Flow requirements for the Bain breathing circuit during anaesthesia for Caesarean section

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We studied the relationship between arterial carbon dioxide tension ($PaCO_2$) and fresh gas flow (FGF) during use of the Bain breathing circuit for Caesarean section anaesthesia. Thirty-one patients undergoing Caesarean section were anaesthetised using the Bain circuit with intermittent positive pressure ventilation. The $PaCO_2$ were measured at FGF of 70 $ml \cdot kg^{-1} \cdot min^{-1}$, 80 $ml \cdot kg^{-1} \cdot min^{-1}$, and 100 $ml \cdot kg^{-1} \cdot min^{-1}$. The FGF requirement to maintain a given $PaCO_2$ during Caesarean section anaesthesia is the same as the requirements for nonpregnant subjects, despite the increase in carbon dioxide production associated with pregnancy. This is probably because the total FGF determined by body weight and given during Caesarean section anaesthesia is 15–20 per cent higher than nonpregnant levels, due to the weight gain associated with pregnancy. A FGF of 100 $ml \cdot kg^{-1}$ of pregnant weight/min maintains $PaCO_2$ of 4.44 kPa pre-delivery, which is in the desirable range of $PaCO_2$ during Caesarean section.

Key words
ANAESTHESIA: obstetrics; EQUIPMENT: Bain breathing circuit; MEASUREMENT: arterial carbon dioxide tension.

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The Bain breathing circuit® which is a modified version of the Mapelson D circuit was described by Bain and Spoerel in 1972.[1] Since then it has been used extensively in children and adults. With controlled ventilation, a fresh gas flow (FGF) of 70 $ml \cdot kg^{-1} \cdot min^{-1}$ produces normocarbia and FGF of 100 $ml \cdot kg^{-1} \cdot min^{-1}$ produces hypocarbia.[2,3] An inverse relationship has been demonstrated between the FGF rate and arterial carbon dioxide tension ($PaCO_2$).[2–4] As the $PaCO_2$ can be predicted for a given FGF, the Bain breathing circuit has been suggested as the anaesthetic system to be used to maintain a predictable $PaCO_2$ during Caesarean section anaesthesia.[4]

Pregnancy is associated with increased carbon dioxide (CO_2) production.[5–12] It has been suggested therefore that higher fresh gas flows are required to maintain a given $PaCO_2$, compared with nonpregnant subjects.[4] Kneeshaw *et al.* determined FGF requirements for Caesarean section anaesthesia using the Bain circuit, based on the end-tidal carbon dioxide tensions ($P\bar{E}CO_2$). They assumed $PaCO_2$ to be higher by 0.67 kPa and suggested that a FGF of 120 $ml \cdot kg^{-1} \cdot min^{-1}$ is necessary to maintain $P\bar{E}CO_2$ at 4.16 kPa and $PaCO_2$ at 4.83 kPa.[4] Since we found no report that evaluated the relationship between FGF and $PaCO_2$ during Caesarean section anaesthesia using the Bain circuit we undertook the following study.

Methods

The study was approved by the Medical Ethics Committee of Queen Elizabeth Hospital and informed consent was obtained from all patients.

Thirty-one patients coming for elective or emergency Caesarean section were selected for the study. None of the subjects had any pre-existing

TABLE I Mean values (± SEM) for pre- and post-delivery $PaCO_2$ and pH in the three groups

		Group A *FGF = 70 ml·kg·min⁻¹*	*Group B* *FGF = 80 ml·kg·min⁻¹*	*Group C* *FGF = 100 ml·kg·min⁻¹*
$PaCO_2$ (kPa)	predelivery	4.76 ± 0.11	4.60 ± 0.09	4.44 ± 0.11
	postdelivery	4.59 ± 0.08	4.38 ± 0.19	4.34 ± 0.12
pH	predelivery	7.373 ± 0.01	7.420 ± 0.01	7.434 ± 0.01
	postdelivery	7.370 ± 0.02	7.400 ± 0.01	7.417 ± 0.01

$p < 0.05$ Group A versus Group C.
p = ns Group A versus Group B.
p = ns Group B versus Group C.

cardiovascular or respiratory disorder and they had never smoked.

The patients were given 30 ml of magnesium trisilicate* half an hour prior to surgery. Anaesthesia was induced with the patient in 15 degrees left lateral tilt after pre-oxygenation with 100 per cent oxygen using a Bain breathing circuit for about five minutes prior to induction of anaesthesia. Induction was with thiopentone 5 $mg \cdot kg^{-1}$ and the patients were intubated after succinylcholine 100 mg with a cuffed endotracheal tube, with use of cricoid pressure. Anaesthesia was maintained with pancuronium 0.08 $mg \cdot kg^{-1}$, 50 per cent oxygen in nitrous oxide and 0.5 per cent halothane until the baby was delivered, and afterwards with 33 per cent oxygen in nitrous oxide and narcotic analgesic supplements.

Controlled ventilation was performed with a Bird mark 4A ventialtor. The tidal volume was maintained at 12 $ml \cdot kg^{-1}$ using a Wright spirometer. The respiratory rate was 12/min (minute expiratory volume = 144 $ml \cdot kg^{-1} \cdot min^{-1}$). The patients were divided at random into three groups. Group A (ten patients) received a FGF of 70 $ml \cdot kg^{-1} \cdot min^{-1}$, Group B (ten patients) 80 $ml \cdot kg^{-1} \cdot min^{-1}$ and Group C (11 patients) 100 $ml \cdot kg^{-1} \cdot min^{-1}$.

Arterial samples were drawn from a radial artery just before uterine incision and approximately 35 minutes after induction (post delivery). The arterial samples were analysed immediately in a Corning blood gas analyser (model 165/2) for $PaCO_2$ after two-point calibration before every sample. The induction–delivery time, uterine incision–delivery time and Apgar scores were noted. The nasopharyngeal temperature of the patients was monitored and blood gas results were corrected for the body temperature.

Student's t test was used to compare mean values of $PaCO_2$, pH, age, weight, induction–delivery interval and uterine incision–delivery interval among the groups.

The relationship between FGF rate $ml \cdot kg^{-1} \cdot min^{-1}$ (x) and $PaCO_2$ (y) was studied with regression analysis (both linear and curvilinear).

Apgar scores were compared among the groups using non-parametric statistics (Mann-Whitney test).

The mean pre- and post-delivery $PaCO_2$ and pH values in each group were compared with a paired 't' test.

Results

Table I shows mean pre- and post-delivery pH and $PaCO_2$ values in the three groups. The mean ages, weights, Apgar scores, induction–delivery intervals and uterine incision delivery intervals are presented in Table II.

The mean $PaCO_2$ at a FGF of 70 $ml \cdot kg^{-1} \cdot min^{-1}$ was 4.76 ± 0.11 kPa before delivery and 4.59 ± 0.08 kPa following delivery. For FGF of 80 $ml \cdot kg^{-1} \cdot min^{-1}$, the pre- and post-delivery $PaCO_2$ values were 4.60 ± 0.09 kPa and 4.38 ± 0.19 kPa respectively. At 100 $ml \cdot kg^{-1} \cdot min^{-1}$ of FGF, the $PaCO_2$ was 4.44 ± 0.11 kPa pre-delivery and 4.34 ± 0.12 kPa post-delivery. There was a statistically significant difference between the $PaCO_2$ and pH values of the Group A and Group C patients ($p < 0.05$).

Regression analysis of FGF rate (x) and $PaCO_2$ (y) showed that the $PaCO_2$ varied inversely with FGF rate delivered to the system ($r = 0.248$, p <

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

TABLE II Mean (± SEM) values for ages, weights, induction–delivery intervals, uterine–incision delivery intervals and Apgar scores in the three groups

	Group A *FGF = 70 ml·kg·min⁻¹*	*Group B* *FGF = 80 ml·kg·min⁻¹*	*Group C* *FGF = 100 ml·kg·min⁻¹*
Age (years)	25.50 ± 1.31	27.70 ± 1.70	27.4 ± 1.47
Weight (kgs)	74.92 ± 3.70	71.15 ± 4.04	76.48 ± 3.17
Induction–delivery interval (min)	7.90 ± 0.28	8.20 ± 0.30	8.09 ± 0.30
Uterine–incision interval (sec)	51.50 ± 1.07	50.00 ± 0.75	49.54 ± 1.06
Apgar scores	8	9	9.5

0.05). Linear analysis produced a better "fit" than curvilinear.

There was no significant difference between pre- and post-delivery $PaCO_2$ and pH values in each group (paired t test). There were no significant differences between the groups with regard to mean age, weight, induction–delivery interval, uterine incision–delivery interval and Apgar score.

Discussion

The fresh gas flow (FGF) requirements for the Bain breathing circuit for controlled ventilation during anaesthesia for nonpregnant subjects has been evaluated by several workers.[1-3] Henville and Adams suggested that a FGF of 70 $ml \cdot kg^{-1} \cdot min^{-1}$ produces normocarbia 5.44 ± 0.57 kPa (±SD) ranging from 4.05–6.53 kPa, and a FGF of 100 $ml \cdot kg^{-1} \cdot min^{-1}$ produces moderate hypocarbia of 4.57 ± 0.60 kPa (±SD) ranging from 3.46–5.98 kPa.[2] Bain and Spoerel found that a FGF of 70 $ml \cdot kg^{-1} \cdot min^{-1}$ maintains an arterial carbon dioxide tension ($PaCO_2$) of 4.88 ± 0.57 kPa (±SD) ranging from 4.0–6.53 kPa.[3]

Our data show that during Caesarean section anaesthesia, a FGF of 70 $ml \cdot kg^{-1} \cdot min^{-1}$ maintains a $PaCO_2$ of 4.76 kPa (range 4.17–5.37 kPa) before delivery and 4.59 kPa (range 4.13–5.05) after delivery. These figures are similar to those suggested by Bain and Spoerel.[3] A FGF of 100 $ml \cdot kg^{-1} \cdot min^{-1}$ resulted in a $PaCO_2$ of 4.44 kPa (range 3.85–4.92) pre-delivery and 4.34 kPa (range 3.52–5.07) post-delivery. Again, these agree closely with the results of Henville and Adams.[2] There was also an inverse relationship between FGF $ml \cdot kg^{-1} \cdot min^{-1}$ and $PaCO_2$ during Caesarean section anaesthesia. A similar relationship has already been demonstrated in nonpregnant patients during anaesthesia with the Bain breathing circuit.[2,3]

Therefore, our study shows that, despite the increase in carbon dioxide production during pregnancy, the FGF based on body weight need not be higher in patients undergoing Caesarean section than in nonpregnant patients to maintain a given $PaCO_2$ with the Bain circuit, during controlled ventilation. The magnitude of the increase in CO_2 production during pregnancy is difficult to measure accurately since CO_2 output varies from minute to minute.[5] However, it is likely to be proportional to the increase in oxygen consumption which is 10–20 per cent higher than prepregnancy levels.[5-12] There is an average weight gain of 13 kg (range: 8–17) or 10–20 per cent over prepregnant weight.[7,8,10] Therefore the total FGF based on pregnant body weight increases by 10–20 per cent over the prepregnant values. Since the magnitude of the increases in CO_2 production and total FGF are likely to be similar, a higher FGF ($ml \cdot kg^{-1} \cdot min^{-1}$) is not required to maintain a given $PaCO_2$ during Caesarean section anaesthesia using the Bain circuit and controlled ventilation.

Keenan and Boyan[13] suggested that variations in physiological dead space would affect the efficiency of FGF in the Bain breathing circuit during controlled ventilation. When physiological dead space is reduced, a lower FGF ($ml \cdot kg^{-1} \cdot min^{-1}$) is required to maintain a given $PaCO_2$.[13] Fisher and Prys-Roberts found a low physiological dead space (0.19) during the first stage of labour.[14] However, during Caesarean section anaesthesia, the physiological dead space was variable, ranging from 0.19–0.53, with a mean of 0.30.[15] This may be due to many factors such as changes in blood pressure, pulmonary blood flow, variations in pulmonary compliance, anaesthetic agents and surgical position, all of which can affect physiological dead space.[16-21] Therefore it is difficult to predict the effect of physiological dead space on FGF requirements.[13] This could probably be one of the factors contributing to the low correlation between FGF ($ml \cdot kg^{-1} \cdot min^{-1}$) and $PaCO_2$ ($r = 0.248$) in our study.

At term, the $PaCO_2$ has been found to be 4.26–4.53 kPa[7-11,22] and the pH to be 7.40–7.44.[7,8] The ideal anaesthetic technique should attempt to achieve a $PaCO_2$ of 4.26–4.53 kPa as the best results are obtained when maternal $PaCO_2$ is near preoperative levels.[7,22,23] Our study shows that a FGF of $100\ ml \cdot kg^{-1} \cdot min^{-1}$ (pregnant weight) produces the desirable maternal $PaCO_2$ of 4.44 ± 0.11 kPa ($\pm$SE) before delivery and 4.34 ± 0.12 kPa ($\pm$SE) after delivery, during Caesarean section anaesthesia with the Bain circuit with controlled ventilation.

Kneeshaw *et al.* advised a higher FGF of $120\ ml \cdot kg^{-1} \cdot min^{-1}$ to achieve a maternal $PaCO_2$ of 4.83 kPa and end-tidal carbon dioxide ($P\acute{E}CO_2$) of 4.16 kPa. They based their study on $P\acute{E}CO_2$ measurement and assumed the $PaCO_2$ to exceed $P\acute{E}CO_2$ by 0.67 kPa. This assumption was based on the findings of Nunn *et al.* in nonpregnant subjects during general anaesthesia.[24] This assumption does not apply during Caesarean section anaesthesia. The $PaCO_2$ was very close to $P\acute{E}CO_2$ and in 50 per cent of instances the $(a\text{-}\acute{E})PCO_2$ was negative.[25] Therefore the FGF recommended by Kneeshaw *et al.* could be higher than required. Further, Raemer *et al.* concluded that estimation of $PaCO_2$ from monitored $P\acute{E}CO_2$ may not be reliable, as deviations up to 1.06 kPa were common in $(a\text{-}\acute{E})PCO_2$ values during the course of anaesthesia.[21]

In conclusion, there was an inverse relationship between FGF and $PaCO_2$ during anaesthesia for Caesarean section using the Bain breathing circuit with controlled ventilation. A FGF of $100\ ml \cdot kg^{-1}$ of pregnant weight/min produces a maternal $PaCO_2$ which is in the desirable range of 4.26–4.53 kPa during Caesarean section anaesthesia.

Acknowledgements

The authors gratefully acknowledge Dr. P. Seshagiri Rao, for his assistance in statistical evaluation of the results. We also wish to thank the members of Obstetrics Department of the Queen Elizabeth Hospital for their cooperation.

References

1 *Bain JA, Spoerel WE.* A streamlined anaesthetic system. Can Anaesth Soc J 1972; 19: 426–35.

2 *Henville JD, Adams AP.* The Bain anaesthetic system. Anaesthesia 1976; 31: 247–56.

3 *Bain JA, Spoerel WE.* Flow requirements for a modified Mapelson D system during controlled ventilation. Can Anaesth Soc J 1973; 20: 629–36.

4 *Kneeshaw JD, Harvey P, Thomas TA.* A method for producing normocarbia during general anaesthesia for Caesarean section. Anaesthesia 1984; 39: 922–5.

5 *Rhodes P.* Respiration. *In*: Reproductive Physiology for Medical Students. London: J. & A. Churchill Ltd. 1969; 168–70.

6 *Sutavik SB.* Pulmonary disease. *In*: Medical Complications During Pregnancy. Burrow GN, Ferris TF, editors. Toronto: W.B. Saunders, 1975; 549–57.

7 *Cohen SE.* Why is the pregnant patient different? Seminars in anesthesia 1982; 1: 273–81.

8 *Bonica JJ.* Physiology of pregnancy. *In*: Principles and Practice of Obstetric Analgesia and Anesthesia. Philadelphia: F.A. Davis Co., 1967; 13–39.

9 *Aladjem S.* Physiology of pregnancy. *In*: Obstetrical practice. Toronto: The C.V. Mosby Company, 1980; 64–77.

10 *Clayton SG.* Changes in maternal anatomy and physiology during pregnancy. *In*: Obstetrics. London: 1975; 47–8.

11 *Gutsche BB.* Maternal physiologic alterations during pregnancy. *In*: Anaesthesia for Obstetrics. Shnider SM, Levinson G, editors. Baltimore: Williams & Wilkins, 1979; 254–75.

12 *Garrey MM, Govan ADTC, Hodge CH, Callender R.* Maternal physiology. *In*: Obstetrics Illustrated. London: Churchill Livingstone, 1972; 21–46.

13 *Keenan RL, Boynan CP.* How rebreathing anaesthetic system control $PaCO_2$. Studies with a mechanical and a mathematical model. Can Anaesth Soc J 1978; 25: 117–21.

14 *Fisher A, Prys-Roberts C.* Maternal pulmonary gas exchange (a study during normal labour and extradural blockade). Anaesthesia 1968; 23: 350–6.

15 *Lyons G, Tunstall ME.* Maternal blood gas tensions (PAO_2-$PaCO_2$), physiological shunt and VD/VT during general anaesthesia for Caesarean section. Br J Anaesth 1979; 51: 1059–62.

16 *Scott DB, Lees MM, Daute IT, Slawson KB, Kerr MG.* Observations in cardiorespiratory function

during Caesarean section. Br J Anaesth 1969; 41: 489–95.

17 *Lees MM, Kerr MG, Scott DB, Taylor SH.* Circulatory effects of supine posture in late pregnancy. Clinical Sciences 1967; 32: 453–7.

18 *Scott DB.* Inferior venacaval occlusion in late pregnancy and its importance in anaesthesia. Br J Anaesth 1968; 40: 120–8.

19 *Farmen JV, Thorpe MH.* Compliance changes during Caesarean section. Br J Anaesth 1969; 41: 999–1001.

20 *Toldy M, Scott DB.* Blood loss during Caesarean section general anaesthesia. Br J Anaesth 1969; 41: 868–73.

21 *Raemer DB, Francis D, James JH, Gabel RA.* Variations in $PaCO_2$ between arterial blood and peak expired gas during anesthesia. Anesth Analg 1983; 62: 1065–9.

22 *Doughty A.* Anaesthesia for operative obstetrics and gynaecology. *In*: A Practice of Anaesthesia. Churchill Davidson HC, editor. London: Lloyd Luke, 1978; 1373.

23 *Shnider SM, Levinson G.* Anesthesia for Cesarean section. *In*: Anesthesia for Obstetrics. Baltimore: Williams & Wilkins 1979; 262–3.

24 *Nunn JF, Hill DW.* Respiratory dead space and arterial to end-tidal CO_2 tension difference in anesthetized man. J Appl Physiol 1960; 15: 383–9.

25 *Shankar KB, Moseley H, Kumar Y, Vemula V.* Arterial to end-tidal carbon dioxide tension difference during Caesarean section anaesthesia. Anaesthesia 1986; in press.

Résumé

On a étudié la relation entre la $PaCO_2$ et le flot de gaz frais lors de l'utilisation du circuit de Bain lors d'une césarienne. Trente et une patientes devant subir une césarienne ont été anesthésiées utilisant le circuit de Bain avec une ventilation à pression positive intermittente. La $PaCO_2$ a été mesurée avec un flot de gaz frais (FGF) de 70 ml·kg^{-1}·min^{-1}, 80 ml·kg^{-1}·min^{-1} et 100 ml·kg^{-1}·min^{-1}. Malgré une augmentation dans la production de CO_2 lors de la grossesse, le flot de gaz frais requis afin de maintenir une $PaCO_2$ donnée lors d'une césarienne demeure le même que celui requis pour des sujets non-gravides. Ceci est probablement dû au fait que le flot de gaz frais est déterminé par le poids corporel. Lors d'une césarienne, le flot de gaz frais est de 15 à 20 pour cent supérieur à celui d'une femme non-gravide à cause de l'augmentation du poids associée à la grossesse. Un flot de gaz frais de 100 ml·kg^{-1}·min^{-1} maintient une $PaCO_2$ de 4.44 kPa avant l'accouchement, ce qui serait la valeur désirable de la $PaCO_2$ lors d'une césarienne.