Alveolar dead space in mechanically ventilated COPD patients and its impact on weaning

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Abstract

Purpose: To determine the value of alveolar dead space as a predictor of weaning failure in mechanically ventilated COPD patients admitted to the intensive care units.
Design*:* A prospective, observational cohort study conducted from 1 March 2014 to 31 August 2014.
Setting: general Intensive care unit of Alexandria main University Hospitals.
Patients: Eighty COPD patients requiring mechanical ventilation.
Methods: After intubation and MV, the patients were evaluated to assess the impact of alveolar dead space on weaning.
Results: sixety patients (75%) were successfully weaned and twenty patients (25%) were failed out. Of the eighty cases, 56 (70%) were males. Mean age of the studied patients was 63±10.95 and mean days of MV was 7.40±3.68. Mean value of alveolar dead space was 42.63±11.15% in the successfully weaned group and 52.09±8.28 in the failed weaning group (p = <0.001).
Conclusion: In the present work; alveolar dead space had a significant impact on weaning in mechanically ventilated COPD patients, higher levels of dead space values were observed in the failed weaning group.

Keywords: COPD, weaning, dead space

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Introduction

COPD is a leading cause of morbidity and mortality worldwide and results in an economic and social burden that is both substantial and increasing.[1,2]
Weaning from MV is a process where MV is gradually withdrawn and the patient resumes spontaneous breathing. The major factor in successful weaning is the resolution of precipitating illness and a stable low requirement for oxygen. However, neither laboratory

nor clinical parameters have been defined on when to begin with the weaning procedure. If the weaning procedure is started early, it can often lead to cardiorespiratory failure. On the other hand, if it is started too late, it can be unsuccessful because of respiratory muscle weakness caused by deconditioning and disrupted breathing regulation.[(3)]

dead space is the volume of air which is inhaled that does not take part in the gas exchange, either because it remains in the conducting airways, or it reaches alveoli that are not or poorly perfused. It is divided into anatomical and alveolar parts.

The anatomical dead space is generally defined as the volume of gas exhaled before the carbon dioxide concentration rises to its alveolar plateau.

Alveolar dead space may be defined as the part of the inspired gas that passes through the anatomical dead space to mix with gas at the alveolar level, but which does not take part in gas exchange. Measured alveolar dead space must sometimes contain a component due to the ventilation of relatively under perfused alveoli, which have a very high ratio. The alveolar dead space is too small to be measured with confidence in healthy supine humans, but becomes appreciable under some circumstances.[(4)]

In healthy person, anatomical dead space is approximately 150 mL, alveolar dead space is negligible, and the Vd/Vt ratio is roughly 0.3. As Vd/Vt increases, minute ventilation and hence the work of breathing must increase to maintain carbon dioxide clearance. When Vd/Vt exceeds 0.7 to 0.8, spontaneous breathing is usually no longer able to maintain carbon dioxide homeostasis.[(5)]

The fact that alveolar dead space was seen to be a good predictor of extubation failure can be explained by its behavior as an indicator of the possible imbalance between the demand and the actual ventilation capacity of the patient. Ventilation demand depends not only on the ventilation requirements, but also on the respiratory system capacity of each patient. Thus, when the MV needed to maintain normal alveolar ventilation exceeds that capacity, weaning will not be satisfactory.[(6)]

The objective of our study is to assess the impact of alveolar dead space on weaning of mechanically ventilated COPD patients.

Materials And Methods

This prospective, observational cohort study started from 1 March 2014 to 31 August 2014. All COPD patients on mechanical ventilation admitted to the units of Critical Care Medicine Department in Alexandria Main University hospitals during this period were included in the study .

Exclusion Criteria:

1.Pregnant females.

2.Patients younger than 17years old.

Informed consent was taken from each patient or his next of kin before enrollment in this study.

All patients on admission were subjected to:

Complete medical, family, drug and occupational histories, and the presence of comorbidities.

Routine laboratory investigations

Arterial blood gases (ABG) were measured upon admission and when needed. PeCO2 was tested using a Datex S/5 instrument that measures PeCO2 with main stream method using main stream CO2 sensor and airway adapter. We connected the special airway adapter between the elbow adapter and Y piece, then attach the main stream CO2 sensor to the adapter, then connect the sensor to the connector on the monitor′s side panel. . Subsequently alveolar dead space was calculated for each patient using the Bohr equation:(7)

$$V_d/V_t = \frac{PaCO_2 - PeCO_2}{PaCO_2}$$ (7)

Where PeCO2 is the partial pressure of carbon dioxide in mixed expired gas and is equal to the mean expired carbon dioxide fraction multiplied by the difference between the atmospheric pressure and the water-vapor pressure.

All patients received treatment according to GOLD guidelines.(1)

The weaning process was conducted according to known clinical and laboratory criteria from the Selected Recommendations in ACCP-SCCM-AARC Evidence-Based Weaning Guidelines Task Force.(8)

Statistical Analysis

Data were fed to the computer and analyzed using IBM SPSS software package version 2010.

Qualitative data were described using number and percent. Quantitative data were described using median, minimum and maximum as well as mean and standard deviation.

For qualitative variables, Chi-square test was used. When more than 20% of the cells had expected count less than 5, correction for Chi-square was conducted using Fisher’s Exact test or Monte Carlo correction.

The distribution of quantitative variables was tested for normality using Kolmogrov-Smirnov test and Shapiro- Wilk test. D’Agstino test was used if there was a conflict between the two previous tests.

Mann-Whitney test (for data distribution that were significantly deviated from normal) was used to analyze two independent populations, while for multi-group comparisons, Kruskal-Wallis one-way analysis of variance was applied. All statistical tests were two-tailed.

Receiver operating characteristic (ROC) curves were used to plot sensitivity (Y-axis) versus the proportion of false positive readings (1 − specificity) (X-axis), establishing the cutoff point corresponding to maximum diagnostic discrimination of the scale, together with its global assessment as expressed by the area under the curve (AUC). The diagnostic characteristics were estimated from the calculation of sensitivity and specificity, with determination of the positive and negative predictive values of the optimum cutoff point. The statistical analysis was carried out using the MedCalc 11.4.2.0 statistical package.

Results

A total of 80 patients were enrolled in this study (56 male and 24 female). Of those, 44 male patients were weaned and 12 male patients suffered failure of weaning and 16 female patients were successfully weaned and 8 female patients failed, the mean age of the successfully weaned group was 63.13±10.95 compared to 68.20 ±7.51 in the failed weaning group. Baseline characteristics were presented in Table 1.

Table (1): Baseline characteristics of subjects in the study

	Weaning				Test of sig.	P
	Weaned (n = 60)		Failed (n = 20)			
	No.	%	No.	%		
Sex					χ^2= 1.270	0.260
Male	44	73.3	12	60.0		
Female	16	26.7	8	40.0		
Age					t= 1.921	0.058
Min – Max.	31.0 - 84.0		58.0 - 85.0			
Mean ± SD.	63.13 ± 10.95		68.20 ± 7.51			
Median	62.0		67.50			
APACHE II	12.78±6.75		13.17±7.27			0.837
Smoking Index Mean ±SD	50.6±9.5		47.23±8.6			0.145

Alveolar dead space was used as a comparative parameter between the 2 groups with a mean value of alveolar dead space = 52.09% in the failed weaning group which was significantly higher than those who weaned successfully with a mean value of alveolar dead space = 38.63% (p< 0.001) (Table 2).

Table (2): Relation between weaning failure and alveolar dead space

	Weaning		T	P
	Weaned (n = 60)	Failed (n = 20)		
Alveolar dead space%				
Min – Max.	36.0 - 50.0	35.0 - 60.70		
Mean ± SD.	38.63 ± 11.15	52.09 ± 8.28	5.469*	<0.001*
Median	44.0	50.50		

The data were analyzed using a ROC curve to determine the optimum cut-off point for alveolar dead space as a predictor of weaning success or failure (Fig. 1). The area under the curve (AUC), with respect to the prediction of weaning failure or success based on the value of the alveolar dead space was 0.857($p < 0.001$)

The alveolar dead space cut off value offering the best sensitivity and specificity was 48% with a sensitivity of 80% and specificity of 76.67% .

The positive predictive value was 53.33%, with a negative predictive value of 92%.(table 3).

Table3: sensitivity, specificity and accuracy for alveolar dead space with failed cases

		Weaned	Failed	Sensitivity	Specificity	PPV	NPV	Accuracy
Alveolar dead space	≤48	46	4	80.0	76.67	53.33	92.0	77.50
	>48	14	16					

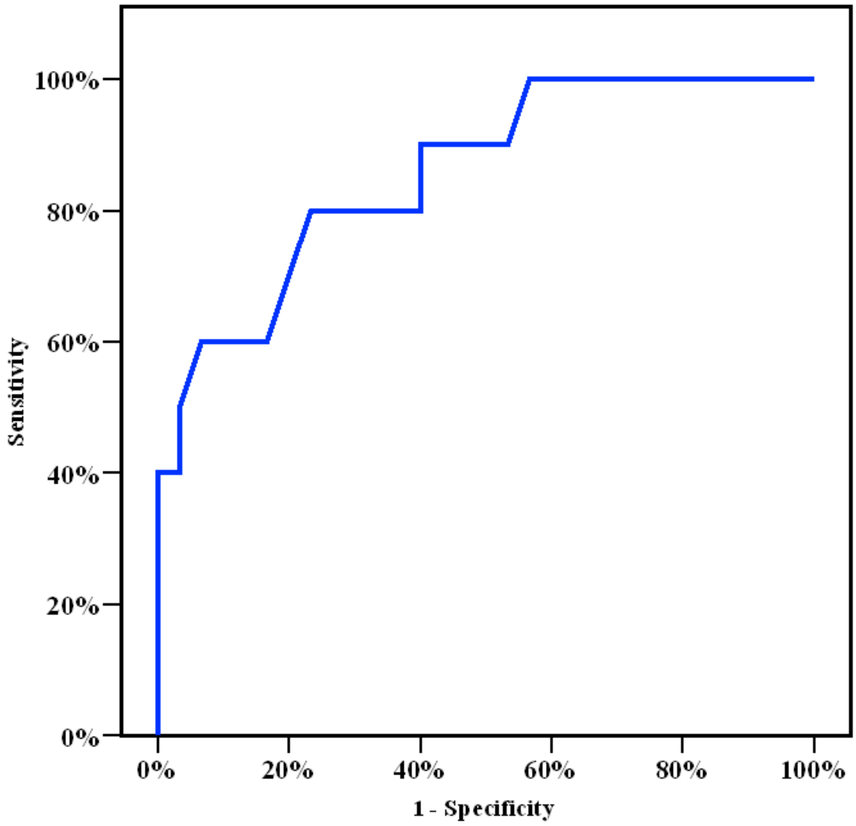

Figure (1): ROC curve for alveolar dead space to diagnose failed cases.

Discussion

The main physiological defects in COPD are increased alveolar dead space, severe ventilation-perfusion misdistributions, marked airflow limitation, air trapping, and hyperinflation. These defects represent major challenges during weaning from MV. Such defects frequently result in poor oxygenation and hypercapnia.[9]

When the MV needed to maintain normal alveolar ventilation exceeds the capacity of the patient, weaning will not be satisfactory. These ventilation requirements are determined by VCO2, the dead space, and the respiratory stimulus at central nervous system level. Since alveolar dead space is a single parameter comprises two of the components that determine the ventilation requirements, its efficacy in predicting extubation failure can be explained.[6] the present study is the first study in adults methodologically designed to determine whether alveolar dead space is a good predictor of extubation failure in COPD patients.

In the medical literature, the first investigations in relation to total dead space date back to 1965[10] with studies of its role as a marker of acute lung injury. In 1983, Pierson[11] identified values of total dead space > 60% as indicators of intubation. However, despite these old studies, total dead space traditionally has not been included in the clinical guides as a parameter to be considered in the extubation of adults subjected to MV. This may be attributed to the complex task of collecting the measurements needed to calculate the fraction, before technological advances simplified this work by introducing new ventilator and sensor measurement and calculation techniques. Recently,[12] emphasis has been placed on the role of total dead space in predicting extubation. Based on a cohort of 35 patients, it has been postulated that the highest total dead space values measured on the first day of hospitalization could be an early predictor of extubation failure. In this case, the sensitivity, specificity, positive predictive value, negative predictive value and a total dead space cutoff point of ≥ 0.60 in predicting extubation failure according to the ROC curve were 70%, 72%, 58%, 81% and 71%, respectively.

In contrast to the above mentioned studies, the present study assessed the usufullness of alveolar dead space as a predictor of weaning failure or success of mechanically ventilated COPD patients, with a cutoff value ≥ 48% , the sensitivity, specificity, positive predictive value and negative predictive value were 80%, 76.67%, 53.33%, and 92% respectively.

On comparing the results obtained for alveolar dead space with the multiple predictors analyzed in the literature, we could rank the alveolar dead space at a level comparable to the CROP index (compliance, respiratory rate, oxygenation and pressure) and the IWI (integrative weaning index). In this sense, the CROP index, developed by Yang and Tobin in a prospective study with a cutoff point of 13 ml/rpm, yielded a positive predictive value and a negative predictive value of 0.71% and 0.70%, respectively.[13] In turn, the IWI, studied by Nemer et al. and calculated as the product of static compliance and SaO2 divided by the Fr/Vt ratio, with a cutoff point of 25 ml/cmH2O/FiO2 yielded a sensitivity of 0.97% and a specificity of 0.94% in predicting extubation failure.[14] Undoubtedly, these values imply a very high level of success, though when extubation failure predictors are compared, not only the numerical values of the statistical analyses must be taken into account. In this field a very important consideration is the complexity of application, integration and interpretation of the values obtained. On the other hand, in calculating alveolar dead space, use of the CO2 sensor can be considered, as well as the conduction of arterial blood gas measurements----this being an already standardized and routine practice in ICUs . However, indices such as the CROP or IWI involve increased complexity of calculation, based on the integration of several formulas, with the added difficulty of measuring static compliance of the respiratory system in spontaneously breathing patients.[15]

Conclusion

In the present study, we came to conclusion that alveolar dead space can be considered as a significant predictor of weaning failure in COPD patients.

Conflict of interest: None.

Acknowledgements

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