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Predictive value of the physiological deadspace/tidal volume ratio in the weaning process of mechanical ventilation in children

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Abstract

Objective: To evaluate the physiological deadspace/tidal volume ratio (V_D/V_T) as a predictor of extubation failure in 42 ventilated children (median age: 4.75 years).

Method: Extubation readiness was determined using the criteria proposed by the 6th International Consensus Conference on Intensive Care Medicine adapted to children.

Results: Non-invasive ventilation (NIV) was used in four patients who developed respiratory failure after extubation; none was reintubated. Children who needed NIV to avoid reintubation had a significantly higher V_D/V_T ratio than those who were extubated without NIV ($p < 0.001$). The cut-off value of V_D/V_T ratio was 0.55 and the area under the receiver operating characteristic curve was 0.86.

Conclusion: Our findings confirm the good predictive value of weaning success/failure of the V_D/V_T ratio and suggest its role for predicting the need for NIV after extubation.

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Introduction

Several studies have demonstrated the usefulness of the single breath CO_2 analysis in patients with abnormalities of pulmonary perfusion. Many have described changes in the physiological deadspace that may reflect alterations in either airway deadspace or alveolar deadspace. Single breath CO_2 analysis offers the precision to differentiate alveolar deadspace from airway deadspace and several studies suggest that the quantification of the alveolar deadspace may be directly related to effective pulmonary perfusion.[1]

Physiological deadspace/tidal volume ratio (V_D/V_T) was found to correlate with severity of lung disease and/or increased risk of death in adults[2-4] or neonates and children,[5-7] and a high value has been proposed as a predictor of extubation failure with contradictory results in children.[8,9] In fact, Hubble et al. reported that V_D/V_T predicted successful extubation or respiratory failure after extubation,[9] while Bousso et al. concluded that V_D/V_T ratio was unable to predict the population at risk of extubation failure or reintubation.[8]

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Therefore, the objective of this study was to evaluate the V_D/V_T ratio as a predictor of extubation success/failure.

Patients and methods

Patient population

During the study period (September 2008 to April 2009) among 297 children hospitalized in the pediatric intensive care unit (ICU), 148 mechanically ventilated were potential candidates for inclusion in the study. Exclusion criteria were patients with intubation < 24 h, known intracardiac shunt, known upper airway obstruction, absent airway reflexes and endotracheal tube leak > 30%. This study was approved by the local Research Ethics Committee.

Study protocol

The investigators determined extubation readiness using the criteria for assessing readiness to wean as proposed by the 6th International Consensus Conference on Intensive Care Medicine,[10] and adapted to children.[11] Once a patient was identified ready for weaning, the ventilator mode was changed to pressure support ventilation, with an expiratory tidal volume of 6 mL/kg, positive end-expiratory pressure (PEEP) of 5-8 cm H_2O and inspiratory oxygen fraction (FiO_2) < 40%. Duration of this phase was variable, depending on the physician in charge of the patient. At the end of this period, a capillary blood gas was drawn. Respiratory mechanics (compliance of the respiratory system and airway resistances) and respiratory deadspace (V_D) were obtained using the CO_2MO Plus Respiratory Profile Monitor (Novametrix Medical Systems, Wallingford, Conn., USA) and its computer software.[12] This device provides a simplified method for calculation of V_D/V_T from single breath CO_2 waveform. Then, a spontaneous breathing trial (SBT), using T-tube or hood canopy, was performed during a 30-minute period. Criteria for passing the SBT were those defined by the 6th international Consensus Conference on Intensive Care Medicine[10] adapted to children,[11] as well as the results of capillary blood gas drawn at the end of this trial. During the post-extubation 48-h period, respiratory rate (RR), heart rate (HR), pulse oxymetry (SpO_2), FiO_2 and capillary blood gas analyses, if needed, were regularly recorded. Extubation failure was defined as reintubation or non-invasive ventilation (NIV) within 48 h after extubation.

Statistical analysis

The software SPSS for Linux, version 15.0 (SPSS, Chicago, IL, USA) was used to create a database and to perform the statistical analysis. The distribution of data was expressed as medians with 25th and 75th interquartile ranges (IQR) (Q1-Q3). Threshold/cut-off chi-square and Youden's index were used to determine the cut-off value of V_D/V_T ratio distinguishing between weaning success and failure. General performance of V_D/V_T ratio was assessed using positive and negative likelihood ratios (LR^+ and LR^-). Receiver operating characteristics curve (ROC) was drawn for displaying the discriminatory accuracy of V_D/V_T ratio, and area under the ROC (AUC) and its 95% confidence interval were calculated.

Results

Forty-two children from 1 month to 15.9 years were enrolled. Median age: 4.8 years (IQR: 0.9-9.3), median weight: 15.0 kg (IQR: 7.7-29.5); male/female: 25/17; median Pediatric Index of Mortality (PIM2) probability of death: 4.38% (IQR 1.46-5.98). Other children were excluded or could not have V_D/V_T ratio determination due to absence of the investigator in charge of the protocol. NIV was used in four patients who developed respiratory failure 8, 18, 20 and 28 h after extubation: none was reintubated (weaning failure: 9.5%). Median duration of mechanical ventilation was 48 h (IQR: 24-120 h). Table 1 lists demographic, clinical and ventilatory data. Univariate analysis revealed statistically significant differences between weaning success and failure for $PaCO_2$ ($p < 0.001$), arterial pH ($p < 0.001$), HCO_3 ($p < 0.001$), ventilatory rate ($p < 0.005$), expired tidal volume ($p < 0.005$) and V_D/V_T ratio ($p < 0.001$). Table 2 reports diagnoses and reasons for admission of the 42 children included in the study.

The cut-off value of V_D/V_T ratio was found at 0.55 (chi-square: 9.86, $p < 0.01$), with Younden's index at 0.76. Using this value as a predictor of the need for post-extubation NIV, sensitivity was 100%, specificity was 76%, positive predictive value was 31%, and negative predictive value was 100%. LR^+ and LR^- were 4.22 and 0.07, respectively (LR^+/LR^- = 64.95). The AUC ROC was 0.86 (0.73-0.98).

Discussion

This study confirms the predictive value of weaning success/failure of V_D/V_T ratio in mechanically ventilated children. Children with V_D/V_T ratio ≤ 0.55 had a high probability of successful extubation, with a likelihood ratio for a negative test equal to 0.065. Children who needed NIV to avoid reintubation had a statistically significantly higher V_D/V_T ratio than those who were successfully extubated. However, no correlations were found between V_D/V_T ratio values and readiness to wean or extubation failure criteria, as defined above.[10,11]

These results are consistent with the findings of three previous studies, two in adults[13,14] and one in children,[9] all with a similar threshold value (between 0.50 and 0.60).

By contrast, our results diverge from those obtained by Bousso et al.,[8] who reported that V_D/V_T ratio was not a useful parameter for predicting extubation success in 86

Table 1 - Pre-extubation demographic and clinical characteristics (mean ± standard deviation)

Variable	Successful extubation (n = 38)	Extubation with NIV* (n = 4)	p
Age (years)	5.9±5.8	4.5±7.2	NS
Weight (kg)	20.6±20.3	14.5±16.5	NS
Ventilation duration (h)	116.1±186.3	216.0±197.2	NS
Pediatric Index of Mortality (%)	5.5±5.4	2.7±2.8	NS
Pulse oxygen saturation (%)	90.0±14.3	93.5±2.5	NS
$PaCO_2$ (mmHg)	35.9±6.51	46.2±9.13	0.001
Arterial pH	7.44±0.07	7.36±0.03	0.001
HCO_3 (mmol/L)	25±4.8	27±6.6	0.001
Ventilatory rate (breaths/min)	29±12.1	36±8.8	0.005
Pressure support (cmH_2O)	15±4	16±2	NS
PEEP (cmH_2O)	4.0±2.1	4.5±2.2	NS
Plateau pressure (cmH_2O)	14±4.6	12±3	NS
Expired tidal volume (mL/kg)	8.3±3.2	6.4±2.8	0.005
Compliance ($mL/cmH_2O/kg$)	0.87±0.53	0.80±0.30	NS
Airway resistance ($cmH_2O/L/sec$)	30±20	32±18	NS
Physiological deadspace (V_D/V_T)	0.41±0.21	0.59±0.14	0.001

NIV = non-invasive ventilation; NS = non significant; V_D/V_T = physiological deadspace/tidal volume ratio.
* Considered as extubation failure.

mechanically ventilated children (the best threshold value was high: 0.65). However, in this study mean expired V_T values were very low (between 4.8 and 6.2 mL/kg) and thus V_D/V_T ratio values may have been overestimated. In our study, median V_T value was 7.2 mL/kg (between 6.8 and 7.8 mL/kg). Bousso et al. explained their results by the pathophysiological characteristics (less resistance to muscle fatigue, less efficiency of cough and proportionally narrower airways) specific to young age observed in their study (median age = 5.5 months) and less important in older population, in accordance with the present study (median age = 4.75 years).

Our study has several limitations. Firstly, the number of patients was relatively smaller than that in previous studies (45[9] and 86[8]). Secondly, only two groups were identified in our population: extubation success without any need for respiratory support, and extubation with the need for NIV considered as weaning failure. In fact, no child needed reintubation during the study period. Thirdly, the NIV group consisted of only four children. For the Consensus Conference,[10,11] extubated patients who remain supported by NIV constitute an intermediate category called "weaning in progress" and should not be considered as weaning success. Our study seems to indicate that V_D/V_T ratio could identify this intermediate group.

NIV is increasingly used after extubation both in adults and in children. A systematic review and meta-analysis of studies on NIV to wean critically ill adults off invasive ventilation showed positive effects on mortality and ventilator-associated pneumonia, mostly in patients with chronic obstructive pulmonary disease.[15] Data in children come from a small number of studies. Lum et al. analyzed 278 children who underwent NIV as a strategy of respiratory support; among them, 98 received NIV to facilitate extubation and 48 due to failed extubation, with a global success rate of 81.9%.[16] No parameter identifying these populations was proposed. Only the study from Mayordomo-Colunga et al. focused on NIV after extubation; among 41 NIV episodes (36 children), 20 belonged to rescue NIV group and 21 to elective NIV group (success rate was 50% and 81%, respectively).[17] At the present time, there are no criteria to select patients in whom post-extubation NIV can be beneficial: intermediate values of V_D/V_T ratio, as observed in our patients requiring NIV, could represent a useful tool to identify them. This was suggested by Hubble et al.'s study.[9]

Conclusion

Our findings are consistent with the results from most previous studies and suggest the good predictive value of weaning success/failure of V_D/V_T ratio in mechanically ventilated children. In this study, V_D/V_T ratio was capable of predicting the need for NIV after extubation, often considered as a weaning failure. Further prospective studies are needed to determine whether V_D/V_T ratio may help to select indication of NIV to facilitate weaning or to prevent respiratory failure after extubation.

Table 2 - Diagnoses and reasons for admission of the 42 children studied

Number	Diagnosis	Reason for admission
1	Ventriculoperitoneal shunt	Pulmonary hemorrhage
2	Foreign body aspiration	Pneumonia
3	Intraventricular communication	Laryngomalacia
4	Spinal amyotrophy	Pneumonia
5*	Purpura fulminans	Septic shock
6	Retropharyngeal abscess	Pneumonia
7	Severe asthma	Obstructive respiratory failure
8	Polyethylen glycol aspiration	Pneumonia
9	Meningococcal meningitis	Coma
10	Rheumatoid purpura	Septic shock
11	Progressive encephalopathy	Aspiration pneumonia
12	Adrenal insufficiency	Aspiration pneumonia
13*	Chronic diarrhea	Pneumonia
14	Coloplasty	Postoperative care
15	Chronic encephalopathy	Peritonitis
16	Intracranial hemorrhage	Postoperative care
17	Spinal amyotrophy	Pneumonia
18	RSV infection	Bronchiolitis
19	Herpetic encephalitis	Status epilepticus
20*	RSV infection	ARDS
21	Burn	ARDS
22	Guillain-Barré syndrome	Pneumonia
23	Cerebral medulloblastoma	Postoperative care
24	Chronic encephalopathy	Status epilepticus
25	Esophageal perforation	Postoperative care
26	Perioperative cardiac arrest	Coma
27	Intestinal occlusion	Septic shock
28	Polytrauma	Pneumonia
29	RSV infection	Bronchiolitis
30	Carbon monoxide poisoning	Coma
31	RSV infection	Pneumonia
32	Moyat and Wilson syndrome	Status epilepticus
33*	Duchenne muscular dystrophy	Postoperative care
34	Pierre Robin syndrome	Cardiac failure
35	Piercing superinfection	Toxic shock
36	Methadone poisoning	Coma
37	Dysmorphic syndrome	Broncholitis
38	Obstructive respiratory failure	Asthma
39	Peritonitis	Pleuropneumopathy
40	Menkes disease	Postoperative care
41	Arrhythmia	Cardiogenic shock
42	Meningitis	Status epilepticus

ARDS = acute respiratory distress syndrome; RSV = respiratory syncytial virus.
* Children who need non-invasive ventilation.

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