Dead Space Ventilation in Volume Controlled *versus* Pressure Controlled Mode of Mechanical Ventilation

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Abstract

Dead space ventilation (VD) is one of the important measurements that indicates the ventilatory efficiency of a patient who requires mechanical ventilation. However, VD is not constant and can change according to the pathology in the lungs, ventilatory patterns, perfusion and ventilation-perfusion matching. The objective of this study was to measure and compare the dead space in pediatric patients who were using pressure controlled and volume controlled modes of mechanical ventilatory by measuring the difference between arterial PCO_2 and end-tidal PCO_2 [$P(a\text{-}ET)CO_2$]. From November 1996 to March 1997, 12 patients who were admitted to the pediatric intensive care unit and needed ventilator support for various reasons, were enrolled in the study. Their ages ranged from 2 to 15 years. The mechanical ventilator (Benett 7200 or Servo 900C) setting during VD measurement i.e. tidal volume, inspiratory time and positive end expiratory pressure were kept constant between changing from pressure controlled to volume controlled mode or vice versa for twenty minutes in order to allow adequate time for equilibration.

The $P(a\text{-}ET)CO_2$ between volume controlled and pressure controlled mode were 3.1 and 2.6 torr (p=0.5) and peak inspiratory pressure were 20.0 and 17.3 torr (p=0.01), respectively; whereas mean airway pressure, PaO_2, O_2 saturation and heart rate revealed no significant difference between these two modes.

The authors concluded that VD in pressure controlled mode from the present study was not significantly different from VD when using volume controlled mode of mechanical ventilation in the same patient. However, VD will change according to the pathophysiologic change in respiratory system and can be used for monitoring of ventilatory pattern of patients in the pediatric intensive care unit.

Key word : Dead Space, Mechanical Ventilation, Respiratory Failure

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In patients with acute respiratory failure who need mechanical ventilator support, the ventilation efficiency is usually determines by arterial blood gases, $PaCO_2$ and pH. Dead space (VD) ventilation is one of the important measurements that indicates the ventilatory efficiency of the patient(1-3). However, VD is not constant and can change according to the pathology of the lungs, ventilatory patterns, perfusion and ventilation-perfusion matching.

The more variable value in dead space ventilation is alveolar dead space. The alveolar dead space which is more sensitive and can increase in some conditions, for example, emphysema, pulmonary hypertension, pulmonary emboli, ventilation-perfusion mismatch and the differences of the regional lung compliances and resistances(1,3-5).

The pressure controlled and volume controlled modes are the ventilating modes that are frequently used in patients with acute respiratory failure (6,7). The advantage of pressure controlled mode is not only providing lower peak inspiratory pressure when compares with the volume controlled mode in the same tidal volume setting but also decreasing the dead space ventilation. The standard measurement of dead space ventilation was determined by using the modified Bohr equation(1,8) of

$$V_D/V_T = \frac{PaCO_2 - P_ECO_2}{PaCO_2}$$

which compares VD with tidal volume (VT). The $PaCO_2$ represents arterial PCO_2 and P_ECO_2 represents expiratory PCO_2. However, there is some technical difficulty because of the need for measuring mixed $PaCO_2$ from the expiratory gases(9).

The measurement of VD by single breath CO_2 analysis using the difference in $PaCO_2$ and PCO_2 at end tidal breathing ($P_{ET}CO_2$) has been proposed and demonstrated by several authors(5,9) to replace the standard technique. The authors, therefore, compared the VD in patient who are using the volume controlled and pressure controlled ventilatory modes by determining the difference in $PaCO_2$ and $P_{ET}CO_2$.

PATIENTS AND METHOD

The measurement of $PaCO_2$ and $P_{ET}CO_2$ in patients using mechanical ventilators (Benette 7200, puritan Benette USA or Servo 900C, Siemens, Sweden) were compared for VD between the volume controlled and pressure controlled modes of mechanical ventilation.

Twelve pediatric patients, who were using either beginning with volume or pressure controlled mode of mechanical ventilator by randomization, were enrolled in the study. Their ages ranged from 2 to 15 years. All the patients received sedation and/or muscle relaxant in order to eliminate the spontaneous breathing and airway drainage was performed before beginning the measurement. The fractional inspiratory oxygen concentration (FiO_2), inspiratory time (Ti), respiratory rate and positive end expiratory pressure (PEEP) were kept constant between the two modes as well as the minute ventilation. The time interval adjustment between the two modes was 20 minutes that allowed the stabilization of the gases exchange. Arterial blood was drawn in a heparinized syringe for which the blood gases were analysed by blood gas machine (ABL 510). Simultaneously, $P_{ET}CO_2$ was measured by capnograph Gemini capnograph/pulse oximeter, micro stream, (Spegas, Israel).

Statistical analysis

The difference between arterial CO_2 and end tidal CO_2 ($P_{ET}CO_2$) was measured and analysed by Wilcoxon match-paires signed-Ranks test. The p-value of less than 0.05 was considered significant.

RESULTS

The demographic data, including chest X-ray findings and the indication for mechanical ven-

Table 1. The descriptive data among 12 studied patients.

	Range	Mean ± SD
Age (yr)	2-15	8.3 ± 4.87
Weight (kg)	8-53.5	25.59 ± 15.61
Height (cm)	81-172	124.6 ± 30.17
Male : Female ratio	12 : 18	
Tidal volume/Weight (ml/kg)	4.5-13.7	8.55 ± 2.33
Minute ventilation (L/min)	1.9-11.2	5.29 ± 2.89

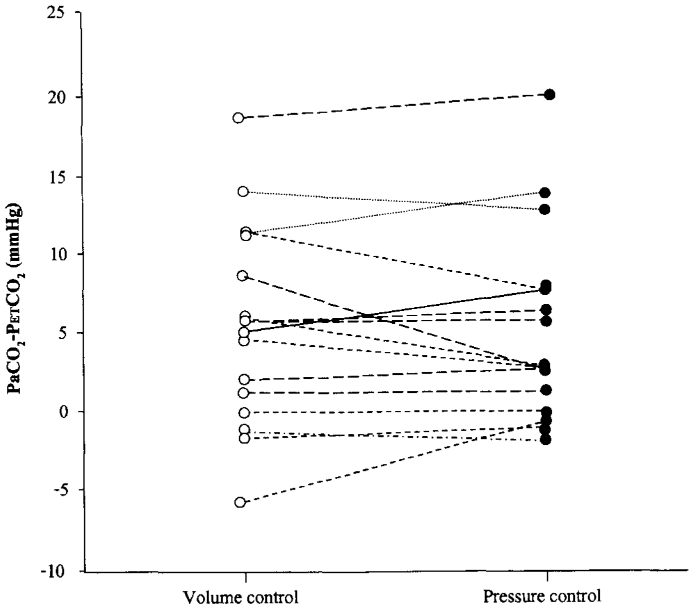

Fig. 1. Comparison of difference between arterial PCO_2 and end tidal PCO_2 ($PETCO_2$) when using volume controlled and pressure controlled modes of mechanical ventilations (represents volume control, represents pressure control).

Table 2. The chest X-ray findings and indications for mechanical ventilation among 12 studied patients.

	Number of patients
Chest X-ray findings	
Alveolar infiltration : bilateral	8
: unilateral	4
Lobar atelectasis	2
Decreased pulmonary vasculature	1
Normal	5
Indication for mechanical ventilation	
Pulmonary	
ARDS	4
Pulmonary edema	3
Pulmonary fibrosis	2
Cardiovascular	2
Neurologic	9
Initial ventilatory setting	
Volume control	12
Pressure control	8

tilation are shown in Table 1 and 2. The ventilatory profile, $P(a\text{-}ET)CO_2$ arterial oxygen tension and oxygen saturation are shown in Table 3. The differences between $PaCO_2$ and $PETCO_2$ in each individual patient both in volume controlled and pressure controlled modes are shown in Fig. 1. The mean peak inspiratory pressure in patients with pressure controlled mode was significantly lower than those in volume controlled mode (p=0.01). However, the difference in $P(a\text{-}ET)CO_2$, mean airway pressure, PaO_2, and oxygen saturation were not significantly different ($p>0.05$). The association of $P(a\text{-}ET)CO_2$ and chest X-ray findings which indicated the pathology of the lung are also shown in Table 4.

DISCUSSION

Dead space ventilation as well as the other arterial blood gas parameters change according to the perfusion, ventilation and ventilation-perfusion matching[1,3-5].

In the present study, the only parameter of ventilator setting was the changing between two modes of ventilation by keeping the tidal volume inspiratory time, positive and expiratory pressure constant. With this study protocol, the authors expected that the ventilation-perfusion matching was not different during the period of the measurement but the difference in flow pattern of the ventilatory mode

Table 3. **Heart rate and blood gas profile when using volume controlled and pressure controlled modes of mechanical ventilation.**

Parameter	Volume controlled mode		Pressure controlled mode		P-value
	Range	Mean ± SD	Range	Mean ± SD	
Heart rate (beat/min)	61-175	123.15 ± 28.30	70-180	122.20 ± 27.18	0.50
$P(a\text{-}ET)CO_2$ (mmHg)	5.7-19.3	4.31 ± 5.83	-1.6-20.5	4.01 ± 5.41	0.01*
Peak inspiratory pressure (cm H_2O)	3.0-44.0	21.39 ± 10.94	3.5-44.0	19.69 ± 10.10	0.16
Mean airway pressure (cm H_2O)	5.3-28.0	11.08 ± 6.12	5.6-25.0	11.84 ± 5.88	0.45
PaO_2 (mmHg)	24.1-452.9	125.88 ± 92.67	27.8-416.7	128.23 ± 88.96	0.18
O_2 saturation (%)	58.0-100.0	94.87 ± 9.42	58.0-100.0	15.29 ± 9.36	0.35

*statistical significance, $p < 0.05$

Table 4. **The association of chest X-ray findings and arterial end-tidal (a-ET) PCO_2 expressed in range when using volume controlled and pressure controlled modes of mechanical ventilations.**

Chest X-ray findings	$P(a\text{-}ET)CO_2$ (mmHg)	
	Volume control	Pressure control
Bilateral alveolar infiltration	4-12.7	2.5-12
Unilateral alveolar infiltration	(-0.8)-(+5.2)	(-1.6)-(+5.2)
Lobar atelectasis	(-1.2)-(+1.8)	(-0.8)-0
Decreased pulmonary vasculature	19.3*	20.5*
Normal	(-5.7)-(+2.1)	(-1.2)-(+3.4)

* mean

might contribute to the change in ventilation in the studied patients(10). The decelerating flow as shown in the pressure controlled mode has been demonstrated in experimental animal studies with a pulmonary edema model that caused a decrease in $PaCO_2$ but not the V_D/V_T(10). Whereas, in an experimental animal model with pulmonary emphysema, the decelerating flow show lower $PaCO_2$ and V_D/V_T. In patients without cardiopulmonary pathology, the decelerating flow causes the increase in V_D/V_T(11,12); but in patients with cardiopulmonary pathology, the decelerating flow causes the increase in compliance, mean airway pressure and decrease peak inspiratory pressure but there is no difference in V_D/V_T when compared with the constant flow of ventilatory pattern(13,14).

The mechanical effect of the decelerating flow pattern is the high initial inspiratory flow rate which causes the gas that passes through to the alveoli faster and distends the alveoli for a longer period of time, therefore, the anatomical dead space should decrease(15). In the present study, $P(a\text{-}ET)CO_2$ which correlated well with the dead space ventilation did not demonstrate the statistically significant difference between the square wave form in the volume controlled mode and decelerating wave form in pressure controlled mode ($p>0.05$), may be due to the underlying pathology of the patients in this studied group and the small number of patients(16).

However, the measurement during the treatment period demonstrated that the $P(a\text{-}ET)CO_2$ changed when the perfusion and vetilation-perfusion matching improved. So $P(a\text{-}ET)CO_2$ can be used as the parameter for monitoring patients in the intensive care unit especially patients with serious cardiorespiratory problem who need full mechanical ventilatory support.

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การเปรียบเทียบ Dead space ventilation ระหว่างการใช้เครื่องช่วยหายใจชนิด Volume control กับ Pressure Control

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Dead space ventilation (VDA) ในผู้ป่วยที่มีปัญหาทางระบบหายใจซึ่งจำเป็นต้องใช้เครื่องช่วยหายใจ สามารถเปลี่ยนไปตามพยาธิสภาพในปอดและลักษณะการหายใจ สภาวะของ ventilation, perfusion และ ventilation-perfusion matching ดังนั้นเราจึงสามารถใช้ VD เป็นตัววัดและติดตามผลการรักษาสภาวะต่าง ๆ ดังกล่าวได้ ผู้วิจัยได้ทำการศึกษาปริมาณของ VD ในผู้ป่วยที่ใช้เครื่องช่วยหายใจชนิดที่ควบคุมโดยปริมาตร (volume controlled mode) และเครื่องช่วยหายใจชนิดที่ควบคุมโดยความดัน (pressure controlled mode) ในผู้ป่วยเด็กที่จำเป็นต้องใช้เครื่องช่วยหายใจเนื่องจากสาเหตุต่าง ๆ กัน ในผู้ป่วยที่เข้ารับการรักษาในหอผู้ป่วยหนัก ภาควิชากุมารเวชศาสตร์ โรงพยาบาลรามาธิบดี โดยใช้วิธีวัดค่าความแตกต่างระหว่าง arterial PCO_2 ($PaCO_2$) และ end tidal PCO_2 ($P_{ET}CO_2$) [$P(a-ET)CO_2$] โดยใช้เครื่อง Gemini capnograph/pulse oximeter ตั้งแต่เดือนพฤศจิกายน 2539 จนถึงเดือนมีนาคม 2540 ผู้ป่วยทั้งหมด 12 ราย อายุระหว่าง 2-15 ปี โดยใช้เครื่องช่วยหายใจชนิด Benette 7200 (Puritan Benette, USA) หรือ Servo 900C (Siemen, Sweden) ควบคุมให้ tidal volume, inspiratory time และ PEEP มีค่าเท่ากันในระหว่างการปรับเปลี่ยน mode พบว่า $P(a-ET)CO_2$ จากการใช้ volume และ pressure controlled mode มีค่า 3.1 และ 2.6 mm Hg ตามลำดับ ($p=0.5$) และเมื่อเปรียบเทียบ peak inspiratory pressure พบว่ามีค่า 20.0 และ 17.3 mm Hg ตามลำดับ ($p=0.01$) ส่วน mean airway pressure, PaO_2, O_2 saturation และอัตราการเต้นของหัวใจไม่พบว่ามีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ

ดังนั้นการใช้ pressure controlled mode สามารถลด peak inspiratory pressure ลงได้ เมื่อเทียบกับ volume controlled mode แต่ไม่พบความแตกต่างของปริมาณ dead space ventilation ระหว่างการใช้เครื่องช่วยหายใจสองแบบนี้

อย่างไรก็ตามพบว่า ถ้ามีการเปลี่ยนแปลงโดยมีการลด perfusion หรือมีการเพิ่มของ dead space ventilation จะ ทำให้ค่า $P(a-ET)CO_2$ กว้างกว่าปกติ และค่ากลับเป็นปกติเมื่อพยาธิสภาพได้รับการรักษา ดังนั้นน่าจะสามารถใช้ค่า $P(a-ET)CO_2$ ในการติดตามการดูแลการเปลี่ยนแปลงของผู้ป่วยที่เข้ารับการรักษาในหอผู้ป่วยหนักได้

คำสำคัญ : dead space, เครื่องช่วยหายใจ, ภาวะการหายใจล้มเหลว

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