Evaluation of the Humphrey A.D.E. breathing system

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A new breathing circuit (the Humphrey A.D.E., double lever model) was evaluated in adults to determine (1) the fresh gas flow (FGF) needed to achieve normocapnia during controlled ventilation and to just induce rebreathing during spontaneous ventilation, (2) end-expired CO_2 ($PECO_2$) at those FGF values, (3) the standard deviation of FGF requirements for controlled and spontaneous breathing (reliability of recommended FGF settings) and (4) the magnitude of change in $PECO_2$ produced by varying FGF from the recommended values (sensitivity of the system). The FGFs that provided normocapnia with controlled ventilation and just induced rebreathing with spontaneous ventilation were 67 ± 10 and 52 ± 7 $ml \cdot kg^{-1} \cdot min^{-1}$ (mean $\pm$ SD), respectively. $PECO_2$ values were 36.0 ± 0.3 and 41.6 ± 3.9 mmHg respectively. During controlled ventilation low reliability was offset by low sensitivity so that $PECO_2$ changed little when FGF was raised or lowered from recommended values (0.2 $mmHg/ml \cdot kg^{-1} \cdot min^{-1}$). In contrast, during spontaneous ventilation low reliability was additive with high sensitivity when using FGFs lower than the mean value that just induced rebreathing. A threshold was reached where lowering FGF from recommended values caused large changes in $PECO_2$ (1.1 $mmHg/ml \cdot kg^{-1} \cdot min^{-1}$). It is concluded that the FGF recommended by Humphrey for controlled ventilation is satisfactory. However, the FGF recommended by Humphrey for spontaneous ventilation may result in hypercapnia in some patients. This can be prevented either by using a higher FGF of 66 $ml \cdot kg^{-1} \cdot min^{-1}$ routinely in all patients or by using lower flows with CO_2 monitoring.

Key words

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A new breathing circuit, the Humphrey A.D.E. system,* has been proposed as a low flow, universal anaesthetic breathing system.[1,2] Results of clinical trials by Humphrey et al.[1-4] and others[5-6] provide some support for this proposal. However, several important ventilatory characteristics of the system have not been examined.

With the circuit set for controlled ventilation, Humphrey et al. reported that a fresh gas flow (FGF) of $70 \, ml \cdot kg^{-1} \cdot min^{-1}$ provided normocapnia in adults when a ventilatory volume of $140 \, ml \cdot kg^{-1} \cdot min^{-1}$ was used.[2,3] However, the FGF requirement for controlled ventilation reported by Humphrey et al.[2,3] has been independently verified in only one preliminary study of five patients.[5] Further, no data have been reported on the reliability of recommended FGF settings (the variability of the FGF required to produce normocapnia) or the sensitivity of the system (the magnitude of the change in end–expired CO_2 [$PECO_2$] produced by varying the FGF from the recommended value) for controlled ventilation.

With the circuit set for spontaneous ventilation, FGFs ranging from 45.6 ± 14.9 (mean $\pm$ SD) to $56 \, ml \cdot kg^{-1} \cdot min^{-1}$ were reported to just induce rebreathing (minimum inspired CO_2 rose from zero to 1–2 mmHg) in anaesthetized adults.[1,3,5,6] However, the $PECO_2$ at the FGF that just induced rebreathing was reported only in one preliminary study of five patients.[5] The reliability of FGF settings was reported in two studies,[1,6] but no data have been reported on the sensitivity of the system for spontaneous ventilation.

The present study was designed to determine (1) the FGF needed to achieve normocapnia during controlled ventilation and to just induce rebreathing (minimum inspired $CO_2 > 2$ mmHg) during spontaneous ventilation, (2) $PECO_2$ at those FGF values, (3) the standard deviation of FGF requirements for controlled and spontaneous breathing (reliability of recommended FGF settings) and (4) the magnitude of change in $PECO_2$ produced by varying the FGF from recommended values (sensitivity of the system). Independent verification of FGF requirements is important because it confirms that the FGF recommendations proposed by Humphrey et al.[1-4] were derived from a representative sample population. The

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reliability of recommended FGF settings is of interest because if the variability of FGF requirements is large, routine use of a mean value for FGF will result in a large proportion of patients being hypo- or hypercapnic. The sensitivity of the system is of interest because if large changes in PÉCO$_2$ accompany an alternation of FGF, routine use of a mean value for FGF again will result in a large proportion of patients being hypo- or hypercapnic.

Methods
This study was approved by the Human Subjects Committee of the University of Washington, Seattle. Thirty-three adult patients undergoing elective, non-thoracic surgery and of ASA physical status I or II participated in the study. Patients received either no premedication or diazepam 10 mg PO 90 min prior to induction of anaesthesia. Anaesthesia was induced with thiopentone 3–4 mg·kg^{-1} IV, the trachea was intubated using succinylcholine 1.5 mg·kg^{-1} IV to enhance muscle relaxation, and anaesthesia was maintained with isoflurane (1.5 per cent, inspired) and nitrous oxide (60 per cent, inspired) in oxygen. Narcotics were not administered. Pancuronium ≥ 0.1 mg·kg^{-1} IV was given to maintain muscle relaxation with no visible muscle twitch in response to percutaneous stimulation of the ulnar nerve. During this time ventilation was controlled using the double lever, noncoaxial version of the Humphrey A.D.E. system. A tidal volume of 12–15 ml·kg^{-1} and a ventilator rate of 9–12 breaths·min^{-1} were used to achieve the recommended ventilatory volume of 135–140 ml·kg^{-1}·min^{-1}.[1–4] Flowmeters on the anaesthesia machine were set to deliver a FGF of ≥ 80 ml·kg^{-1}·min^{-1}. To insure the accuracy of FGF delivery, the flowmeters on the anaesthesia machine were calibrated each day to a paediatric turbine-vane flowmeter (Boehringer Laboratories, Wynnewood, PA 19096). Peak end–expired isoflurane concentrations and inspired and expired CO$_2$ values were determined at 0.5–1.5 min intervals using mass spectroscopy (The Perkin-Elmer Corp., Pomona, CA 91767). Gas samples were obtained from the endotracheal tube at 6 cm distal (relative to anaesthesia machine) from the "Y" of the non-coaxial breathing circuit. At these ventilator settings PÉCO$_2$ was < 34 mmHg in all patients.

Controlled ventilation
FGF and PÉCO$_2$ values for controlled ventilation were examined in all patients. Values were determined after patients had been receiving isoflurane for ≥ 25 min and after the inspired concentration of isoflurane had been adjusted to provide a stable end–expired concentration of isoflurane of 1.0 per cent. All data were collected during a period of moderate surgical stimulation of deeper tissues following incision of the skin and surgical exposure.

FGF PROVIDING NORMAL PÉCO$_2$
To determine the normocapnic FGF value, ventilatory volume was continued at 135–140 ml·kg^{-1}·min^{-1} and FGF was decreased from ≥ 80 ml·kg^{-1}·min^{-1}, in 0.25 L·min^{-1} steps (5–6 min at each setting) until PÉCO$_2$ stabilized at 36 mmHg. For the purposes of this study PÉCO$_2$ = 36 mmHg was considered to be normocapnia. Arterial blood samples were obtained for blood gas analysis in 8/33 patients to confirm normocapnia. FGF at normocapnia was recorded for each patient and the values averaged to determine the mean FGF needed to provide normocapnia during controlled ventilation for this group. The reliability of the system was determined from the variability (standard deviation) of the FGF values providing normocapnia.

SENSITIVITY OF PÉCO$_2$ TO ALTERED FGF
The FGF then was set at +10 and −10 ml·kg^{-1}·min^{-1} from the normocapnic FGF (8–10 min at each setting), and PÉCO$_2$ values recorded. Mean PÉCO$_2$ at +10 and −10 ml·kg^{-1}·min^{-1} from normocapnic FGF was used to calculate the magnitude of the change in PÉCO$_2$ produced by varying the FGF from the recommended value during controlled ventilation.

Spontaneous ventilation
In 19/33 patients the FGF was continued at the high values used for controlled ventilation, and recovery from the effects of pancuronium was permitted. Once full recovery from pancuronium was complete (as assured by a normal muscle response to percutaneous stimulation of the ulnar nerve), patients were allowed to breathe spontaneously until stable PÉCO$_2$ values were observed with no rebreathing of CO$_2$ (minimum inspired CO$_2$ of near zero). As above, all data were collected during a period of moderate surgical stimulation of deeper tissues and a stable end–expired concentration of isoflurane of 1.0 per cent.

FGF THAT JUST INDUCES REBREATHING
To determine the minimum FGF providing stable PÉCO$_2$, FGF was lowered, in 0.25 L·min^{-1} steps (5–6 min at each setting) until rebreathing occurred (minimum inspired CO$_2$ > 2 mmHg) without a detectable increase in PÉCO$_2$. The mean of these FGF values was considered the minimum for providing stable PÉCO$_2$. The reliability of the system was determined from the variability of FGF values that just induced rebreathing.

SENSITIVITY OF PÉCO$_2$ TO ALTERED FGF
FGF then was lowered further, in 0.25 L·min^{-1} steps

TABLE   Fresh gas flow, end–expired CO_2 and ventilatory volume, mean $\pm$ SD

	Fresh gas flow $ml \cdot kg^{-1} \cdot min^{-1}$	$P\acute{E}CO_2$ mmHg	Ventilatory volume $L \cdot min^{-1}$
Controlled ventilation n = 33	77.4 ± 10.4	$34.8 \pm 0.5*$	8.3 ± 1.6
	67.4 ± 10.3	36 ± 0.3 (defined as normocapnia)	8.3 ± 1.6
	57.4 ± 10.2	$38.8 \pm 0.9*$	8.3 ± 1.6
Spontaneous ventilation n = 19	54.9 ± 7.2	41.6 ± 3.8	8.8 ± 1.7
	51.6 ± 7.4	41.6 ± 3.9	$10.2 \pm 2.0\ddagger$
	48.3 ± 6.8	$45.1 \pm 4.2\dagger$	$10.3 \pm 2.0\ddagger$

*Significantly different from $P\acute{E}CO_2$ at normocapnic FGF, $p < 0.05$.

†Significantly different from $P\acute{E}CO_2$ at FGF $\geq 51.6 \, ml \cdot kg^{-1} \cdot min^{-1}$, $p < 0.05$.

‡Significantly different from ventilatory volume at FGF $\geq 54.9 \, ml \cdot kg^{-1} \cdot min^{-1}$, $p < 0.05$.

(5–6 min at each setting), until $P\acute{E}CO_2$ values rose by more than twice the variability of the values on the mass spectrometer at stable $P\acute{E}CO_2$, i.e., an increase in $P\acute{E}CO_2$ of ≥ 3 mmHg from stable values. The mean of these lower FGF values was considered the FGF at which a significant increase in $P\acute{E}CO_2$ occurred during spontaneous ventilation. Mean $P\acute{E}CO_2$ at this FGF represented the magnitude of the change in $P\acute{E}CO_2$ produced by lowering FGF from the value that just induced rebreathing during spontaneous ventilation. Mean $P\acute{E}CO_2$ at the FGF step just prior to that which just induced rebreathing represented the magnitude of change in $P\acute{E}CO_2$ produced by raising FGF from the minimum value providing stable $P\acute{E}CO_2$. Respiratory rate and tidal volume were recorded for each step change in FGF during sptontaneous ventilation. Ventilatory volume at each step change in FGF was determined as the product of respiratory rate and tidal volume.

$P\acute{E}CO_2$ values at altered FGF were compared to $P\acute{E}CO_2$ values at either the FGF providing normocapnoia (controlled ventilation) or the FGF that just induced rebreathing (spontaneous ventilation) using Student's t test for paired values with the Bonferroni correction. A p value less than 0.05 was considered significant.

Results
Patient characteristics (mean $\pm$ SD) were as follows: age = 39.9 ± 15.8 years, and weight = 60.0 ± 9.9 kg. There were 9 males and 24 females.

Controlled ventilation
The FGF providing normocapnia ($P\acute{E}CO_2 = 36$ mmHg) for controlled ventilation was $67.4 \pm 10.3 \, ml \cdot kg^{-1} \cdot min^{-1}$ (mean $\pm$ SD, Table). "Normocapnic FGF" was lower in females ($63.8 \pm 10.5 \, ml \cdot kg^{-1} \cdot min^{-1}$, n = 24) than in males ($76.9 \pm 9.9 \, ml \cdot kg^{-1} \cdot min^{-1}$, n = 9). Arterial blood samples obtained when $P\acute{E}CO_2 = 36$ mmHg (8/33 patients) confirmed normocapnia, with all $PaCO_2$ values

equalling 39–40 mmHg. At FGF $+10 \, ml \cdot kg^{-1} \cdot min^{-1}$ above normocapnic FGF, $P\acute{E}CO_2$ was 34.8 ± 0.5 mmHg, a fall in $P\acute{E}CO_2$ of 1.2 mmHg from normocapnia. At FGF $-10 \, ml \cdot kg^{-1} \cdot min^{-1}$ below normocapnic FGF, $P\acute{E}CO_2$ was 38.8 ± 0.9 mmHg, a rise in $P\acute{E}CO_2$ of 2.8 mmHg from normocapnia. The calculated mean $P\acute{E}CO_2$ change for alteration of FGF was 0.2 $mmHg/ml \cdot kg^{-1} \cdot min^{-1}$.

Spontaneous ventilation
During spontaneous ventilation $P\acute{E}CO_2$ was 41.6 ± 3.9 mmHg when FGF was still set at high values. As FGF was lowered, rebreathing of CO_2 (minimum inspired $CO_2 > 2$ mmHg) without a detectable increase in $P\acute{E}CO_2$ occurred when FGF reached $51.6 \pm 7.4 \, ml \cdot kg^{-1} \cdot min^{-1}$ (Table). "Rebreathing FGF" was lower in females ($49.1 \pm 7.3 \, ml \cdot kg^{-1} \cdot min^{-1}$, n = 14) than in males ($59.1 \pm 7.4 \, ml \cdot kg^{-1} \cdot min^{-1}$, n = 5). Significant increase in $P\acute{E}CO_2$ occurred when the FGF was further reduced to $48.3 \pm 6.8 \, ml \cdot kg^{-1} \cdot min^{-1}$. Thus, the minimum FGF providing stable $P\acute{E}CO_2$ for spontaneous ventilation was $51.6 \pm 7.4 \, ml \cdot kg^{-1} \cdot min^{-1}$. At the lower FGF, $P\acute{E}CO_2$ was 45.1 ± 4.2 mmHg. The calculated mean $P\acute{E}CO_2$ change for reduction of FGF was $1.1 \, mmHg/ml \cdot kg^{-1} \cdot min^{-1}$.

Ventilatory volume increased as FGF was lowered to the value where minimum inspired CO_2 exceeded 2 mmHg. However, ventilatory volume rose no higher as FGF was lowered below the value that just induced rebreathing and $P\acute{E}CO_2$ increased. That ventilatory volume did not increase when FGF was reduced to this low value identifies a potential hazard should any further reduction of FGF or increase of CO_2 production occur.

Discussion
When the Humphrey A.D.E.System is used, elimination of CO_2 from the lung is determined by two factors, namely ventilatory volume and FGF. During controlled ventilation there is a reciprocal relationship between these

two determinants so that as ventilatory volume is reduced FGF must be increased to maintain $P\acute{E}CO_2$ constant and vice versa. During controlled ventilation ventilatory volume is set to a fixed high value. As FGF is lowered from high values, $P\acute{E}CO_2$ increases until normocapnia is achieved. In our study we observed that a FGF of 67.4 ± 10.3 ml·kg^{-1}·min^{-1} provided normocapnia. Our results confirm the FGF value recommended by Humphrey for controlled ventilation (70 ml·kg^{-1}·min^{-1}).[2,3] Our results also are in good agreement with a recent preliminary publication by Shulman and Brodsky who examined five patients during controlled ventilation and reported that normocapnia was achieved with a FGF of 70 ml·kg^{-1}·min^{-1}.[5] In both our study and the previous ones the ventilatory volume was set at 135–140 ml·kg^{-1}·min^{-1}. That the mean FGF required for females was lower than for males is consistent with a previous report by Romano et al.[7]

Our results indicate that the variability of the FGF required to produce normocapnia for controlled ventilation is large (SD = 15 per cent of mean FGF). Only part of this variability can be accounted for by the magnitude of the step changes in FGF used here (0.25 L·min^{-1}). The step changes in FGF used here are similar to those used in previous studies (0.1 − 0.5 L·min^{-1}).[2,3,6]

However, the low reliability of the recommended FGF setting for controlled ventilation is offset by the low sensitivity of the system when FGF is not set exactly at the normocapnoic FGF. Varying the FGF by ± 10 ml·kg^{-1}·min^{-1} from the mean FGF that provided normocapnoia resulted in clinically insignificant changes in $P\acute{E}CO_2$ (1–3 mmHg). That low reliability was offset by low sensitivity is consistent with comments made about use of the Bain system for controlled ventilation.[8]

During spontaneous ventilation with the Humphrey A.D.E. system CO_2 elimination from the lung still is determined by ventilatory volume and FGF. However, ventilatory volume is not set at a fixed value but instead is determined by the patients' own respiratory rate and tidal volume. Respiratory rate and tidal volume also vary with surgical stimulation and depth of anaesthesia.[9] In attempt to control these variables, data were collected only after a stable end–expired concentration of isoflurane had been achieved and when a moderate level of surgical stimulation was present. We observed that as FGF was lowered from high values patients initially maintained a stable $P\acute{E}CO_2$ by increasing their ventilatory volume. As FGF was lowered further patients were unable to proportionately increase their ventilatory volume and rebreathing of CO_2 (defined as minimum inspired $CO_2 > 2$ mmHg) occurred at a FGF of 51.6 ± 7.4 ml·kg^{-1}·min^{-1}. This value is consistent with previous reports of the FGF at which rebreathing occurs during spontaneous ventilation

with the Humphrey A.D.E. system during anaesthesia with halothane[1,3,6] or isoflurane[5] (range of 45.6 ± 14.9 to 56 ml·kg^{-1}·min^{-1}). Based on the "rebreathing FGF" of about 52 ml·kg^{-1}·min^{-1} determined in this study, the calculated FGFs to just induce rebreathing in 84 per cent (1 SD) and 97.5 per cent (2 SD) of patients are 59 and 66 ml·kg^{-1}·min^{-1}, respectively. That the mean FGF required for females was lower than for males is consistent with a previous report by Romano et al.[7]

For the determination of "rebreathing FGF" in the present study, minimum inspired CO_2 was recorded during the inspiratory phase and rebreathing was defined as minimum inspired $CO_2 > 2$ mmHg. It is possible that as FGF was lowered from high values, CO_2 was present in inspired gases at times other than when minimum inspired CO_2 occurred. CO_2 in inspired gases may stimulate ventilatory volume causing little change in $P\acute{E}CO_2$ so long as patients are able to increase ventilatory volume. Had rebreathing been defined relative to mean inspired CO_2, the FGF at which rebreathing occurred would have been higher than that reported here.

In the present study $P\acute{E}CO_2$ at the FGF that just induced rebreathing was 41.6 ± 3.9 mmHg. A previous preliminary study reported higher $P\acute{E}CO_2$ (49.6 ± 3.7 mmHg) at the FGF that just induced rebreathing.[5] However, in that preliminary study patients received meperidine 1 mg·kg^{-1} IM preoperatively. Thus, narcotic-induced respiratory depression may have contributed to the higher $P\acute{E}CO_2$ reported in that preliminary study.

Our results indicate that the variability of the FGF that just induced rebreathing for spontaneous ventilation is large (SD = 14 per cent of mean FGF), indicating low reliability of the recommended FGF setting for controlled ventilation. This large variability in the FGF requirement is consistent with previous reports (SD = 10–33 per cent of mean FGF).[1,6] Further, the sensitivity of the system is high at FGFs ten per cent below the mean, although at FGFs ten per cent above the mean sensitivity falls to zero, i.e., $P\acute{E}CO_2$ cannot be further reduced by increasing the FGF. That the sensitivity of the Humphrey A.D.E. system during spontaneous ventilation was high during low FGF but fell to zero at high FGF is consistent with a recent report by Jonsson on the sensitivity of the Lack system.[10] The Lack system functions identically to the Humphrey A.D.E. system set in its "A" mode for spontaneous ventilation.[3] Jonsson reported high sensitivity at low FGF and sensitivity of zero at FGF > 5 L·min^{-1} with the Lack system. In contrast, in the same study high sensitivity at low FGF and moderate sensitivity at high FGF was reported with the Bain system.[10]

When FGF was lowered by 0.25 L·min^{-1} from the value that just induced rebreathing, patients did not increase their ventilatory volume and a detectable in-

crease in $P\acute{E}CO_2$ occurred. Lowering FGF by only $3\,ml\cdot kg^{-1}\cdot min^{-1}$ increased $P\acute{E}CO_2$ by $4\,mmHg$. That patients appeared to have reached maximum ventilatory volume for their level of anaesthesia suggests that further reduction of FGF would cause even greater, proportionate increases of $P\acute{E}CO_2$.

As regards clinical practice, our results suggest that, for controlled ventilation, using the recommended FGF ($70\,ml\cdot kg^{-1}\cdot min^{-1}$) with a ventilatory volume of $140\,ml\cdot kg^{-1}\cdot min^{-1}$ should prove satisfactory for usual adult patients (though perhaps not for patients with fever, sepsis or increased dead space to tidal volume ratios). It should not be necessary to monitor $P\acute{E}CO_2$ because of FGF of $70\,ml\cdot kg^{-1}\cdot min^{-1}$ provides normocapnia ($P\acute{E}CO_2$ of $36 \pm 0.3\,mmHg$) for > 95 per cent of patients. Though the variability of the FGF providing normocapnia for controlled ventilation was large ($SD = \pm 10\,ml\cdot kg^{-1}\cdot min^{-1}$), varying the FGF by $\pm 10\,ml\cdot kg^{-1}\cdot min^{-1}$ resulted in clinically insignificant changes in $P\acute{E}CO_2$ ($1-3\,mmHg$). However, for spontaneous ventilation $P\acute{E}CO_2$ was sensitive to reduction of FGF values below $51\,ml\cdot kg^{-1}\cdot min^{-1}$. Lowering FGF by only $3\,ml\cdot kg^{-1}\cdot min^{-1}$ increased $P\acute{E}CO_2$ by $4\,mmHg$. Because patients appeared to reach maximum ventilatory volume by the time FGF was lowered to just induce rebreathing, any further reduction of FGF or increase of CO_2 production should proportionately increase $P\acute{E}CO_2$. Therefore for spontaneous ventilation a higher FGF of $66\,ml\cdot kg^{-1}\cdot min^{-1}$ should be used, or some measurement of adequacy of ventilation should be used, such as blood gas sampling, or monitoring $P\acute{E}CO_2$ or transcutaneous CO_2.

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Résumé

Un nouveau circuit respiratoire (le Humphrey A.D.E., modèle à double levier) a été évalué chez l'adulte afin de déterminer 1) le débit de gaz frais (DGF) nécessaire pour atteindre un normocapnie durant la ventilation contrôlée et afin d'induire, à peine, la réinspiration durant une ventilation spontanée, 2) le CO_2 de fin d'expiration ($P\acute{E}CO_2$) à ces valeurs du DGF, 3) la déviation normale des exigences en DGF pour une respiration contrôlée et spontanée (la fiabilité des réglages recommandés du DGF) et 4) l'importance du changement dans la $P\acute{E}CO_2$ produite par la variation des valeurs de DGF recommandées (sensibilité du système). Les DGF produisant une normocapnie avec une ventilation contrôlée et une réinspiration à peine induite avec une ventilation spontanée étaient de 67 ± 10 et $52 \pm 7\,ml\cdot kg^{-1}\cdot min^{-1}$ (moyenne $\pm$ SD) respectivement. Les valeurs de la $P\acute{E}CO_2$ étaient de 36.0 ± 0.3 et $41.6 \pm 3.9\,mmHg$, respectivement. Durant la ventilation contrôlée la faible fiabilité était contrebalancée par la faible sensibilité de telle sorte qu'il se produisait peu de changement dans la $PECOP_2$ lorsque le DGF était plus élevé ou plus bas que les valeurs recommandées ($0.2\,mmHg/ml\cdot kg^{-1}\cdot min^{-1}$). Par contre, durant la ventilation spontanée la faible fiabilité s'ajoutait à la sensibilité élevée quand on utilisait des DGF allant au-dessous de la valeur moyenne qui induisait à peine la réinspiration. Un seuil était atteint quand le DGF se trouvant au-dessous des valeurs recommandées causaient des changements importants dans le $P\acute{E}CO_2$ ($1.1\,mmHg/ml\cdot kg^{-1}\cdot min^{-1}$). En conclusion, le DGF recommandé par Humphrey pour la ventilation contrôlée est satisfaisant. Cependant, le DGF recommandé par Humphrey pour la ventilation spontanée peut aboutir en hypercapnie chez certains patients. Ce résultat peut être prévenu en utilisant un DGF plus élevé à $66\,ml\cdot kg^{-1}\cdot min^{-1}$ de façon habituelle chez tous les patients ou en utilisant des débits plus faibles avec monitorage du CO_2.