access Maced J Med Sci. 2021 Nov 05; 9(B):1370-1380. https://doi.org/10.3889/oamjms.2021.7026
Keywords: Weaning from mechanical ventilation; Spontaneous breathing trial; IVC indices; Internal jugular venous indices; Mitral Septal E/E'; Tricuspid annular planimetric systolic excursion
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Received: 09-Aug-2021
Revised: 13-Sep-2021
Accepted: 26-Oct-2021

Funding: There was no funding obtained for this research work.
Competing Interests: The authors declare no conflict of interest.

Abstract

BACKGROUND: Elevation of the left ventricular (LV) filling pressure can occur during weaning of mechanical ventilation due to increase in LV preload and/or changes in LV compliance and LV afterload.

AIM: The aim of the study was to evaluate respiratory changes in internal jugular vein and inferior vena cava during weaning from mechanical ventilation.

METHODS: Prospective observational study conducted on 80 consecutive patients**.** Patients were divided randomly into two groups who met the readiness criteria to start spontaneous breathing trial (SBT) either on pressure support ventilation (PS/CPAP) for 30 min or T-piece for 120 min. Weaning failure was defined as a failed SBT or reintubation within 48 h. Echocardiographic evaluation was done on assisted controlled ventilation and at the end of SBT for preload assessment.

RESULTS: Mitral Septal E/E' Cutoff value ≥6.1 with sensitivity 81% and specificity 84.2%, and AUC 0.73 for predicting weaning failure**.** IVC distensibility index on CPAP cutoff value ≥66.5% with sensitivity 100% and specificity 68.4%, and AUC 0.85. In Group II, Mitral Septal E/E' Cut off value ≥5.8 with sensitivity 83% and specificity 90.9%, AUC 0.83, IVC collapsibility index Cut off value ≥45.5% with sensitivity 72% and specificity 86%, AUC 0.73.

CONCLUSION: Mitral Septal E/E' could predict weaning-induced diastolic dysfunction. IVC plays an important role in predicting weaning failure.

Introduction

Weaning is an important phase for the ventilated patient. The timing of weaning is essential; the least risk for a premature extubation is reintubation, with possibly unstable clinical situation and significant risk of nosocomial pneumonia [1].

Elevation of the left ventricle (LV) filling pressure can occur during weaning due to an increase in LV preload and/or decrease in LV compliance and/or increase in LV afterload. Previous studies showed that weaning might be associated with increase in filling pressures with a suggested increase in work of breathing and its effect on cardiac performance.

Pressure and volume change within the intrathoracic systemic venous compartment are accompanied by changes in extrathoracic veins such as in the intra-abdominal IVC or extra-thoracic internal jugular vein (IJV). Based on this linkage, we hypothesized that right heart function could be reflected by changes in IJV pressures as assessed by IJV diameter changes [2], [3], [4], [5].

Patients and Methods

This prospective observational study was conducted on 80 patients admitted to the Department of Critical Care Medicine, Faculty of Medicine, Cairo University, from November 2017 to September 2019. The study was approved by the Ethical Committee of Cairo University. Informed consent was obtained from the first-degree relative.

Patients

Patients were observed under assisted controlled mechanical ventilation for up to 48 h before they were considered ready to undergo an initial spontaneous breathing trial (SBT).

Patients were included in the weaning trial if they met the following criteria: Adult patients >18 years, improved the underlying condition of invasive mechanical ventilation, body temperature <39°C, hemoglobin level >7 g/dl, PaO_2 >60 mmHg, FIO_2 ≤40%, PEEP ≤8 cm H_2O, respiratory rate was <35 breaths/

min, systolic arterial pressure >90 mmHg (without need for/or high dose vasoactive drugs) and <160 mmHg, no sedation, and stable neurological status [6].

Patients were excluded if they had inappropriate acoustic windows, arrhythmias, and impaired consciousness who cannot protect their airways. Those who were dependent on high FiO_2 >0.5 and high PEEP (>8 cm H_2O), on high doses of vasopressor, and/or inotropic support. Furthermore, patients whom were diagnosed with severe neuromuscular disorders.

All patients were subjected to detailed history taking, general and local clinical examination. They had laboratory investigations as complete blood count, liver and renal chemistry and blood gases on admission, before trial, and the end of weaning trial. Bedside twelve leads electrocardiogram was done and examined for any evidence of arrhythmia. Chest radiographs: were examined serially for all patients to detect progression and/or improvement of the underlying pathology. APACHE II and SOFA score in the 1st 24 h [7], [8].

SBT procedure

Patients were divided randomly into two groups who were ready to start SBT either on pressure support ventilation (PS/CPAP pressure support 8 cm H_2O, CPAP 5 cm H_2O for 30 min or for T-piece with continuous oxygen source for 120 min [9]. Continuous hemodynamic monitoring, measuring, and recording of the parameters during two phases: assisted controlled ventilation and at the end of SBT either on PS/CPAP or T-piece with continuous oxygen supply.

Patients who succeeded to pass SBT were then extubated with continuous monitoring and observation for signs of failure of weaning for 48 h.

Failure of the weaning process was defined as a failed SBT or the need for reintubation within 48 h following extubation. Hence, all patients included in the study were observed for 48 h after the SBT [10].

Transthoracic echocardiographic evaluation was done at bedside to all patients using TOSHIBA platinum Xario 200 series, with a probe PSU-30BT 3 MHz with frequency range 1.8~4.8 MHz on assisted controlled ventilation and at the end of SBT. M-mode, two-dimensional (2D), Color flow mapping, Doppler measurements, and Tissue Doppler imaging (TDI) parameters were recorded. We used it to assess inferior vena cava indices

LV global systolic function

We assessed LV Global systolic function using M-mode modality in the long axis parasternal view for linear measurement of RV and LV [11].

The M-mode cursor was positioned at the level of the mitral valve leaflets tips to measure: -The right ventricular end-diastolic diameter, interventricular septal thickness in diastole, the left ventricular end-systolic (LVESd), and end-diastolic dimensions (LVEDd) (normally up to 5.6 cm), posterior wall thickness.

LV fractional shortening percentage was calculated as:

[(LVEDd – LVESd)/LVEDd] × 100 (normally: 25–45%) [11].

LV ejection fraction (EF). Systolic dysfunction was defined as EF below 50%. LV systolic function was also measured using modified Simpson's method in the apical window [12].

LV diastolic function

We assessed LV diastolic function using mitral flow velocities that were obtained with the sample volume positioned between the tips of the mitral leaflets, where maximal flow velocity is recorded. For all measurements, five cycles were recorded using a sweep speed of 100 mm/s., We measured Peak early (E) and atrial (A) flow velocity (cm/s), E/A ratio.

TDI of the mitral annulus was obtained from the apical 4-chamber view. A 1.5-mm sample volume was placed at the lateral and septal mitral annulus.

Analysis was then performed for: Septal E´ mitral: with normal value is 10.4 ± 2.1 cm/s [13]. Septal E/E´ ratio: with normal value is <8 [13]. The recommended variables for identifying diastolic dysfunction and their abnormal cutoff values are annular e′ velocity: septal e′<7 cm/s, lateral e′ <10 cm/s, average E/e′ ratio >14, LA volume index >34 mL/m^2, and peak TR velocity >2.8 m/s [13].

Right ventricular systolic function

Right ventricular systolic function assessment was done using tricuspid annular planimetric systolic excursion (TAPSE) on M-mode using the 2D four-chamber view. The cursor was placed at the junction of tricuspid valve plan with the free wall of the RV, whereas data were averaged over five beats. A TAPSE measurement of <16 mm is highly specific for RV dysfunction [14].

Preload indices

We evaluated cardiac preload using inferior vana caval indices and IJV indices. Each was recorded on assisted controlled mode, and at the end of mode of weaning either PS/CPAP or T-piece.

IVC collapsibility and distensibilty indices were recorded from subcostal view: The transducer position is just below the xiphisternum 1–2 cm to the right of the midline. After obtaining a 2-D image of the IVC entering the right atrium and verifying that the IVC visualization is not lost during movements of respiration, place a M-mode line through the IVC 1 cm caudal from its junction with the hepatic vein, and obtain a M-mode tracing then measure the maximum and minimum diameter of the IVC tracing [15], [16].

IVC distensibilty index is expressed as the difference between the value of the maximum diameter and the minimum diameter, divided by the minimum of the two values for mechanically ventilated patients using the formula (IVC d max – IVC d min)/IVC d min × 100% [16].

The IVC collapsibility index (IVC ci) is expressed as the difference between the value of the maximum diameter and the minimum diameter, divided by the maximum of the two values. (IVC d max – IVC d min)/IVC d max × 100% for patients spontaneously breathing on T-piece [15].

IJV collapsibility and distensibilty indices were recorded using linear probe PLU-704 BT with Frequency range 2~11 MHz. The IJV was measured using the M mode. The prescribed measurement technique was followed to determine the IJV anterior–posterior (AP) diameter during a respiratory cycle.

The IJV collapsibility index was calculated as IJV maximal AP diameter during expiration minus IJV maximal AP diameter during inspiration divided by the maximal AP diameter during expiration. This relation was reversed in mechanically ventilated patients [17].

The protocol used for the measurement of IJV collapsibility and distensibilty indices [17]: the patient's position is at 30 degree head elevation with the head slightly rotated to expose right or left IJV. We placed the transducer transversely across the patient neck, the area lateral to the cricoid cartilage.

IJV vessel identification was done by identifying 2 vessels lateral to the trachea and IJV was identified by compressibility, color flow or pulse wave Doppler with applying minimum pressure, enough to obtain an adequate ultrasound image of the right/left IJV then rotating the transducer clockwise or counter-clockwise to obtain the most circular cross-sectional image of the IJV through complete respiratory cycle.

We measured the Anteroposterior diameter during maximum and minimum distention during a respiratory cycle.

We calculated IJV collapsibility index = (IJV d max – IJV d min)/IJV d max × 100% for spontaneously breathing patients on T-piece [18].

IJV distensibilty index on mechanical ventilation was calculated = (IJV d max – IJV d min)/IJV d min × 100% % [17].

Statistical methods

Data were collected and analyzed using the statistical package SPSS (Statistical Package for the Social Science; SPSS Inc., Chicago, IL, USA) version 22. Numerical values were expressed in Mean ± SD format. Frequency and relative frequency were mentioned for categorical data. Comparative analysis was run for non-parametric variable using Mann–-Whitney tests. Serial paired comparisons were done using Wilcoxon signed-rank. Chi-square ($\chi 2$) test was performed for comparing categorical data. ROC curve was constructed with area under curve analysis performed to detect best cutoff value for the detection of success of 1st SBT. $p < 0.05$ were considered as statistically significant.

Results

Our study was conducted as a prospective randomized study at the critical care medicine department, faculty of medicine Cairo University, included 80 intubated and mechanically ventilated patients who were eligible for SBT between November 2017 and September 2019.

The study population were divided into two groups according to mode of weaning, and patients were assigned randomly into one of the weaning processes.

Group I (n = 40): 40 patients met the readiness criteria to start SBT using pressure support ventilation (PS/CPAP pressure support 8 cm H_2O, CPAP 5 cm H_2O for 30 min. (CPAP group) Group II (n = 40): 40 patients met the readiness criteria to start SBT using T-piece with continuous oxygen source for 120 min (T-piece group).

Each group will be analyzed and discussed separately.

Table 1: Comorbidities and their prevalence for CPAP group

Weaning	Failed group	Success group	p value
Hypertensive	21 (100%)	17 (89%)	0.22
Diabetic	19 (90%)	3 (15%)	<0.005

Group I (CPAP)

This group included 40 patients, where 19 patients (47.5%) succeeded to pass the weaning trial, 11 patients failed (27.5%) and 10 patients (25%) were reintubated.

Demographic data

The mean age of the studied patients was 59.17 ± 16.7 years. Succeeded group had age of 50.4 years ± 20.3 versus 67.1±6.3 with a statistically significance p = 0.003. In the studied population, there were 13 male representing 33% and 27 females representing 67%.

There was a significant difference between males and females regarding failure rates where males showed higher failure rates (76% vs. 40% in females, p = 0.034).

Clinical data of the patients

The Most prevalent comorbidities among the studied population was hypertension, 38 patients were hypertensive (95%), followed by diabetes (22 patients, 55%) as shown in Table 1.

Table 2: APACHE II and SOFA scores and their statistically significance

Score	CPAP	Succeeded	Failed	p value
APACHE II	18 ± 4	16 ± 3	21 ± 3	<0.001
SOFA	7 ± 2	7 ± 2	8 ± 2	0.313

Laboratory values and clinical scores

There is statistically significant difference between the succeeded and failed groups regarding the following lab: pH and pO_2 before SBT trial. As well as pCO_2 and SO_2 at the end of SBT trial.

APACHE II score showed statistically significant difference between the succeeded and failed groups (16 ± 3 vs. 21 ± 3) with p < 0.001 as shown in Tables 2-4.

Table 3: Blood gases before SBT and significance in outcome of SBT

Lab values	CPAP	Failed	Succeeded	p value
pH	7.37 ± −0.12	7.37 ± 0.01	7.38 ± −0.01	0.003
pCO_2	41.2 ± −7.3	42.9 ± 7.5	39.3 ± 6.9	0.126
pO_2	75.6 ± 8.5	79.4 ± 9.1	71.4 ± 5.5	0.002
HCO_3	25.5 ± 4.5	26.7 ± −4.1	24.1 ± 4.6	0.058
SO_2	95.3 ± 1.2	95.2 ± 1.1	95.4 ± 1.2	0.544

SBT: Start spontaneous breathing trial.

Echocardiographic data

Diastolic mitral inflow assessment as indices for cardiac dysfunction

We recorded Mitral E/A and Septal E/E' during assisted controlled ventilation and CPAP trial. A statistically significant difference was found between the succeeded and failed groups regarding E/A, Septal E/E' during CPAP SBT with p = 0.015 and 0.001 respectively. This is shown in Table 5.

ROC curve was plotted to determine the cuff off values to predict weaning failure on CPAP mode for CPAP group showed as illustrated in Figure 1 and Table 6

- Mitral E/A cut off value ≥0.88 with sensitivity 71% and specificity 68.4%, AUC 0.7
- Mitral Septal E/E' Cut off value ≥6.1 with sensitivity 81% and specificity 84.2%, AUC 0.73
- RV TAPSE Cut off value ≤22.5 with sensitivity 43% and specificity 68%, AUC 0.45.

Table 4: Blood gases after SBT and significance in outcome of SBT

Lab	CPAP	Failed	Succeeded	p value
pH	7.37 ± 0.4	7.37 ± 0.05	7.39 ± 0.02	0.266
PCO_2	43.5 ± 12.5	47.8 ± 14.1	38.7 ± 8.7	0.021
pO_2	72.2 ± 8.1	71.7 ± 9.7	72.7 ± 5.8	0.68
HCO_3	25.6 ± 5.1	26.8 ± 5.4	24.3 ± 4.4	0.126
SO_2	93.9 ± 2.6	92.2 ± 2.3	95.7 ± 1.6	<0.001

SBT: Start spontaneous breathing trial.

Preload indices during assisted controlled ventilation and CPAP trial

We assessed preload indices during assisted controlled ventilation and CPAP trial. A statistically significant difference was found between the succeeded and failed groups regrading IJV distensibilty index on ACV and inferior vena cava distensibilty index on ACV and during CPAP SBT as shown in Table 7.

ROC curve was plotted to determine cuffoff value for CPAP group to predict weaning failure during weaning CPAP mode. IJV distensibilty index cut off value ≥66% with sensitivity 100% and specificity 31.6%, AUC 0.49, IVC distensibilty index cutoff value ≥66.5% with sensitivity 100% and specificity 68.4%, AUC 0.85 as shown in Table 8 and Figure 2.

Mitral Septal E/E' on CPAP was correlated to IVC distensibilty index during weaning on CPAP (r=0.599, P value<0.001). TAPSE was correlated to IVC distensibilty index during weaning on CPAP (r= -0.42, P value =0.007) as shown in Table 9.

RV function by TAPSE showed no statistically significance between the succeeded and failed groups as shown in Table 10.

Group II (T-piece)

This group included 40 patients, where 22 patients (55%) succeeded to pass the weaning trial, 9 patients (22.5%) failed, and 9 patients (22.5%) were reintubated.

Table 5: Mitral flow indices on ACV and during CPAP SBT trial

Parameters	CPAP	Failed	Success	p value
E/A ACV	0.93 ± 0.37	0.97 ± 0.47	0.89 ± 0.25	0.49
E/A CPAP	0.94 ± 0.36	1.07 ± 0.42	0.8 ± 0.21	0.015
Septal E/E' ACV	6.01 ± 2.4	5.7 ± 2.7	6.4 ± 2.1	0.38
Septal E/E' CPAP	6.9 ± 2.2	8 ± 2.02	5.87 ± 1.88	0.001

SBT: Start spontaneous breathing trial.

Demographic data

The mean age of the studied patients was 58.1 ± 0.4 years. Succeeded group was younger (51.9 ± 21.2 vs. 65.7 ± 5.7) with statistically significance p = 0.007. In the studied population, there were 15 males representing 37% and 25 females representing 63%. There was a significant difference between males and females regarding failure rates where males showed higher failure rates (11/15versus 7/25, p = 0.007) as shown in Table 11.

Table 6: Mitral flow and TAPSE indices during CPAP SBT to predict weaning failure

Weaning failure CPAP	AUC	Significance	Cutoff	Sensitivity (%)	Specificity (%)
E/A CPAP	0.703	0.028	0.88	71.4	68.4
Septal E/E' CPAP	0.732	0.012	6.1	81.0	84.2
TAPSE CPAP	0.456	0.636	22.5	42.9	68.4

TAPSE: Tricuspid annular planimetric systolic excursion.

Clinical data of the patients

The most prevalent comorbidities among the studied population was hypertension; 33 from 40 patients were hypertensive (83%), which is insignificant then diabetes; 18 from 40 were diabetic (45%) where only 3 diabetic patients succeeded with statistically significance p = 0.007 as shown in Table 12.

Table 7: Preload indices for CPAP group during ACV and CPAP SBT trial

Parameters	CPAP	Failed	Succeed	p value
IJV di ACV	0.81 ± 0.25	0.89 ± 0.29	0.72 ± 0.17	0.032
IJV di CPAP	0.84 ± 0.19	0.85 ± 0.17	0.83 ± 0.21	0.783
IVC di ACV	0.8 ± 0.25	0.87 ± 0.29	0.72 ± 0.17	0.052
IVC di CPAP	0.78 ± 0.29	0.95 ± 0.23	0.6 ± 0.24	<0.001

Laboratory value and clinical scores

Statistically significant difference was found between the succeeded and failed groups regarding PO_2 and HCO_3, before SBT trial and HCO_3 and SO_2 end of SBT trial.

APACHE II score showed a statistically significant difference between the succeeded and failed groups in SBT p = 0.03 while SOFA score did not show significance as shown in Tables 13-15.

Table 8: ROC analysis for preload indices during CPAP SBT to predict weaning failure. CPAP group

Weaning failure CPAP	AUC	Significance	Cutoff (%)	Sensitivity (%)	Specificity (%)
IJV distensibilty index	0.499	0.989	66	100.0	31.6
IVC distensibilty index	0.857	0.000	66.5	100.0	68.4

SBT: Start spontaneous breathing trial, IJV: Internal jugular vein.

Echocardiographic data

Diastolic mitral inflow assessment as indices for cardiac dysfunction

We recorded Mitral E/A, and Septal E/E' during assisted controlled ventilation, and T-piece SBT trial.

Mitral Septal E/E' during T-piece showed statistically significant in Succeeded group p = 0.001 as shown in Table 16.

ROC curve was plotted to determine cuff off value for T-tube group to predict weaning failure on T-piece as shown in Table 17 and Figure 3.

- Mitral E/A T-tube Cut off value ≥0.6 with sensitivity 94% and specificity 27.3%, AUC 0.48
- Mitral Septal E/E' Cut off value ≥5.8 with sensitivity 83% and specificity 90.9%,AUC 0.83
- RV TAPSE cut off value ≤19.5 with sensitivity 61% and specificity 68%, AUC 0.59.

Table 9: Correlation mitral septal E/E' and TAPSE during weaning to IVC di

CPAP	IVC distensibilty index weaning
Septal E/E' weaning	
r	0.599
p value	0.000
TAPSE weaning	
r	−0.42
p value	0.007

TAPSE: Tricuspid annular planimetric systolic excursion.

Preload indices during assisted controlled ventilation and T-piece trial

IVC ci was statistically significant in success of weaning with p = 0.005 during SBT with T-piece. IJV collapsibility index did not show any statistically significance in success of SBT trial as shown in Table 18.

ROC curve was plotted to determine cuff off value for T-tube group to predict weaning failure during weaning as shown in Table 19 and Figure 4.

- IJV collapsibility index cut off value ≥52.5% with sensitivity 22% and specificity 95.5%, AUC 0.52
- IVC ci cut off value ≥45.5% with sensitivity 72% and specificity 86%, AUC 0.73.
- Mitral Septal E/E' was correlated to IVC collapsibility index during weaning on T-tube(r=0.45, P value=0.003) as shown in Table 20.

Table 10: TAPSE during ACV and CPAP SBT in CPAP group

Parameters	CPAP	Failed	Succeeded	p value
TAPSE ACV	21.8 ± 3.2	21.8 ± 3.6	21.8 ± 2.8	0.93
TAPSE CPAP	21.9 ± 4.1	21.8 ± 4.1	22.2 ± 4.3	0.77

TAPSE: Tricuspid annular planimetric systolic excursion.

RV function assessment by TAPSE

RV function by TAPSE showed no statistically significance in success of weaning success as shown in Table 21.

Table 11: Gender distribution, % of outcome and significance

Gender	T-piece (%)	Failed (%)	Succeeded (%)	p
Female	25 (63)	7 (38)	18 (81)	0.007
Male	15 (37)	11 (62)	4 (19)	0.007

Discussion

We aimed to study the hemodynamic changes and preload indices occurring during different modes of weaning from MV starting through changes of LV compliance and its reflection over Mitral flow velocities by performing a focused trans-thoracic echocardiography examination.

Table 12: Comorbidities and prevalence

Parameters	T-piece	Failed group (%)	Succeeded group (%)	p
Diabetic	18	15 (83)	3 (13)	0.007
hypertensive	33	16 (88)	17 (77)	0.2

We used easy and non-invasive tools in our study. We focused on data with maximum benefit, quickest to obtain with minimal stress on the study patients who were already stressed during weaning from mechanical ventilation.

Table 13: Clinical scores and outcome

Lab	T-piece	Succeeded	failed	p value
APACHE II	19.6 ± 6	17.2 ± 3.2	21.7 ± 7.5	0.018
SOFA	7 ± 2	7 ± 2	7 ± 2	0.905

In our study, the patients who were intubated and mechanically ventilated and met the readiness criteria for weaning were included, we randomly divided the patients to do SBT through T-piece for 120 min or Pressure support for 30 min [9], [18].

Table 14: Blood gases on ACV before T -piece SBT

Lab	T-piece	Failed	Success	p value
pH	7.37 ± −0.12	7.37 ± 0.01	7.37 ± 0.01	0.438
pCO_2	41.6 ± 7.8	43.5 ± 7.8	40 ± 7.5	0.155
pO_2	73.3 ± 7.8	76.4 ± 9.4	70.8 ± 5.4	0.034
HCO_3	25.1 ± 5	27.2 ± 3.7	23.3 ± 5.4	0.013
SO_2	95 ± −1.3	95.2 ± 1.1	94.0 ± 1.4	0.464

The success rate of SBT in our study was 47.5% in CPAP group, and 55% in T-piece group with p = 0.6, the rate of success in other trials was very variable. Similar to our rate success rate was 55%, in Liu *et al*., who monitored 283 consecutive SBTs (SBT; T-piece trial) performed in 81 patients [19].

Table 15: Blood gases at the end of SBT trial on T-piece

Lab	T-piece	Failed	Success	p value
pH	7.36 ± 0.38	7.37 ± 0.04	7.37 ± 0.04	0.594
PCO_2	45.2 ± 13.2	49.1 ± 14.5	42.1 ± 11.6	0.096
pO_2	71.7 ± 7.9	71.8 ± 9.2	71.7 ± 6.9	0.984
HCO_3	25.2 ± 5.3	27.2 ± 4.5	23.5 ± 5.3	0.026
SO_2	93.6 ± 2.2	92.78 ± 2.1	94.3 ± 2.2	0.033

SBT: Start spontaneous breathing trial.

A lot of studies done to demonstrate the different types of SBT, Sanfilippo *et al*. conducted systematic review to clarify the preferable SBT mode (T-piece or pressure support ventilation; the conclusion was that SBT technique did not influence weaning success [20].

Table 16: Mitral flow indices on ACV and during T-piece

Mitral indices	T-piece	Failed	Success	P value
E/A ACV	0.78 ± 0.24	0.74 ± 0.22	0.82 ± 0.26	0.341
E/A CPAP	0.85 ± 0.22	0.86 ± 0.23	0.85 ± 0.22	0.887
Septal E/E' ACV	5.7 ± 2.5	4.94 ± 2.6	6.34 ± 2.37	0.086
Septal E/E' T-piece	6.1 ± 2.2	8 ± 2	5.87 ± 1.88	0.001

Subirà *et al*. who studied 1153 patients under Successful extubation occurred in 473 patients (82.3%) in the pressure support ventilation group and 428 patients (74.0%) in the T-piece group (difference, 8.2%; 95% CI, 3.4%-13.0%; *P* = 0.001) [9].

The difference in success rates may be due to heterogeneity in patients' demographic data and comorbidities.

Table 17: ROC analysis for Mitral flow indices and TAPSE on T-piece

Weaning failure T-tube	AUC	Significance	Cutoff	Sensitivity (%)	Specificity (%)
E/A T-tube	0.487	0.892	0.61	94.4	27.3
Septal E/E' T-tube	0.826	0.000	5.8	83.3	90.9
TAPSE T-tube	0.597	0.295	19.5	61.1	68.2

TAPSE: Tricuspid annular planimetric systolic excursion.

Regarding Age in both groups, succeeded patients were younger (50.4 years ± 20.3 vs 67.1 ± 6.3 in CPAP group)(51.9 ± 21.2 vs 65.7 ± 5.7 in T-piece group) with statistically significance P value 0.003. This was similar to Jinglun et al. (2016) [19]. Amarja et al. (2019) [21] and Subira et al. (2019) [9] where succeeded groups were younger but statistically insignificant.

Table 18: IVC distensibilty index, IVC collapsibility index, IJV distensibilty index and IJV collapsibility index on ACV and t-piece SBT

Preload indices	T piece	Failed	Succeed	p value
IJV di ACV	0.41 ± 0.84	0.43 ± 0.01	0.39 ± 0.1	0.170
IJV CI T-piece	0.44 ± 0.12	0.43 ± 0.14	0.45 ± 0.1	0.603
IVC di ACV	0.41 ± 0.84	0.43 ± 0.01	0.39 ± 0.1	0.170
IVC Ci T-piece	0.41 ± 0.9	0.46 ± 0.1	0.37 ± 0.1	0.005

IJV: Internal jugular vein, SBT: Start spontaneous breathing trial.

Diabetic patients showed high weaning failure rates in our study in both groups and this was similar to Moschietto et al. (2012) on PS-SBT [22]; this was disconcordant to Ahlem et al. (2018) [23] who showed that diabetic patients included in the study didn't reach statistically significant difference as risk factor for weaning failure (p value =0.5).

Table 19: ROC analysis showing IVC and IJV ci on T-piece

Weaning failure T-tube	AUC	Significance	Cutoff (%)	Sensitivity (%)	Specificity (%)
IJV collapsibility index	0.525	0.786	52.5	22.2	95.5
IVC collapsibility index	0.737	0.011	45.5	72.2	86.4

IJV: Internal jugular vein.

APACHE II Score in CPAP trial group was 18 ± 4 and, failed group showed higher value 21 ± 3 in comparison to succeeded group 16 ± 3 with p < 0.001.

In T-piece trial group APACHE II score 19.6 ± 6. Failed group showed higher value 21 ± 7 in comparison to succeeded group 17.2 ± 3.2 with p < 0.018.

While SOFA score in both groups did not show any statistically significant difference between the succeeded and failed groups.

Table 20: Correlating mitral septal E/E' to IVC Ci on T-tube

T-tube	Correlation	IVC collapsibility index weaning
Septal E/E' weaning	R value	0.457
	p value	0.003

Our results were similar to Anna et al. (2017) which studied 130 consecutive hospitalized patients, APACHE II score was assessed based on the worst values taken during the first 24 hours after admission. Among survivors (n = 115), 88.2% were successfully liberated from mechanical ventilation and 60.9% from tracheostomy. APACHE II failed to predict weaning from mechanical ventilation (area under the receiver–operating characteristic curve [AUROC] = 0.534; 95%

confidence interval [CI]: 0.439–0.628; p = 0.65) and tracheostomy tube removal (AUROC = 0.527; 95% CI: 0.431–0.621; p = 0.63), (p = 0.41). APACHE II couldn't predict weaning outcome in patients requiring PMV [24].

Our results were similar to Bien et al. (2016) which studied 195 patient with 150 were successfully extubated and 45 were not. Subjects who were unsuccessfully weaned from MV had significantly higher APACHE II (7.65 ± 4.0.2 ± 3.6, p <0.001) and SOFA (3.20 ± 1.94 and 11.69 ± 3.10, p <0.001)scores [25].

Table 21: TAPSE before and after SBT in both succeeded and failed groups

TAPSE	T-piece	Failed	Succeeded	p value
TAPSE ACV	21.2 ± 3.7	21.9 ± 4.4	20.7 ± 3.1	0.298
TAPSE T-piece	19.9 ± 3.2	20.6 ± 4.1	19.4 ± 2.2	0.268

TAPSE: Tricuspid annular planimetric systolic excursion.

In CPAP trial; Succeeded group showed higher pH lower PCO_2, lower PO_2 before trial and higher SO2 at the end of trial (p = 0.003, 0.02, 0.002 and <0.001) respectively.

In T- piece trial; Succeeded group showed lower PO_2, before trial, lower HCO_3 before and after trial and higher SO_2 at the end of trial (p = 0.034, 0.01, 0.02, 0.03 respectively).

Metwally et al. (2018) who studied and divided 80 patients with COPD into two groups: group I included 40 patients who were weaned off by PSV mode and group II included 40 patients when there was no significant difference regrading partial arterial oxygen pressure, partial arterial carbon dioxide pressure, and arterial oxygen saturation at the end of PSV mode in both groups. A significant decline in partial arterial oxygen pressure and arterial oxygen saturation and increase in partial arterial carbon dioxide pressure were observed in group II patients after adding T-piece trial [26].

Jinglun-Liu et al. (2016) studied 283 SBT on t-piece and showed similar results regarding PCO2 which was significantly higher in patients who failed SBT [19].

Schiefbien et al. (2011) patients whose weaning was successful showed higher PaO2 and SaO2 in both groups [27].

Mitral Septal E/E' during CPAP trial showed statistically significant difference in with Cut off value of ≥6.1 (sensitivity 81% and specificity 84.2%, AUC 0.73) for predicting weaning failure which was concordant to Moschietto *et al.* [22] who studied 68 patients from which 20 patients failed.The failed group showed higher E/Ea with cut of value of 14.5 with a sensitivity of 75% and a specificity of 95.8%. that was similar to our study during Assisted controlled mode A cutoff ≥12.6 was associated with the highest diagnostic accuracy and predicted weaning failure with a sensitivity of 60% and a specificity of 95.8%, while in our study, ROC analysis for Mitral flow Septal did not predict weaning failure on ACV mode [22] and disconcordant to Amarja *et al*. (2019) who studied pre and post-extubation for both failed and successful extubations using PS CPAP mode, pre extubation assessment E/e`(7.68 vs. 8.21, p = 0.45) was not found as a statistically significant parameter [28].

In our study, Mitral E/A during CPAP showed statistically significant in Succeeded group with p = 0.015 Cut off value ≤0.88 (sensitivity 71% and specificity 68.4%, AUC 0.7) which was disconcordant to Haji *et al*. that measured mitral flow E/A at the beginning of the weaning trial and there was no statistically significant difference between the succeeded and failed groups [29].

Also Mitral E/A on ACV was correlated to E/A during weaning on CPAP (r = 0.73 and p < 0.001) and Mitral Septal E/E' on ACV was correlated to Mitral Septal E/E' during weaning on CPAP (r = 0.41, p = 0.009).

Recent published data have demonstrated a positive association between the echocardiographic measurements of diastolic failure, in particular E/E′, and weaning failure [22], [30], [31], [32]. E/E′ is a marker of left atrial pressure, left ventricular diastolic pressure. E/E′ is well correlated with pulmonary artery occlusion pressure [33]. However, this correlation in the operating room setting was debatable [34]. E/E′ range of cut-off values of 7–14 has been suggested for determining patients at risk of failing weaning from mechanical ventilation [30], [31], [32].

While In T-piece group, Mitral Septal E/E' Cut off value to predict weaning failure was ≥5.8 with sensitivity 83% and specificity 90.9%, AUC 0.83, Mitral Septal E/E' on ACV was correlated to Mitral Septal E/E' during weaning on T-tube (r = 0.34, p = 0.02) to predict failure weaning,which was similar to Liu *et al*. who studied Mitral flow E/E' for patients before and after the SBT Mean E/E'10.5 ± 4.3 for failed group versus E/E' 8.8 ± 3.2 with p < 0.01 [19].

Also in Konomi *et al*. study, 22 succeeded and 12 failed to wean. No statistically significant differences were observed in the Doppler echocardiographic variables (E, A, E/A, septal e', septal E/e') between the weaning success and failure patients at baseline.

LV diastolic dysfunction was significantly associated with weaning failure (p < 0.001) and was the best independent risk factor for weaning failure [35].

This was contradictory to Schifelbain *et al*. who studied 24 critical patients to analyze changes in cardiac function during weaning from MV. He used two different weaning methods: pressure support ventilation and T-tube. He did not find any differences between Doppler echocardiography and cardiorespiratory variables during pressure support ventilation and T-piece either in success or failure [27].

RV function by TAPSE showed no statistically significance in weaning success in both groups which was concordant to Saeed et al. (2018) [36] who studied 50 mechanically ventilated chronic obstructive pulmonary disease patients. Chest ultrasonography for the assessment of diaphragmatic mobility in addition to echocardiography was performed on different modes of mechanical ventilation in the same session at any time since mechanical ventilation. There was an insignificant correlation between echocardiography in ejection fraction, RVSP, TAPSE, and different modes of mechanical ventilation. This was in agreement with Luciele et al. (2011) and Alexandre et al (2005) who found that no echocardiographic differences were observed between PSV and T-tube [27], [37], this was similar to Ahlem et al. (2018) who found that there was no difference in either TAPSE or SPAP between the two groups at baseline and before/after T-tube. This likely reflects the absence of pulmonary hypertension induced by T-tube test [23].

In our study, the T-piece group, IVC ci was 0.46 ± 0.1 in the failed group and 0.37 ± 0.1 in the succeeded group which showed statistically significant difference in success of weaning with p = 0.005 during SBT with T-piece IVC ci Cut off value 45.5% with sensitivity 72% and specificity 86%, AUC 0.73.

IJV collapsibility index didn't show any statistically significance in success of SBT trial between the failed and succeeded groups this maybe related to methodological issues as collapsibility indices weren't tested. which was disconcordant to Ahlem et al. (2018) Collapsibility index of IVC was similar before and after T-piece test, suggesting more that this parameter represents a dynamic preload index rather than hyperinflation [23]. Also Daif et al. (2018) There was no statistically significant relation between inferior vena cava (IVC) collapsibility index and SBT outcome in patients with COPD [38] and Airapetian et al. (2015) where echocardiography and Doppler ultrasound were used to record the stroke volume (SV), cardiac output (CO) and IVC collapsibility index (IVC ci) at baseline, after a passive leg-raising maneuver (PLR) which showed that neither the IVC diameter nor IVC variability (P=0.4) accurately predict fluid responsiveness in spontaneously breathing patients hospitalized in the ICU [39].

Bauman *et al*. found that The IVC and IJV collapsibility had a significantly high correlation in the setting of spontaneous breathing ($r2 = 0.86$, $p < 0.01$) [40].

In our study, Mitral Septal E/E' during weaning on T-tube was correlated to IVC ci during weaning on T-tube ($r = 0.45$, $p = 0.003$).

Regarding, CPAP group in our study, IJV distensibilty index during ACV was 0.72 ± 0.17 in the succeeded group and 0.89 ± 0.29 in the failed group which showed statistically significant difference p = 0.03, IVC distensibilty index during ACV was 0.72 ± 0.17 in the succeeded group and 0.87 ± 0.29 in the failed group with statistically significant difference p = 0.05

IVC distensibilty index during CPAP was 0.6 ± 0.24 in the succeeded group and 0.95 ± 0.2 w in the failed group with statistically significant difference p < 0.001.

This was disconcordant to Ahlem, 2018 [23] that IVC Di index didn't show any significance in CPAP group weaning and Juhl-Olsen *et al*. showed in a small study that at least IVC-C did not seem to be a valid measure of preload status during positive pressure ventilation [41].

Tongyoo *et al*. who aimed to investigate the efficacy of echocardiography during SBT with low-level pressure support for predicting weaning failure among medical critically ill patients. Inferior vena cava maximum diameter >17 and E/Ea ratio ≥14 independently predict weaning failure in patients with preserved LV systolic function while IVC distensibilty index was statistically insignificant [42].

Also Saritaş *et al*. studied IVC di had a more accurate predictive role in predicting volume status when compared with the CI-IVC and ΔIVC, and may be used reliably with positive pressure supports. The median value for the dIVC percentages was ≤18% for all of the positive pressure support hypervolemic groups, apart from the hypervolemic T tube group (19%) [43].

IVC distensibilty index cut off value 66.5% to predict weaning failure with sensitivity 100% and specificity 68.4%, AUC 0.85 in our study.

Few relevant clinical studies on IJV and IVC distensibilty indices to predict weaning induced Cardiac dysfunction, Most of the studies done to evaluate IJV distensibilty index as a substitute to IVC di index as indicator for fluid responsiveness in mechanically ventilated patients. Apart from Baumann *et al*. found

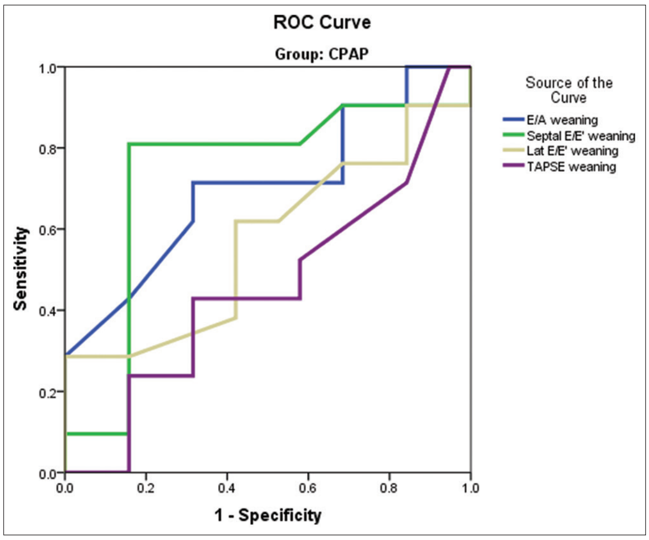

Figure 1: ROC curve analysis for Mitral flow indices during weaning on CPAP and weaning failure

a good correlation between IVC Ci and IJV ci in patients with spontaneous respiration; however, they determined that there was no statistically significant correlation when positive pressure ventilation was applied [40]. This was confirmed by our study.

Study limitations

The study is a single center trial. Relatively with small sample size. Both echocardiography and vascular ultrasound are an operator dependent techniques and mechanical ventilation represented a somewhat difficulty during their performance. IJV ultrasonography dictate patients' cooperation which might obscure accurate data interpretation. Some problems like chest wall lesions or obesity might be troublesome during ultrasound evaluation.

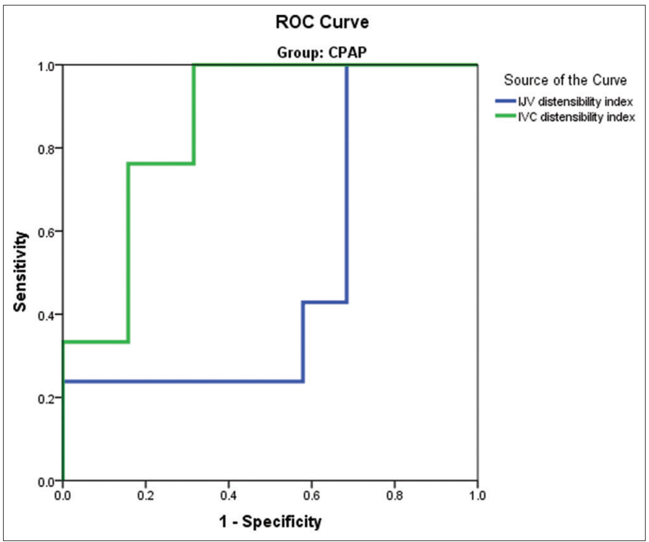

Figure 2: ROC curve for preload indices during weaning during CPAP start spontaneous breathing trial and weaning failure. Mitral Septal E/E' on CPAP was correlated to IVC distensibilty index during weaning on CPAP (r = 0.599, p < 0.001).

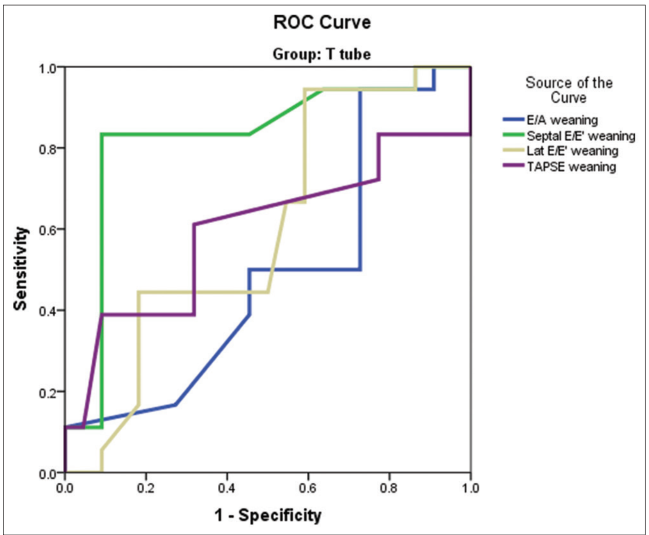

Figure 3: ROC curve analysis for mitral flow indices and TAPSE during weaning on T-piece to predict weaning failure

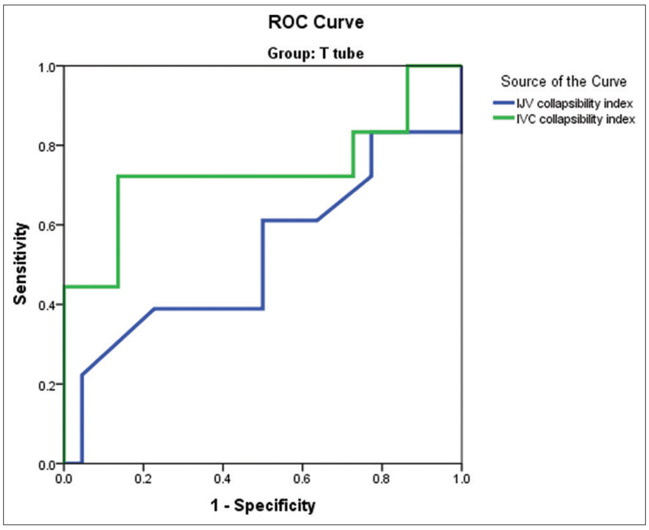

Figure 4: ROC curve showing preload indices during weaning on T-piece.

Conclusion and Recommendations

Cardiac dysfunction is an important cause of weaning failure. Mitral Septal E/E' could predict weaning induced diastolic dysfunction. IVC plays important role in determining fluid status and predict weaning failure IJV ultrasonography plays minimal role for predicting weaning failure.

RV echocardiographic assessment is inconclusive in predicting weaning failure. Further studies are needed to investigate Respiratory changes in both IJV and inferior vena cava during weaning as predictors of weaning failure.

Acknowledgment

We are deeply thankful Critical Care Medicine department staff, Cairo University for their great help, patience and outstanding support throughout the practicing this work and handling difficulties and technical support.

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