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ORIGINAL ARTICLE

The Prediction of Extubation Success of Postoperative Neurosurgical Patients Using Frequency–Tidal Volume Ratios

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Abstract
Background The process of discontinuing neurological patients from mechanical ventilation is still controversial. The aim of this study was to report the outcome from extubating patients undergoing elective craniotomy and correlate the result with the measured f/V_t ratio.
Materials and Methods In a cohort prospective study, all consecutive patients who required mechanical ventilation for up to 6 h after elective craniotomy were eligible for inclusion in this study. Patients passing daily screening criteria automatically received a spontaneous breathing trial (SBT). Immediately previous to the extubation, the expired minute volume (VE), breathing frequency (f), and tidal volume (V_t) were measured and the breathing frequency-to-tidal volume ratio (f/V_t) was calculated; consciousness level based on Glasgow Coma Scale (GCS) was evaluated at the same time. The extubation was considered a failure when patients needed reintubation within 48 h.
Results Ninety-two patients were extubated and failure occurred in 16%. Despite 15 patients failed extubation just one of them presented the f/V_t score over 105. The best cutoff value for f/V_t observed was 62, but with low specificity (0.53) and negative predictive values (0.29). Area under the ROC curve for the f/V_t was 0.69 ± 0.07 ($P = 0.02$). Patients who failed the extubation process presented higher incidence of pneumonia (80%), higher need for tracheostomy (33%) and mortality rate of 40%.
Conclusion The f/V_t ratio does not predict extubation failure in patients who have undergone elective craniotomy. Patients who fail extubation present higher incidence of pneumonia, tracheostomy and higher mortality rate.

Keywords Ventilator weaning · Mechanical ventilation · Neurosurgery · Craniotomy · Weaning failure · Frequency–tidal volume ratio

Introduction

The process of discontinuing patients from mechanical ventilation is still controversial and consists of two components: weaning from ventilatory support and extubation. Both delayed and premature extubation have been associated with adverse outcomes. Delayed extubation is associated with increased length of hospital stay, increased risk for ventilator-associated pneumonia, and increased mortality in brain-injured patients [1]. On the other hand, extubation failure is also associated with

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adverse outcomes as increased hospital mortality, prolonged hospital stay, higher costs, and greater need for tracheostomy [2–6].

Different strategies have been documented for weaning neurosurgical patients from mechanical ventilation and extubation [7, 8]. Neurosurgical patients are predisposed to a number of complications related to mechanical ventilation and retrospective and prospective investigations have documented increased rates of reintubation, pneumonia, and prolonged mechanical ventilation among these patients [9–11]. However, a weaning protocol based on traditional respiratory physiologic parameters may have limitations for use in neurosurgical patients [8].

Several studies [12–20] have addressed objective criteria to predict weaning from mechanical ventilation in the intensive care unit. Attention has now moved toward redefining the decision of patient extubation, as 10–20% of extubations may still fail and require reintubation [21–25]. Multiple weaning parameters have been investigated as possible predictors of extubation outcome [26–31]. Breathing frequency–tidal volume ratio (f/V_t) has been the one most studied, although it has not been proven to be accurate [32]. Cutoff value of 105 has been pointed out as a predictor for extubation success/failure. As far as we know an f/V_t score has not yet been developed to predict extubation success in neurosurgical patients. This ratio has been developed for mechanical ventilated patients with heterogeneous diagnosis and they usually are very awake. However, it is not uncommon for neurosurgical patients under mechanical ventilation to present an abnormal consciousness level, which should be a factor accounted for during weaning process.

The aim of this study was to report the outcome from extubating patients undergoing elective craniotomy and correlate the result with the measured f/V_t ratio.

Materials and Methods

Population Studied

Between July 2002 and July 2006, consecutive patients who required mechanical ventilation for more than 6 h after elective craniotomy for tumor, aneurysm, and arteriovenous malformation (AVM) were enrolled from the neurosurgical ICU in the Sao Paulo Federal University Hospital. Patients who underwent tracheostomy or died before weaning trial; unplanned extubation and patients intubated before surgery were excluded from this study. This study was approved by the Ethics Committee for Human Research of the University and informed consent was obtained from all patients.

Data Collection

Preoperative Assessment

All patients answered a questionnaire on the presence of respiratory symptoms, lung and other clinical diseases and smoking. Physical examination included the observation of the type of cough and expectoration, pulmonary auscultation, chest evaluation and determination of the level of consciousness based on Glasgow Coma Scale (GCS).

Postoperative Assessment

Patients who remained intubated after the surgery were referred to the ICU and maintained under mechanical ventilation using a Bear 1000 ventilator (Allied Health Care Productions, USA), Monterey ventilator (Takaoka, Brazil) or Bird 8400 STI PC Vaps ventilator (Bird, USA). Patients were followed-up daily during the postoperative period by the same team that assessed the preoperative period, until they were discharged or died.

Patients passing daily screening criteria automatically received a spontaneous breathing trial (SBT). The following criteria had to be satisfactory to pass the daily screening: (a) responsible neurosurgeon consent; (b) GCS $\geq$ 8; (c) core temperature not >38°C; (d) no therapy with vasoactive drugs (dobutamine or dopamine was allowed in doses $\leq$5 μ/kg body weight/min); and (e) adequate gas exchange, as indicated by a PO_2 of at least 60 mmHg with an inspired fraction of oxygen of $\leq$0.4 and a positive end-expiratory pressure not >5 cmH_2O. The weaning consisted of a minimum 30 to 120-min trial of spontaneous breathing performed on a T-tube or pressure support of $\leq$8 cmH_2O and peep level $\leq$5 cm H_2O. All patients ultimately passed a SBT and were extubated. The criteria used to define failure to tolerate the SBT were (a) oxygen saturation <90%; (b) respiratory rate of >35 breaths/min for >10 min; (c) decrease or increase in the systolic blood pressure by >20%; (d) signs of increase of work of breathing for >15 min; and (e) diaphoresis or agitation. For the SBT to be considered a failure, any two criteria above had to be met. The SBT was terminated and mechanical ventilation reinstituted at the original settings if the physician identified two of the set predictors for poor tolerance.

After successful completion of a SBT and immediately prior to extubation, the expired minute volume (VE), breathing frequency (f), and tidal volume (V_t) were measured using a ventilometer attached to the endotracheal tube (model RM 121, Ohmeda, Japan) without ventilatory support and the breathing frequency-to-tidal volume ratio (f/V_t) was calculated; consciousness level based on GCS was evaluated at the same time. Physicians caring for the patients were blinded to ventilometry results.

Extubation failure was considered when patients needed reintubation within 48 h. The decision to reintubate the patient was based on clinical deterioration as evidenced by at least one of the following criteria: decreased mental status; worsening in arterial pH or PCO_2; decrease in the oxygen saturation to <90%, despite inspired fraction of oxygen >0.5; and increased signs of respiratory work (tachypnea, use of accessory respiratory muscles, thoracoabdominal paradox).

Patients were divided into two groups based on the level of consciousness at the moment of extubation: GCS of 10–11T and 8–9T, where the letter T shows that patients were submitted to orotracheal intubation at the time of evaluation. We considered the group with GCS of 10–11T basically normal once they were able to respond to simple commands and the group with GCS of 8–9T altered because they did not show logical response to simple commands.

Pulmonary infection complications were monitored. Pneumonia was defined as the presence of pulmonary infiltration on the chest X-ray associated with at least two of the following signs: purulent tracheobronchial secretion and increased body temperature (above 38.3°C) and blood leukocytes (over 25% above the base line count) [33].

Statistical Analysis

Results are shown as mean and standard deviation. Clinical threshold value for frequency-to-tidal volume ratio (f/V_t) of $\leq$62 breath/min/l was derived from the current study and threshold values for respiratory rate of $\leq$25 breaths/min and minute volume $\leq$10 l/min from previous studies [13, 32, 34]. A true positive (TP) test was defined as one which predicted extubation success when extubation was successful; true negative (TN), one which predicted failure and the patient was reintubated; false positive (FP), one which predicted success and the patient failed; false negative (FN), one which predicted failure and the patient succeeded. Sensitivity (TP/TP + FN), specificity (TN/TN + FP), positive predictive value (TP/TP + FP) and negative predictive value (TN/TN + FN) were determined for rate/volume ratio, minute volume, and respiratory rate. Receiver operator curves (ROC) were constructed for f/V_t, minute volume and respiratory rate. For univariate analysis, the chi-square test was used for 2 × 2 and 3 × 2 tables and Fisher's exact test for 2 × 2 tables when one or more of the expected frequencies was less than five. Statistical analysis was performed with SPSS (version 13.0; SPSS, Chicago, IL). A P-value $\leq$ 0.05 was considered to be significant for all tests.

Results

Four hundred and twenty patients submitted to intracranial surgery were admitted in the neurosurgical ICU during the study period, 173 under mechanical ventilation and 92 of them were enrolled in the study. Out of the 81 excluded patients, 10 had had a tracheostomy before the weaning process, 17 died before weaning, 20 were extubated within 6 h after surgery, seven had an unplanned extubation, 10 were submitted to endovascular procedure and five to ventricular derivation, and 12 patients were intubated before surgery. The characteristics of the 92 patients included in this study are listed in Table 1.

All 92 patients were successfully weaned from mechanical ventilation and extubated, but 15 of them (16%) required reintubation within 48 h. Reasons for failed extubation were: decrease in consciousness level in 53%, worsening in work of breathing with normal consciousness level in 20%, inability to protect airway (witnessed aspiration or an inability to maintain airway patency because of pulmonary secretions) in 13.5% and seizures in 13.5%. Ninety out ninety-two patients had an f/V_t ratio <105. Table 2 lists the predictive characteristics of f/V_t ratio, respiratory rate and minute volume. Areas under the ROC curves for the respiratory rate and the f/V_t were 0.74 ± 0.07 ($P = 0.003$) and 0.69 ± 0.07 ($P = 0.02$), respectively (Fig. 1).

Patients with normal consciousness levels had more chance of success, patients who failed extubation presented a higher incidence of pneumonia, tracheostomy, and higher mortality rate (Table 3).

Discussion

We evaluated a homogeneous cohort of 92 neurosurgical patients submitted to elective craniotomy and found no association between the f/V_t ratio and extubation failure. In addition we found an incidence of 16% of reintubation, in agreement with another study with similar population [8].

Yang and Tobin [12], first described that a value of 105 or over for the f/V_t ratio would predict unsuccessful extubation. However, they evaluated a heterogeneous population. Subsequent studies showed that the different results observed for the relation of f/V_t ratio and extubation success was mainly related to the point in time of the extubation process, the test was applied and to the kind of patients evaluated [3, 5, 8, 13, 18, 20, 26, 32, 34].

Currently, the predictive extubation indexes are being applied at the moment of extubation, as it is considered to be more important to detect the failure in the extubation process than in the weaning process.

Table 1 Characteristics of 92 neurosurgical patients extubated after elective craniotomy

Characteristic	Total number	Success	Failure	*P*
Age (years) (mean ± SD)	46 ± 15	46 ± 14	48 ± 18	0.63
Gender				0.107
Male	42(46%)	38(90.5%)	4(9.5%)	
Female	50(54%)	39(78%)	11(22%)	
BMI (kg/m^2) (mean ± SD)	25 ± 4	25 ± 4	24 ± 5	0.95
Duration of MV (h)				0.15
<24	58(63%)	51(87.9%)	7(12.1%)	
>24	34(15%)	26(76.5%)	8(23.5%)	
Type of surgery				0.89
Tumor	60(65%)	50(83.3%)	10(16.7%)	
An/AVM	32(35%)	27(84.4%)	5(15.6%)	
Site of surgery				0.95
Supratentorial	73(79%)	61(83.6%)	12(16.4%)	
Infratentorial	19(21%)	16(84.2%)	3(15.8%)	
Surgery duration (min) (mean ± SD)	302 ± 85	304 ± 80	289 ± 109	0.51
Anesthesia duration (min) (mean ± SD)	392 ± 114	395 ± 111	378 ± 132	0.61
Smoking habits				0.23
Non-smoker	48(52%)	39(81.3%)	9(8.8%)	
Smoker	27(29%)	25(92.6%)	2(7.4%)	
Former smoker	17(19%)	13(76.5%)	4(23.5%)	
Respiratory symptoms				0.31
Present	5(6%)	5(100%)	0(0%)	
Absent	87(94%)	72(82.8%)	15(17.2%)	
Associated diseases				0.55
Present	37(40%)	32(86.5%)	5(13.5%)	
Absent	55(60%)	45(81.8%)	10(18.2%)	

BMI, body mass index; MV, mechanical ventilation; AVM, arterio-venous malformation; An, Aneurysm

* $P < 0.05$

Table 2 Predictive characteristics of the frequency–tidal volume ratio, respiratory rate, and expired minute volume

Threshold value	Sensitivity	Specificity	PPV	NPV
Frequency–tidal volume ratio <62 breaths/min/l	0.75	0.53	0.89	0.29
VE ≤ 10 l	0.73	0.53	0.88	0.28
RR ≤ 25 breaths/min	0.89	0.33	0.86	0.38

PPV, positive predictive value; NPV, negative predictive value; RR, respiratory rate; VE, expired minute volume

We observed that the 105 score for f/V_t is not applicable to neurosurgical patients. Despite 15 patients failed extubation just one of them presented a score of over 105. The best cutoff value observed by us was 62, but with low specificity (0.53) and negative predictive values (0.29). Even though, sensitivity was 0.75 and positive predictive value 0.89, we believe that the most important aspect in a predictive index should be its ability to predict failure but not success.

Other studies have also observed different cutoff points for population with homogeneous diagnosis, such as COPD patients [32] with a cutoff of 84 or aging patients with cutoff of 130 [26]. In a recent multicenter study, Frutos-Vivar et al., found a cutoff value for f/V_t ratio of 57 in patients who had undergone invasive mechanical ventilation for >48 h and had been extubated following a successful SBT [5].

Yang and Tobin [12], demonstrated that the f/V_t ratio measured during 1 min of spontaneous breathing through the endotracheal tube had a very high negative predictive value (NPV = 0.95) and a high positive predictive value (PPV = 0.78) for weaning failure. Several subsequent

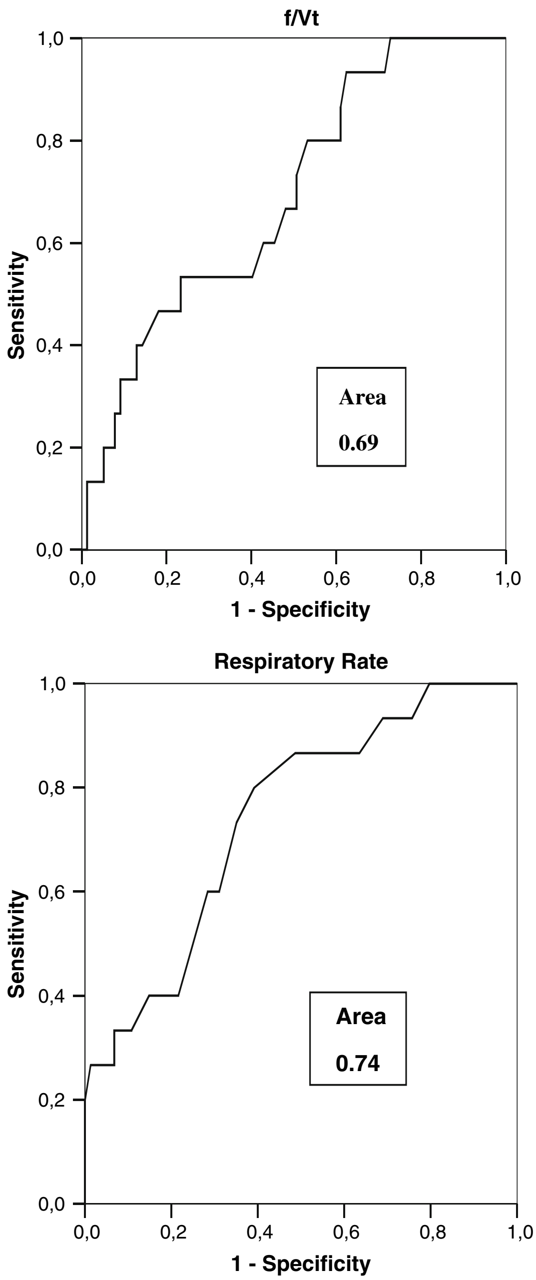

Fig. 1 ROC curves for f/V_t ratio and respiratory rate

reports have noted a significantly lower predictive accuracy for *f*/*V*t [7, 26, 27, 34, 35] and in our study we also found a low NPV (0.29) and high PPV (0.89) even with a cutoff of 62. A recent randomized study showed that including the f/V_t ratio in a protocol prolonged weaning time did not confer survival benefit or reduce the incidence of extubation failure or tracheostomy [20].

Fast and shallow breathing frequency usually indicates an abnormal lung condition. Breathing frequency over 35 is considered as tachypnea and these patients are expected to have a more difficult evolution from the perspective of extubation and mechanical ventilation [4, 36, 37]. We considered 25 respirations per minute in our patients as a cutoff point for unsuccessful extubation. However taken isolatedly, breathing frequency showed low specificity (0.33) and negative predictive value (0.38). Minute ventilation of 10 l was not a good predictor either, with a specificity of 0.53 and negative predictive value of 0.28.

The accuracy of the f/V_t test depends on how well it separates those patients that will be successful and those with failure extubation. Accuracy is measured by the area under the ROC curve. An area of 1 represents a perfect test; an area of 0.5 represents a worthless test. A rough guide for classifying the accuracy of a diagnostic test is the traditional point system: 0.9–1 = excellent; 0.8–0.9 = good; 0.7–0.8 = fair; 0.6–0.7 = poor; and 0.5–0.6 = fail. The values for the area under the ROC curve in this study for the respiratory rate was 0.74 and for the f/V_t ratio 0.69, confirming they were not good predictors of extubation failure [38].

Multiple weaning parameters have been investigated as possible predictors of extubation outcome and studies have shown that they are not accurate predictors [18, 27–29, 39–42]. On the basis of the difficulty to find predictors of failure extubation, few studies have been reported, however, that link the relationship between preoperative/intraoperative characteristics and postoperative extubation outcome [43–45].

Clinical and surgical characteristics of the patients who succeeded or failed extubation were not significantly different, but we observed that patients with a consciousness level at the moment of extubation considered to be normal (10–11T) were more likely to be successful. In other words, the chance of a patient with a normal consciousness level is higher for him/her to be among the ones with successful extubation that among the ones who fail. However, the f/V_t ratio did not seem to be influenced by the level of consciousness, since patients with a low consciousness level presented an f/V_t ratio mean of 50 ± 24, while patients with normal consciousness levels presented 56 ± 28 ($P = 0.51$).

Results have been controversial concerning the level of consciousness and the ability to maintain a satisfactory airway after extubation. Namen et al., found more extubation failure on neurosurgical patients with low consciousness level [8]. Chevron et al., in a prospective case–control study, found that a low consciousness level correlated with unplanned extubation and the need for re-intubation [46]. On the contrary, others studies have shown that patients with a low consciousness level may be extubated successfully [1, 7]. Currently, a normal level of consciousness is still considered as a main variable for extubation.

Table 3 Presence of abnormal consciousness level, pneumonia, tracheostomy, and death in 92 extubated neurosurgical patients

Characteristic	Success	Failure	*P*	Odds ratio	95% CI
Consciousness level			0.005*	9.12	[2.09; 39.75]
Normal	73(88%)	10(12%)			
Abnormal	4(44.4%)	5(55.6%)			
Pneumonia			0.001*	30.94	[7.13; 128.02]
Absent	68(95.8%)	3(4.2%)			
Present	9(42.9%)	12(57.1%)			
Tracheostomy			0.001*	18.75	[3.20; 109.81]
Absent	75(88.2%)	10(11.8%)			
Present	2(28.6%)	5(71.4%)			
Deaths			0.0001*	16.44	[3.49; 77.40]
No	74(89.2%)	9(10.8%)			
Yes	3(33.3%)	6(66.7%)			

CI, confidence interval

* $P < 0.05$

Extubation failure is considered to be a risk factor for pulmonary complications and death [19]. Some studies have suggested an increased incidence of nosocomial pneumonia in patients undergoing reintubation [5, 9, 47, 48]. The patients of this study, who failed the extubation process presented a higher incidence of pneumonia (80%), a higher need for tracheostomy (33%), and a mortality rate of 40%.

A limitation on our study was the low median time of orotracheal intubation, 20.6 (11.2–34.0) h, but was similar to findings in a population of surgical patients (24 h) who also had the f/Vt ratio evaluated [34]. Heterogeneous populations may present a longer orotracheal intubation length of time.

In summary, we have found that the f/V_t does not predict extubation failure in patients who have undergone elective craniotomy. Patients with a normal consciousness level presented a higher success rate for extubation. The extubation failure was associated to a higher incidence of pneumonia, tracheostomy, and death.

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