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

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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 re-intubation, 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, PaO₂ >60 mmHg, FiO₂ ≤40%, PEEP ≤8 cm H₂O, 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$_2$O), 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$_2$O, CPAP 5 cm H$_2$O 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:

\[
\frac{(LVEDd – LVEsd)}{LVEDd} \times 100 \quad (\text{normally: 25–45%}) \quad [11].
\]

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 vena 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 distensibility 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 distensibility 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 distensibility 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 distensibility 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 min × 100% for spontaneously breathing patients on T-piece [18].

IJV distensibility 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 (χ²) 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 H₂O, CPAP 5 cm H₂O 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.
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.

| 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 |

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

**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.

| 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 |
| $pO_2$     | 76.5 ± 5.5 | 76.4 ± 5.1 | 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 |

| 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.

| Parameters | CPAP | Failed | Succeeded | 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 |

ROC curve was plotted to determine cutoff value for CPAP group to predict weaning failure during weaning CPAP mode. IJV distensibility index cut off value ≥66% with sensitivity 100% and specificity 31.6%, AUC 0.49, IVC distensibility 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 distensibility index during weaning on CPAP ($r=0.599$, P value<0.001). TAPSE was correlated to IVC distensibility 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.

**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.
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.

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 $\geq 52.5\%$ with sensitivity 22% and specificity 95.5%, AUC 0.52
- IVC ci cut off value $\geq 45.5\%$ 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.

RV function assessment by TAPSE

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

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.
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 Failed | Success | p value |
|-------------|----------------|---------|---------|
| APACHE II   | 19.5 ± 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

| Parameters | T-piece Failed | Success | p value |
|------------|----------------|---------|---------|
| pH         | 7.37 ± 0.12    | 7.37 ± 0.01 | 7.37 ± 0.01 | 0.642 |
| pCO₂       | 41.6 ± 7.8     | 43.5 ± 7.8 | 40 ± 7.5 | 0.155 |
| pO₂        | 73.3 ± 7.8     | 76.4 ± 9.4 | 70.5 ± 5.4 | 0.034 |
| HCO₃       | 25.1 ± 5       | 27.2 ± 3.7 | 23.3 ± 5.4 | 0.013 |
| SO₂        | 95 ± 1.3       | 95 ± 2.1 | 94.0 ± 1.4 | 0.464 |

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

| Parameters | T-piece Failed | Success | p value |
|------------|----------------|---------|---------|
| pH         | 7.36 ± 0.38    | 7.37 ± 0.04 | 7.37 ± 0.04 | 0.694 |
| pCO₂       | 45.2 ± 13.2    | 49.1 ± 14.5 | 42.1 ± 11.6 | 0.096 |
| pO₂        | 71.7 ± 7.9     | 71.8 ± 9.2 | 71.7 ± 6.9 | 0.984 |
| HCO₃       | 25.2 ± 5.3     | 27.2 ± 4.5 | 23.5 ± 5.5 | 0.026 |
| SO₂        | 95 ± 1.3       | 95 ± 2.1 | 94.0 ± 1.4 | 0.033 |

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 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/A ACV | 5.7 ± 2.5      | 4.94 ± 2.6 | 6.34 ± 2.37 | 0.086 |
| Septal E/A T-piece | 6.1 ± 2.2 | 8 ± 2 | 5.87 ± 1.88 | 0.001 |

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

| Weaning failure | AUC | Significance | Cutoff | Sensitivity (%) | Specificity (%) | p value |
|-----------------|-----|--------------|--------|-----------------|-----------------|---------|
| E/A T-piece     | 0.487 | 0.892       | 0.61 | 94.4 | 27.3 |
| Septal E/E T-piece | 0.526 | 0.000 | 5.8 | 83.3 | 50.9 |
| T-piece         | 0.597 | 0.295       | 19.5 | 61.1 | 68.2 |

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 distensibility index, IVC collapsibility index, IJV distensibility index and IJV collapsibility index on ACV and T-piece SBT

| Parameters | T-piece Failed | Success | p value |
|------------|----------------|---------|---------|
| IJV collapsibility index | 0.525 | 0.786 | 52.5 | 22.2 | 95.5 |
| IJV ci T-piece | 0.737 | 0.011 | 45.5 | 72.2 | 86.4 |

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 discordant 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 (%) | p value |
|------------------------|-----|--------------|--------|-----------------|-----------------|---------|
| IJV collapsibility index | 0.525 | 0.786 | 52.5 | 22.2 | 95.5 |
| IJV ci T-piece | 0.737 | 0.011 | 45.5 | 72.2 | 86.4 |

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

| Weaning failure T-tube | Correlation | IVC collapsibility index | p value |
|------------------------|-------------|--------------------------|---------|
| Septal E/E' T-tube | 0.457 | 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) [25].

| Table 21: TAPSE before and after SBT in both succeeded and failed groups |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| TAPSE ACV                  | T-piece                    | Failed                      | Succeeded                   | p value                     |
| 21.2 ± 3.7                 | 21.9 ± 4.4                 | 20.7 ± 3.1                  | 20.9 ± 4.4                  | 0.208                       |
| TAPSE T-piece              | 19.9 ± 3.2                 | 20.6 ± 4.1                  | 19.4 ± 2.2                  | 0.206                       |

In CPAP trial; Succeeded group showed higher pH lower PCO₂, lower PO₂ 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 PO₂ before trial, lower HCO₃ before and after trial and higher SO₂ at the end of trial (p = 0.034, 0.01, 0.02, 0.03 respectively).

Mettwally 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/A 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/Aa 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 discordant 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 discordant 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’ on ACV was correlated to Mitral Septal 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’ Cut off value to predict weaning failure was ≥5.8 with sensitivity 83% and specificity 90.9%, AUC 0.83, Mitral Septal E’ on ACV was correlated to Mitral Septal 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’ for patients before and after the SBT Mean E’ 10.5 ± 4.3 for failed group versus 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 significant in weaning success in both groups which
IVC distensibility 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 distensibility 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 concordant 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 distensibility 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 distensibility 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 distensibility indices to predict weaning induced Cardiac dysfunction. Most of the studies done to evaluate IJV distensibility index as a substitute to IVC di index as indicator for fluid responsiveness in mechanically ventilated patients. Apart from Baumann et al. found 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 discordant 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 distensibility 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.
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.

ROC Curve Group: CPAP

**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.

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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 distensibility 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.
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