Physiological dead space during general anaesthesia for Caesarean section

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The physiological dead space and its components were determined during general anaesthesia for Caesarean section in seventeen patients and compared with similar values for seventeen patients undergoing abdominal hysterectomy under general anaesthesia. The physiological dead space was smaller in the pregnant patients, due to a smaller alveolar dead space. The anatomical dead space was similar in both groups. A lowered physiological dead space suggests that there will be a decrease in the pulmonary ventilation perfusion ratio ($\dot{V}/\dot{Q}$) during Caesarean section; this could result from better perfusion of the ventilated alveoli than in the non-pregnant group, due to the increased cardiac output of pregnancy. An improvement in alveolar perfusion should also produce more efficient carbon dioxide elimination in pregnant patients, when compared to non-pregnant subjects.

Pregnancy is associated with physiological changes such as increased cardiac output, haemodilution and increased pulmonary ventilation.¹ The increase in pulmonary ventilation has been shown to produce higher than normal arterial oxygen tensions during pregnancy.² It has been further suggested that the changes in ventilation, cardiac output and haemodilution result in better matching of ventilation and perfusion during pregnancy,³ which could reduce the physiological dead space.

The arterial to end-tidal carbon dioxide tension difference ($a-\dot{E})\text{PCO}_2$ representing alveolar dead space has been shown to be smaller during anaesthesia for Caesarean section than during general anaesthesia in non-pregnant females.^{4,5} Further, the ($a-\dot{E})\text{PCO}_2$ difference has been found to be reduced in the puerperal period for several days following delivery of the baby.⁶ This therefore implies that the physiological dead space could

also be reduced during Caesarean section, as compared to non-pregnant subjects.

There is only one study in the literature which has evaluated the physiological dead space during general anaesthesia for Caesarean section.⁷ A mean value for $\dot{V}_D/\dot{V}_T$ of 0.32 ± 0.03 , was found after correction for apparatus dead space and 0.35 after applying a correction factor for volume measurement. These values are higher than the previously quoted values for physiological dead space ratio ($\dot{V}_D/\dot{V}_T$) in pregnant women at 38 weeks of gestation,⁸ and in pregnant women in labour,⁹ as shown in Table I. Therefore our study was designed to estimate the physiological dead space in women at Caesarean section (pregnant group) and, for comparison in non-pregnant women, under general anaesthesia (control group).

Methods

Seventeen patients undergoing elective abdominal hysterectomy formed the non-pregnant control group while the study group comprised 17 patients undergoing elective or emergency Caesarean section. All patients were nonsmokers and none had respiratory or cardiac abnormalities. None of the patients were obese according to the usual weight and height indices. The study was approved by hospital ethics committee and informed consent was obtained from all patients.

The patients in the non-pregnant group received meperidine $1.0 \text{ mg} \cdot \text{kg}^{-1}$ and promethazine $0.5 \text{ mg} \cdot \text{kg}^{-1}$ IM one hour before surgery. Induction was achieved with thiopentone $5 \text{ mg} \cdot \text{kg}^{-1}$ IV and the patients were intubated with a cuffed endotracheal tube after $1.5 \text{ mg} \cdot \text{kg}^{-1}$ succinylcholine IV. Anaesthesia was maintained with 50 per cent oxygen in nitrous oxide, 1 per cent halothane, meperidine supplements IV for additional analgesia when required and relaxation with pancuronium $0.08 \text{ mg} \cdot \text{kg}^{-1}$.

All patients in the pregnant group were given 30 ml of magnesium trisilicate* and before surgery were placed in a left lateral tilt sufficient to cause an obvious visual displacement of the uterus to the left. After preoxygenation

Key words

ANAESTHESIA: obstetric, general; LUNG: physiological dead space.

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*At the time of the study, it was the practice in our hospital to use magnesium trisilicate as antacid before Caesarean section, but now it has been replaced with sodium citrate.

TABLE 1 Published values of physiological dead space ratio in pregnant women. All values are corrected for apparatus dead space

Authors	V_D/V_T
Templeton & Kelman ⁸ 38 weeks gestation	0.20
Fischer & Prys-Roberts ⁹ 1st stage of labour	0.19 (SD 0.06)
During extradural block	0.21 (SD 0.05)
During extradural block and uterine contraction	0.27 (SD 0.06)
One hour after delivery of the baby	0.24 (SD 0.05)
Lyons & Tunstall ⁷ During Caesarean section	0.32 (SEM 0.03)
During Caesarean section, with volume correction	0.35

tion for five minutes, anaesthesia was induced with $5 \text{ mg} \cdot \text{kg}^{-1}$ of thiopentone followed by succinylcholine $1.5 \text{ mg} \cdot \text{kg}^{-1}$ and the trachea was intubated with a cuffed tube while cricoid pressure was applied. Anaesthesia was maintained with a mixture of 50 per cent oxygen in nitrous oxide with 0.5 per cent halothane and pancuronium $0.08 \text{ mg} \cdot \text{kg}^{-1}$ used to maintain relaxation. After the delivery of the baby, anaesthesia was maintained with 50 per cent oxygen in nitrous oxide and meperidine $1.0 \text{ mg} \cdot \text{kg}^{-1}$. Non-rebreathing artificial ventilation was maintained in both groups with a Seimens-Elerna Servo ventilator (900 B), fitted with a Seimens carbon dioxide analyser (930). The minute volume was $100 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and the respiratory rate was $12 \cdot \text{min}^{-1}$. Expiratory minute volumes ($\dot{V}_E$) were read from the ventilator. The carbon dioxide production per minute ($\dot{V}\text{CO}_2$), as well as end-tidal carbon dioxide concentration ($\text{F}\text{E}\text{CO}_2$) were obtained from the digital output of the CO_2 analyser at the time of drawing arterial blood. The calibration of the expiratory flow meter of the ventilator was checked with Wright's respirometer before each case. We chose 50 per cent nitrous oxide in oxygen because the accuracy of the Seimens flowmeter is best at this composition.¹⁰ The carbon dioxide analyser was calibrated with known concentrations of carbon dioxide before each case.

$\dot{V}\text{CO}_2$ and $\text{F}\text{E}\text{CO}_2$ were corrected for errors resulting from (a) variations of humidity, (b) internal compliance of the breathing circuit, (c) analyser delay and (d) presence of 50 per cent nitrous oxide in the anaesthetic mixture.¹⁰ The $\dot{V}_E$ was corrected to body temperature and pressure (BTPS) using a correction factor to account for variations in the humidity.¹⁰ We derived $\text{F}\text{E}\text{CO}_2$ from $\dot{V}\text{CO}_2$ and $\dot{V}_E$.¹¹

Arterial blood was taken from a radial artery 25 minutes after anaesthetic induction in both groups, as well as just before the uterine incision in the pregnant group. The samples were analysed for PCO_2 immediately in a Corning blood gas analyser (165/2) after two point calibration at 37°C . The blood gas results were corrected

for the temperature difference between the subject and the measuring electrode using the nomograms of Kelman and Nunn.¹²

Physiological dead space (V_D) was calculated using the equations of Fisher and Prys-Roberts⁹ and Nunn and Hill.¹³ The anatomical dead space was estimated according to the Bohr's equation (Nunn 1977).¹⁴ The values were corrected for apparatus dead space which was 20 ml. We used the equation of Nunn and Hill (1960);¹³ $(a-\text{E})\text{PCO}_2/\text{PaCO}_2$, to estimate alveolar dead space (fraction of end-tidal gas coming from unperfused alveoli).

Student's paired *t* test was used to evaluate the statistical significance between the variables within groups and the unpaired *t* test was used for comparing between groups. Multiple regression analysis was performed between the dependent variable V_D ($\hat{Y}$) and the independent variables tidal volume as (X_1), age as (X_2), and weight as (X_3). Regressed values of V_D for each subject in the two groups were calculated using respective multiple regression equations. The means of the regressed values (corrected V_D) among the two groups were compared using Student's *t* test.

Results

The mean ($\pm$ SEM) ages and weights in the non-pregnant group were 26.5 ± 1.09 yr and 76.2 ± 3.6 kg and for the pregnant group were 24 ± 0.7 yr and 83.1 ± 3.5 kg respectively ($P = \text{NS}$ between the two groups). The results of the study are presented in Table II. There were no significant differences between pre- and post-delivery values of various parameters shown in Table II in the pregnant group except for PaCO_2 , $\text{P}\text{E}\text{CO}_2$ and $\dot{V}\text{CO}_2$. They were lower after delivery than before delivery. The values for physiological dead space ratio (V_D/V_T), V_D and alveolar dead space were significantly lower in the pregnant group than in the non-pregnant group.

The results of multiple linear regression between V_D ($\hat{Y}$) and V_T (X_1), age (X_2) and weight (X_3) in the two groups were as follows: non-pregnant group: $Y = 0.72 X_1 - 2.81 X_2 - 0.63 X_3 - 104.38$, $r = 0.92$ ($p < 0.001$). Pregnant group: $Y = 0.64 X_1 - 5.96 X_2 - 2.38 X_3 + 32.06$, $r = 0.86$ ($p < 0.001$). When V_D was corrected for V_T , age and weight in the two groups using respective multiple regression equations, it was found to be significantly lower in the pregnant group than in the non-pregnant group (Table II).

Discussion

The physiological dead space ratio (V_D/V_T) in our non-pregnant subjects undergoing abdominal hysterectomy was 0.37 ± 0.02 . This is similar to values in healthy adult patients undergoing general anaesthesia reported by Nunn *et al.* (0.36),¹⁵ and Heidenstierna and McCarthy (0.38).¹⁶

TABLE II Mean values for V_T , V_D , V_D/V_T , anatomical dead space, alveolar dead space, $PaCO_2$, $P\dot{V}CO_2$ and CO_2 output (mean $\pm$ SEM)

	Non-pregnant group <i>n</i> = 17	Pregnant group <i>n</i> = 17				
		Pre-delivery (Pre-d)	Pre-d vs NP <i>p</i>	Post-delivery (Post-d)	Post-d vs NP <i>p</i>	Pre-d vs Post-d <i>p</i>
V_T (ml)	674.41 $\pm$ 26.83	789.70 $\pm$ 30.70	<0.01	778.29 $\pm$ 32.29	<0.05	NS
V_D (ml)	255.17 $\pm$ 20.41	201.36 $\pm$ 20.08	0.1–0.05	209.85 $\pm$ 22.91	0.1–0.05	NS
V_T (ml·kg ⁻¹)	8.99 $\pm$ 0.33	9.48 $\pm$ 0.31	NS	†	†	†
V_D (ml·kg ⁻¹)	3.37 $\pm$ 0.23	2.46 $\pm$ 0.28	<0.05	†	†	†
V_D corrected (ml)*	255.18 $\pm$ 18.82	201.36 $\pm$ 17.20	<0.05	†	†	†
V_D/V_T	0.37 $\pm$ 0.02	0.25 $\pm$ 0.02	<0.001	0.27 $\pm$ 0.02	<0.01	NS
V_D anatomical	166.89 $\pm$ 19.72	194.96 $\pm$ 17.13	NS	184.86 $\pm$ 14.03	NS	NS
V_D alveolar	0.19 $\pm$ 0.01	0.01 $\pm$ 0.02	<0.001	0.03 $\pm$ 0.03	<0.001	NS
$PaCO_2$ (kPa)	3.41 $\pm$ 0.07	3.83 $\pm$ 0.09	<0.001	3.34 $\pm$ 0.08	NS	<0.001
$P\dot{V}CO_2$	2.75 $\pm$ 0.09	3.76 $\pm$ 0.07	<0.001	3.22 $\pm$ 0.09	<0.001	<0.001
CO_2 output (ml·min ⁻¹)	168.43 $\pm$ 6.72	271.18 $\pm$ 11.43	<0.001	229.92 $\pm$ 10.11	<0.001	<0.001

* V_D corrected for V_T , age and weight using multiple regression equations.

†Values could not be calculated due to variation in the weight following delivery of the baby.

During anaesthesia for Caesarean section the physiological dead space ratio was 0.25 ± 0.02 before delivery and 0.27 ± 0.02 after delivery. These values are close to those obtained by Fisher and Prys-Roberts during extradural block analgesia in pregnant women in labour and those obtained one hour after delivery.⁹ The $PaCO_2$ and $P\dot{V}CO_2$ were lower following the delivery due to a significant reduction in CO_2 production, compared to the pre-delivery state.

The physiological dead space ratio (V_D/V_T) was lower in the pregnant group than in the non-pregnant group. The absolute physiological dead space (V_D) was also lower in the pregnant group (Table II). It has been suggested that the absolute physiological dead space which is corrected for tidal volume, age, body build, breathing pattern and respiratory frequency is a better representation of ventilation/perfusion status of a patient than the standard ratio (V_D/V_T).^{17,18} The corrected V_D was significantly lower in the pregnant group (pre-delivery) than in the non-pregnant group. We did not consider respiratory frequency and breathing pattern as variables in the regression analysis as they were the same for all subjects studied.

There was no significant difference in anatomical dead space between the two groups. The alveolar dead space was considerably smaller in the pregnant group than in the non-pregnant group. It has been suggested that mixing and distribution of gas in the lungs is more efficient during pregnancy.¹⁹ The increased cardiac output associated with pregnancy could lead to a better perfusion of the alveoli in the upper parts of the lungs. This would result in a decrease in the number of alveoli with high V/Q ratios ($V/Q > 1$) contributing to a lowered alveolar dead space, a reduced (a- $\dot{E}$) PCO_2 difference and more efficient CO_2 excretion in the pregnant group.^{4,20} For similar values of $PaCO_2$, the $P\dot{V}CO_2$ was higher in the pregnant group (after delivery) than in the non-pregnant group implying

that CO_2 excretion is more efficient in the pregnant group.²⁰

Anaesthesia for Caesarean section is associated with changing haemodynamics resulting from anaesthetic agents, manipulations of the uterus, variations in compliance and variable amounts of blood loss.^{21–25} Therefore the resulting variations in pulmonary artery pressure could lead to alterations in ventilation/perfusion ratios, resulting in changes in alveolar dead space.²⁰ This would probably explain the wider range of physiological dead space observed in the pregnant group (0.08–0.42) than in the non-pregnant group (0.25–0.52).

The value of the physiological dead space ratio (V_D/V_T) reported by Lyons and Tunstall⁷ is higher than our values as well as those reported by other authors during pregnancy and labour (Table I).^{8,9} They compared their value to normal non-pregnant values of V_D/V_T reported by Nunn, Bergman and Coleman, and stated that factors peculiar to pregnancy do not play a role in altering the physiological dead space during Caesarean section. However, their conclusions have to be viewed cautiously, since they did not have a control group of non-pregnant patients undergoing general anaesthesia for comparison. This may have been an important omission as the reported values of V_D/V_T in normal healthy adults varies from 0.19 to 0.45.^{8,9,18,26,27} Furthermore, they did not study the components of the physiological dead space during Caesarean section.

We conclude that the physiological dead space is reduced in patients receiving general anaesthesia for Caesarean section, in comparison with anaesthetized non-pregnant patients. The anatomical dead space was similar in both groups but the alveolar dead space was considerably reduced, resulting in a lowered physiological dead space in the pregnant group.

Acknowledgments

The authors gratefully acknowledge Dr. P. Seshagiri Rao, PhD, for his assistance in the statistical evaluation of the results. We wish to thank James McCaskie and Roger King, the technicians who calibrated our equipment.

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Résumé

On a déterminé l'espace mort physiologique et ses composantes durant une anesthésie générale pour césarienne chez 17 patientes et on a comparé les valeurs similaires pour 17 patientes subissant une hystérectomie abdominale sous anesthésie générale. L'espace mort physiologique était réduit chez les patientes enceintes du fait d'un espace mort alvéolaire plus petit. L'espace mort anatomique était semblable dans les deux groupes. Un espace mort physiologique abaissé laisse entendre qu'il y a une diminution dans le rapport de perfusion-ventilation pulmonaire (V/Q) durant une césarienne; cette réaction pourrait découler d'une meilleure perfusion alvéolaire résultant d'une augmentation du débit cardiaque dans la grossesse. L'amélioration de la perfusion alvéolaire est aussi le résultat d'une excrétion plus efficace de gaz carbonique chez les patientes enceintes comparativement aux patientes qui ne sont pas enceintes.