

Comparison of Breathing Comfort during Weaning with Two Ventilatory Modes

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In twenty-one patients ventilated for ≥ 3 days, we compared similar levels of partial support provided by synchronized intermittent mandatory ventilation (SIMV) and pressure support ventilation (PSV) in terms of breathing comfort. On a single day, eligible subjects experienced, in random order, both SIMV and PSV weaning protocols (sequential 20% reductions in support at timed intervals) separated by a 1 to 3 h rest. Breathing comfort was defined by subjective ratings of dyspnea and anxiety. Subjects reported significant levels of preweaning dyspnea and anxiety despite resting for at least 6 h. Dyspnea and anxiety were not significantly different between the two methods at any level of support. Our findings suggest that dyspnea and anxiety are higher than expected on "full" ventilator support, and that comfort may not differ between PSV and SIMV during active withdrawal of machine support. **Knebel AR, Janson-Bjerklie SL, Malley JD, Wilson AG, Marini JJ. Comparison of breathing comfort during weaning with two ventilatory modes. Am J Respir Crit Care Med 1994; 149:14-8.**

For most patients who require mechanical ventilation, the return to spontaneous breathing is a simple matter of discontinuing ventilatory support when the patient appears ready. However, because abrupt transitions are poorly tolerated by some patients, ventilator support must often be removed more gradually.

Two techniques of partial ventilatory support are widely used to wean patients from mechanical ventilation. Synchronized intermittent mandatory ventilation (SIMV) coordinates the onset of machine assistance with patient effort and ensures the delivery each minute of a prescribed number of machine-delivered cycles of known volume. However, recent work suggests that SIMV does not reduce patient work in quite the same fashion as was commonly believed (1).

Pressure support ventilation (PSV) reduces the breathing workload of each breath and overcomes endotracheal tube resistance (2, 3). Unlike SIMV, this pressure-limited mode does not guarantee a minimum tidal volume (VT) or minute ventilation (VE) (4). Uncontrolled observations suggest that PSV promotes patient-ventilator synchrony with respect to cycle length and that it may be more comfortable than SIMV (5). In theory, such benefits could improve tolerance and facilitate the weaning process. Therefore the purpose of this study was to compare weaning with SIMV to weaning with PSV in terms of breathing comfort.

(Received in original form August 27, 1992 and in revised form July 29, 1993)
Supported by American Lung Association of California, Pulmonary Nursing Fellowship; and Graduate Division, University of California, San Francisco.

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Am J Respir Crit Care Med Vol 149, pp 14-18, 1994

METHODS

Subjects

We studied 21 alert subjects who were intubated for respiratory failure secondary to varied pulmonary (not cardiovascular) causes. Each subject had been ventilated for ≥ 3 days in the medical/surgical intensive care unit at the Medical Center at the University of California, San Francisco. All subjects were hemodynamically stable, were capable of sustaining brief periods of spontaneous ventilation, and had not experienced a weaning attempt during the preceding 12 h. Each patient was oriented to time, place, and person and responded appropriately to directed questions. Each was judged by attending staff to be an appropriate candidate for a weaning trial.

Apparatus

All subjects were ventilated with a Puritan-Bennett 7200 ventilator (Carlsbad, CA) using standard disposable circuitry. Airway pressure was monitored in the external circuit (model DP15-30; Validyne, Northridge, CA). A Fleisch-style pneumotachygraph (Bionix 400, Richmond, CA) was connected to the endotracheal tube proximal to the Y piece of the ventilator circuit. The pneumotachygraph (accurate $\pm 2\%$ of full scale) used an internal integrating circuit to continuously measure airflow and compute volume. This instrument repeatedly reestablished the zero-flow baseline, thus preventing electrical drift and enhancing the reliability of measurements at low flow rates. The waveforms of airway pressure, airflow, and tidal volume were recorded on a four-channel recorder (model 7754B; Hewlett Packard, Waltham, MA) calibrated with standardized signals. The added dead space of the experimental apparatus was approximately 100 ml, and added inspiratory resistance was 0.6 cm H₂O/L/s. Maximal static inspiratory pressure ($P_{i,max}$) was measured from the airway pressure waveform recorded during a maximal inspiratory effort maneuver at or below functional residual capacity (6).

Psychometric Instruments

For purposes of this study, breathing comfort was assessed by indices of dyspnea and anxiety. The intensity of generalized breathing discomfort was rated with a dyspnea visual analogue scale (VAS). The dyspnea

VAS asked subjects to place a vertical mark on a printed 100 mm horizontal scale in response to the question: "How short of breath are you right now?" The line had descriptors below the extreme ends. On the left was the word "none," indicating no shortness of breath, and on the right was the opposite response, "extremely severe." For each weaning technique and stage, subjects placed a vertical mark on the line that best represented the intensity of their dyspnea. Intensity was measured as the distance in millimeters from the left side of the horizontal line (corresponding to no dyspnea) to the mark placed by the patient. A fresh scale was presented each time these measures of breathing comfort were assessed.

Because patients occasionally have difficulty understanding how to mark the VAS (7), our subjects were carefully instructed on the appropriate use of the scale before the protocol began. Standardized directions were read aloud and all patients then practiced marking the scale. The feasibility of using the VAS in ventilated patients has been previously established (8).

A VAS was also used to quantify anxiety, an emotion frequently experienced by ventilated patients (9, 10). This instrument was chosen to decrease response burden in these critically ill patients during weaning and to chart subtle changes in anxiety. The anxiety VAS asked subjects to rate, "How do you feel right now?" by marking on a 100 mm line. Descriptors at the extreme ends read "not at all anxious" and "extremely anxious." The anxiety VAS was printed in large type on a card separate from the dyspnea VAS and was administered before the weaning attempt and during each weaning condition. The anxiety VAS score was measured as the distance in millimeters from the left edge of the line to the mark placed by the patient.

Procedure

The Committee for Human Research at the University of California, San Francisco approved the protocol. All subjects were studied while sitting semi-upright (45 to 90 degrees from horizontal). Prewaning measurements of anxiety and dyspnea were first collected, and then the airway pressure monitoring equipment and pneumotachograph were connected to the endotracheal tube.

After the equipment was placed and adjusted, subjects performed an inspiratory maneuver against occlusion using a one-way valve to ensure maximal effort (6). The subjects then recovered from the exertion for several minutes, breathing with assist-control ventilation (AMV). The resting \dot{V}_E was then recorded. Next, still using AMV, a brief series of passive, machine-controlled breaths (where the patient did not initiate inspiration) were obtained by gradually increasing the machine's backup breathing frequency to the point of suppressing patient triggering of the ventilator. The shape and contour of the airway pressure tracing indicated that passive inspiration was achieved (11). These passive breaths were used to calculate the resistance and compliance of the respiratory system, which provided information about the impedance characteristics of the lung and chest wall.

Machine support was provided by either PSV or SIMV, and all subjects experienced both protocols. Five cm H₂O of continuous positive airway pressure (CPAP) was applied during both modes for several reasons. It is our practice to use low levels of CPAP to counterbalance the loss of end-expiratory lung volume that occurs when patients are supine or semi-upright. Also, in patients with dynamic hyperinflation, such as those with emphysema, low CPAP levels may prevent dynamic airway collapse or help counterbalance dynamic hyperinflation (12).

Half of our subjects received the SIMV protocol first, while the others received the PSV protocol first. The order of presentation was varied, according to a table of random numbers. A 1- to 3-h rest preceded the start of the second protocol. Care was taken to ensure that subjects felt well rested and ready to begin. All subjects started at a level of ventilation intended to provide "full support" (100%). For the PSV phase, pressure support was adjusted until the patient achieved a \dot{V}_T of 10 ml/kg. The level of support necessary to achieve this volume varied from subject to subject, depending on the impedance to chest inflation.

Applied pressure was then decreased progressively in 20% decrements from full support until the patient breathed spontaneously with 5 cm H₂O CPAP (0%). For example, the patient may have started at 20 cm H₂O pressure support (peak airway pressure 25 cm H₂O) to achieve a \dot{V}_T of 10 ml/kg. In that case, the ventilatory support level was decreased in 4 cm

H₂O decrements. Therefore, 16 cm H₂O support (21 cm H₂O peak pressure) was defined as 80% support; and spontaneous breathing (0 cm H₂O pressure support, 5 cm H₂O CPAP) was 0% support.

During the SIMV protocol, full support was first achieved by setting the ventilator-delivered \dot{V}_T equal to 10 ml/kg and adjusting the ventilator's frequency to achieve a \dot{V}_E equal to that previously set by the patient during relaxed assist-control ventilation. For SIMV machine cycles, constant inspiratory flow was delivered at 60 L/min. During this weaning protocol, the ventilator-delivered frequency was decreased in 20% decrements. No pressure support was applied to the unsupported spontaneous breaths. For example, if the patient weighed 70 kg, the ventilator-delivered \dot{V}_T was 0.70 L. Therefore, if the baseline \dot{V}_E on assist-control ventilation was 10 L/min, the ventilator frequency was set at 14 breaths per minute ($(10 \text{ L/min})/[0.70 \text{ L}] = 14 \text{ breaths/min}$). In this example, the ventilator rate was decreased sequentially from 14 to 11, 8, 5, 2, and 0 breaths per minute. Zero breaths per minute with 5 cm H₂O CPAP represented 0% support.

During both protocols, measurements of airway pressure, airflow, and volume were sampled 10 min after accommodation to each new ventilator setting. VAS for dyspnea and anxiety were then recorded. The order of presentation of the scales was randomized. Data collection at each ventilator setting required 3 to 5 min, so the subject breathed for about 15 min at each level of support. Each weaning protocol lasted approximately 2 h. Because the protocols were separated by a rest period of approximately 2 h, data collection lasted about 6 h.

Subjects were monitored closely as ventilatory support was decreased. They were returned to full support and the protocol limb terminated if cardiorespiratory instability occurred as evidenced by any of the following: increased heart rate > 120 beats/min, change in systolic blood pressure to < 80 mm Hg or to > 180 mm Hg, development of a new arrhythmia, oxygen saturation less than 90%, or requests for increased ventilation because of severe dyspnea or anxiety.

Subjects were followed for 24 h after the study was completed, to see if extubation was successfully accomplished. House staff and attending physicians made all clinical decisions regarding care and extubation without knowing the study results or receiving input from the investigators.

Data Analysis

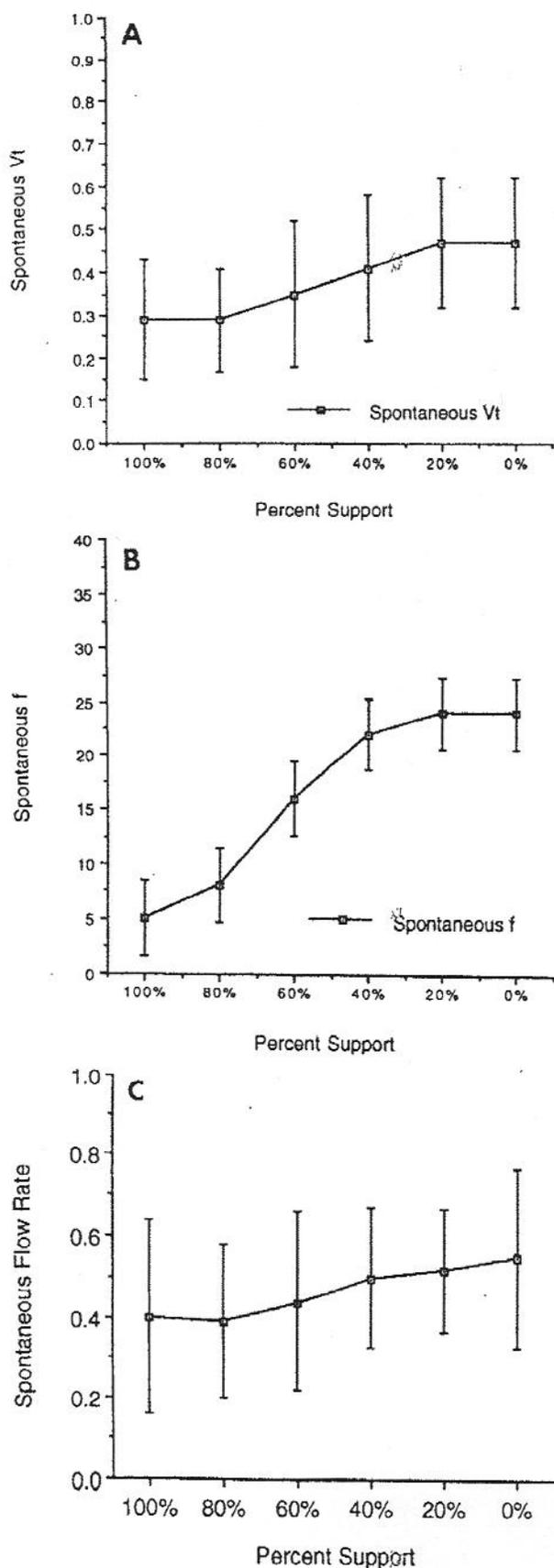
A two-way repeated measures analysis of variance (using a biomedical statistical package, BMDP 5V [BMDP Statistical Software, Los Angeles, CA], for the expectation maximization [EM] algorithm for maximal likelihood estimation in the presence of missing data [13]) evaluated the differences between dyspnea intensity and anxiety intensity between the two weaning methods. Group differences were evaluated using paired *t* tests (with a Bonferroni correction for multiple tests) to locate where the differences occurred. Level of significance was set at $p < 0.05$ for all statistical tests.

RESULTS

The mean age of the subjects in the sample was 52 ± 21.7 yr. The number of days they were ventilated before study ranged from 3 to 55. Etiologies for respiratory failure varied across subjects (table 1). All subjects, except one with a tracheostomy, had oral endotracheal tubes that ranged in size from 7 to 8 mm (internal diameter). The mean $P_{i,max}$ exceeded the standard criterion (14) of 30 cm H₂O used to predict successful weaning (46.1 ± 18.7 cm

TABLE 1
ETIOLOGY OF RESPIRATORY FAILURE

Primary Clinical Diagnosis	No. of Patients
Adult respiratory distress syndrome	3
Chronic obstructive pulmonary disease	6
Neuromuscular weakness	3
Pneumonia	3
Postoperative surgical procedure	5
Asthma	1



H₂O). The total VE on baseline ventilator settings, before the start of weaning, averaged 11.8 ± 4.7 L/min (range, 4.5 to 17.8 L/min). Compliance measured under passive conditions was 0.053 ± 0.02 L/cm H₂O. The mean inspiratory resistance was 23.1 ± 6.4 cm H₂O/L/s.

All 21 subjects, 10 men and 11 women, experienced both weaning methods; 11 received SIMV first, whereas the others received PSV first. More subjects completed the lowest level of support (spontaneous breathing with 5 cm H₂O CPAP) following the PSV protocol ($n = 16$), compared with the SIMV protocol ($n = 13$). During PSV weaning, two subjects stopped after 40% support and three more stopped after 20% support. During SIMV weaning, two subjects stopped after 60% support, three more stopped after 40% support, and an additional three subjects stopped after 20% support.

Responses to Weaning

Breathing pattern: During SIMV weaning, machine VT remained unchanged (0.85 ± 0.2 L) as the frequency of ventilator-delivered breaths was gradually decreased: 14.4 ± 7.2 (100%) to 0 min⁻¹ (0%). Spontaneous VT and breathing frequency both increased as machine support was withdrawn (figure 1). Total VE decreased: 15.09 ± 6.08 L/min on 100% to 11.82 ± 3.31 L/min on 0% (CPAP). The average inspiratory flow rate of spontaneous breaths increased from 0.40 ± 0.24 cm H₂O/L/sec on 100% support to 0.55 ± 0.22 cm H₂O/L/sec on 0% support (figure 1).

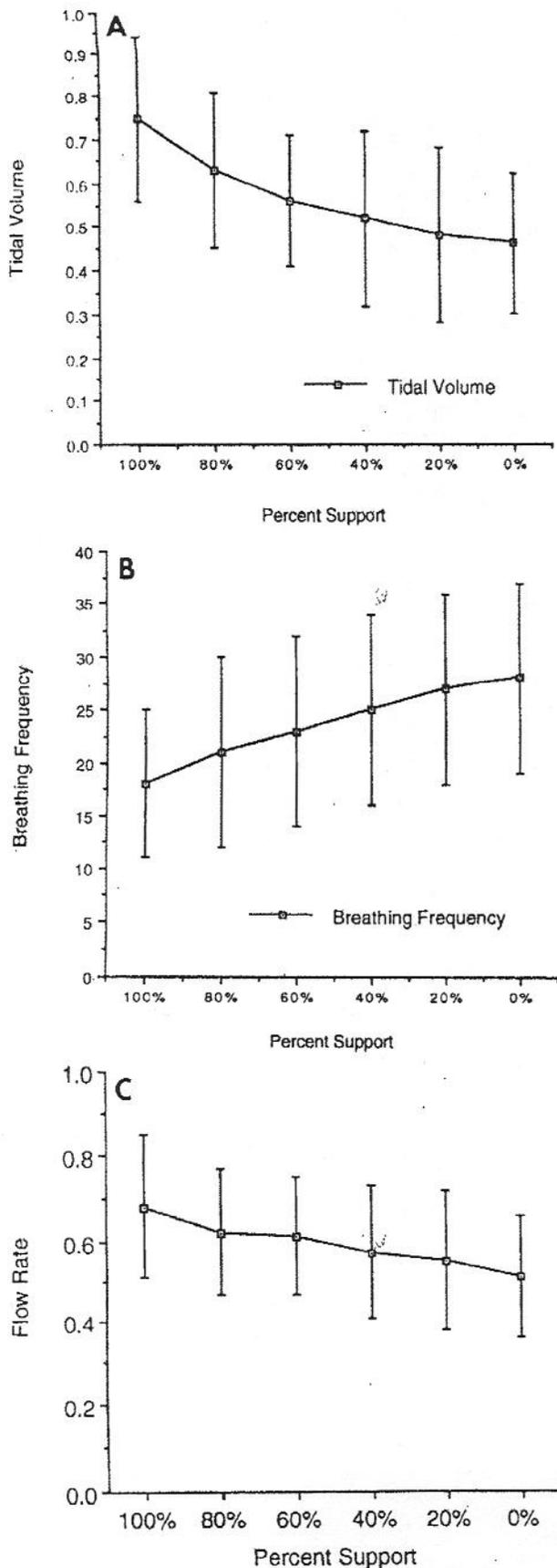
With PSV, in contrast to SIMV, every breath was partially supported by the ventilator. VT and breathing frequency varied, depending on the level of applied pressure and thoracic impedance. The starting pressure support level for 100% averaged 22 ± 7.1 cm H₂O (range 10 to 35 cm H₂O). As the level of applied pressure decreased, the VT decreased and the breathing frequency increased (figure 2). Total VE changed little as the pressure support level decreased and remained close to the initial value of 12.58 L/min throughout. Except at the highest level of support, the mean total VE for the two weaning methods was comparable at each support level. At the lowest levels of machine support, spontaneous VT and breathing frequency were the same for the two weaning methods. The inspiratory flow rate ranged from 0.68 ± 0.17 cm H₂O/L/sec on 100% support to 0.51 ± 0.15 cm H₂O/L/sec on 0% support (figure 2).

Subjective responses: Before weaning, scores for dyspnea and anxiety were 32.2 ± 22.6 and 43.1 ± 31.4 mm, respectively. Box-plots (15) illustrate that dyspnea and anxiety intensities generally remained stable across SIMV levels and across PSV levels (figure 3). Dyspnea and anxiety were positively correlated during SIMV weaning ($r = 0.55$) and during PSV weaning ($r = 0.61$). Dyspnea and anxiety intensities were not significantly different between the two weaning methods (figure 3).

Weaning Outcome

Some subjects were unable to continue the weaning protocol through the lower support levels, and the ability to complete the unsupported CPAP level did not depend on which weaning method was applied first (completed PSV-CPAP: $\chi^2 = 0.40$, $p = 0.53$; completed SIMV-CPAP: $\chi^2 = 1.15$, $p = 0.28$). Even though more subjects completed the full PSV protocol, the ability to complete

Figure 1. Spontaneous tidal volume (Vt) (panel A), breathing frequency (f) (panel B), and flow rate (panel C) during synchronized intermittent mandatory ventilation (SIMV) weaning. Note that Vt, f, and inspiratory flow rate increase as ventilator support decreases.



the SIMV-CPAP level better predicted the ability to wean within 24 h of study completion ($\chi^2 = 6.4$, $p = 0.01$). Dyspnea during SIMV-CPAP also predicted ability to wean (Mann Whitney U = 20, $p < 0.05$).

Ten of 21 subjects could be weaned from mechanical ventilation within 24 h of the study, as evidenced by their continued tolerance for spontaneous breathing. Reasons for continuing ventilator support and postponing extubation included hypoxemia refractory to a fraction of inspired oxygen (FI_{O_2}) of 0.6 (two subjects); poor respiratory muscle strength and lack of endurance (six subjects); and increased \dot{V}_E requirement, possibly caused by fever or anxiety (three subjects).

DISCUSSION

The purpose of this study was to compare weaning with SIMV to weaning with PSV in terms of breathing comfort. The breathing comfort of ventilator-dependent patients is difficult to quantify. In this study, VASs were used to measure two aspects of comfort: dyspnea and anxiety. Aitken recommended the measurement of sensations by VAS as a means of accurately describing subjective experiences (16). Because the lack of quantitative terms in the English language limits the range of descriptions, a horizontal line allows freedom of rating without imposing artificial categories (16). In alert, cooperative subjects the VAS sensitively measures intensity change in response to stimulus (17).

The question used to assess dyspnea: "How short of breath are you right now?" appears to validly represent the generalized experience of breathlessness in subjects with pulmonary disease. Elliott and colleagues found that patients most frequently chose from a list of 45 descriptors the statement "I feel short of breath" to describe the feelings they experience when their breathing troubles them (18). In that study, this descriptor was reliable as patients consistently chose it over time. The construct validity of the dyspnea VAS instrument itself has been established by comparison with other measures of dyspnea (8, 19) and by the correlation between the change in intensity in response to increased physiologic impairment (20).

Anxiety is a term frequently used by mechanically ventilated patients to describe their experience (9, 10). The measurement of anxiety with VASs has been recommended as a sensitive indicator of this important emotion (21–23). In the present study, subjects reported substantial preweaning dyspnea and anxiety despite receiving moderate to high levels of ventilatory support (an SIMV frequency of ≥ 6 breaths/min) for the 6 h before the study. These findings suggest that practitioners frequently underestimate the discomfort that occurs, even at high levels of ventilator support.

Correlations between dyspnea and anxiety in the present study support a theoretical relationship thought to exist between these two variables (24). Respiratory rate can increase if patients become anxious. With the large ventilator-delivered V_T , air trapping and asynchrony with the ventilator can occur. Air trapping and asynchrony can produce a sense of dyspnea contributing to a further increase in anxiety, creating a panic cycle.

In summary, the results of this study indicate that PSV weaning is not necessarily more comfortable than SIMV. Patients in our sample expressed similar levels of dyspnea and anxiety at

Figure 2. Tidal volume (panel A), breathing frequency (panel B), and inspiratory flow rate (panel C) during pressure support ventilation (PSV) weaning. Note that tidal volume and inspiratory flow decreased and the breathing frequency increased as support was withdrawn.

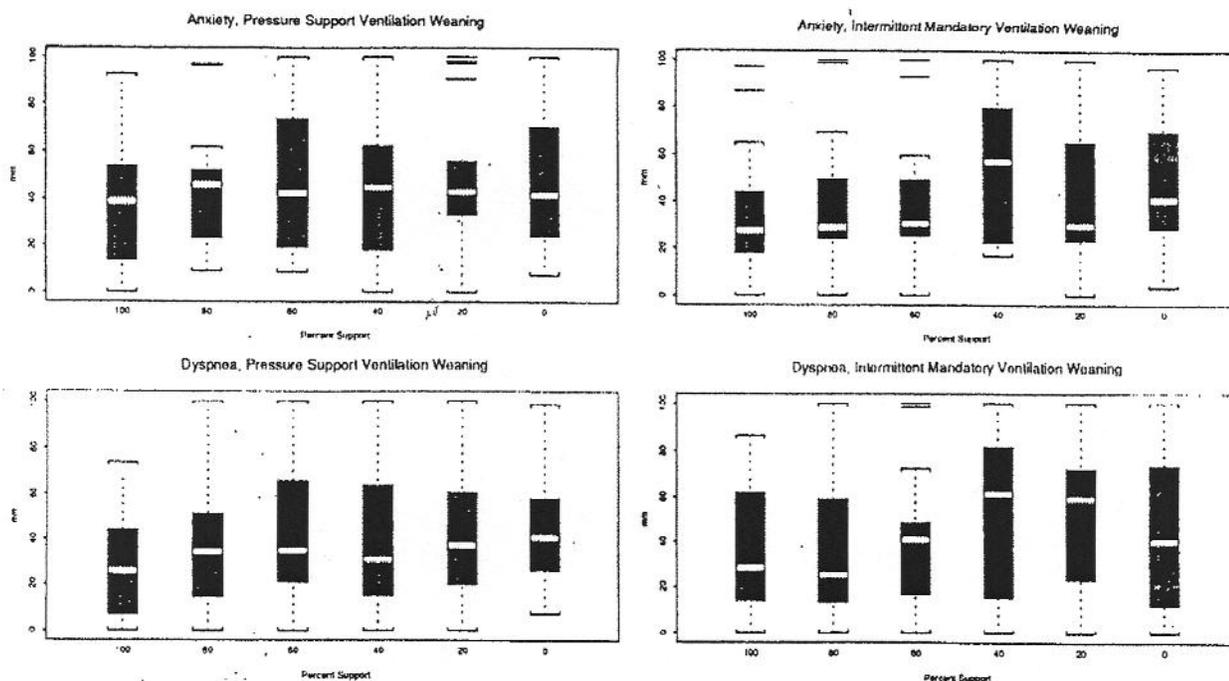


Figure 3. Box plots (13) are used to graphically represent the dyspnea and anxiety. The box plots identify the midpoint and spread of the data. White horizontal lines are drawn at the median values. The top of the shaded bar indicates the 75th quartile, and the bottom indicates the 25th quartile. The dotted lines above and below the shaded area are drawn to include values contained within a 1.5 multiple of the interquartile range (IQR). IQR = (upper quartile-lower quartile) and is used to identify values that fall outside the norm. Any points outside the range are denoted with black horizontal lines and may represent outliers.

each stage during weaning with both methods. Subjective comfort is impossible to estimate without questioning the patient directly, but other indices of distress, such as heart rate, were also not different between the two methods. The largest mean difference at any support level was four beats per minute.

The results of this study indicate that semiquantitative measures of dyspnea and anxiety are greater than expected during mechanical ventilation and weaning. Although individual patients may prefer one mode over another, these data demonstrate that during active withdrawal of machine support dyspnea and anxiety may not routinely differ between SIMV and PSV.

Acknowledgment: The authors wish to thank Jane Norbeck, RN, DNSc, FAAN; Marianne Chulay, RN, DNSc, FCCM; Gladys Campbell, RN, MSN; and the nurses; respiratory therapists; and physicians, especially Michael Matthey, MD, of the UCSF Moffitt Hospital ICU, for their support and assistance with this work.

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