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TIDAL VOLUMES ON CARBON DIOXIDE ELIMINATION ANDOXYGEN SATURATIONS IN OVERWEIGHT PATIENTS

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ABSTRACT
Sickle cell disease (SCD) is the most common genetic hemoglobin disorder in which there is an inheritance of mutant Obesity poses particular challenges to adequate mechanical ventilation in addition to surgical constraints, primarily by restricted lung mechanics due to excessive adiposity, frequent respiratory comorbidities (i.e. sleep apnea, asthma), and concerns of postoperative respiratory depression and other pulmonary complications. Patients with known pulmonary or cardiovascular disease were excluded. The investigations included ASA physical status 1 or 2 patients, scheduled for abdominal surgery. Patients were considered for inclusion in the trial if they were over 18 yr age. Ventilation with larger tidal volumes with isocapnia maintained with added apparatus dead space increases the tension of oxygen and sevoflurane in arterial blood in overweight patients. Further studies are needed to better define optimum protective ventilation strategies and analyze their impact on the perioperative outcomes of surgical patients with obesity.

Key words: Anaesthesia, Functional Residual Capacity, Pulmonary Gas Exchange.

INTRODUCTION

General anaesthesia impairs respiratory function in overweight patients. We wanted to determine whether increased tidal volume (VT), with unchanged end-tidal carbon dioxide partial pressure (PETCO2), affects blood concentrations of oxygen and sevoflurane in overweight patients. General anaesthesia impairs respiratory function. The present studies were performed to compare arterial concentration of sevoflurane, oxygen and carbon dioxide in normal and overweight patients ventilated with increased tidal volume (VT), or normal tidal volume with and without PEEP.

Proper ventilatory settings have a proven impact on clinical outcomes in Intensive Care Unit (ICU) patients with or without risk for the Acute Respiratory Distress Syndrome (ARDS) [1,2]. While lung protective ventilation with low tidal volumes (VT) and the use of positive end-expiratory pressure (PEEP) are now considered routine for ICU patients, the implementation of protective ventilation strategies in the operating room is not widespread [3-5]. These practices may reflect the shortage of convincing prospective trials showing a significant negative impact of non-protective ventilation of short duration on clinical outcomes of patients with healthy lungs. However, the relevance of optimal mechanical ventilation for surgical patients during general anesthesia is being increasingly recognized. Recent studies [6-8] and meta-analyses [9,10] suggest that intraoperative ventilatory practices may contribute not only to ARDS but also to the development of other postoperative pulmonary complications.

Obesity poses particular challenges to adequate mechanical ventilation in addition to surgical constraints, primarily by restricted lung mechanics due to excessive adiposity, frequent respiratory comorbidities (i.e. sleep apnea, asthma), and concerns of postoperative respiratory depression and other pulmonary complications.

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The number of surgical patients with obesity is increasing, and facing these challenges is common in the operating rooms and critical care units worldwide. In this review we summarize the existing literature which supports the following recommendations for the perioperative ventilation in obese patients: (1) the use of protective ventilation with low tidal volumes (approximately 8 mL/kg, calculated based on predicted -not actual- body weight) to avoid volutrauma; (2) a focus on lung recruitment by utilizing PEEP (8–15 cmH2O) in addition to recruitment maneuvers during the intraoperative period, as well as incentivized deep breathing and noninvasive ventilation early in the postoperative period, to avoid atelectasis, hypoxemia and atelectrauma; and (3) a judicious oxygen use (ideally less than 0.8) to avoid hypoxemia but also possible reabsorption atelectasis. Obesity poses an additional challenge for achieving adequate protective ventilation during one-lung ventilation, but different lung isolation techniques have been adequately performed in obese patients by experienced providers. Undoubtedly contribute to obesity being a recurrent risk factor for receiving inappropriately large tidal volumes during mechanical ventilation [3,5,11].

If a larger tidal volume, with an unchanged PETCO2and FiO2 affects carbon dioxide elimination, arterial blood oxygenation and/or arterial concentration of volatile anaesthetics in normal or overweight patients.

Material and Methods:

The studies were approved by the Institutional Ethics Committee . In all studies consent to participate were received from each patient. Patients with known pulmonary or cardiovascular disease were excluded. The investigations included ASA physical status 1 or 2 patients, scheduled for abdominal surgery. Patients were considered for inclusion in the trial if they were over 18 yr age. All procedures were estimated to last more than 60 minutes (120 min in study I). The patients in study I were included regardless of BMI, while the patients in study II all had a BMI less than 25 and the patients in study III and IV all had a BMI more than 25. The number of patients in each study is found in Patient data table. Patients were randomized to one of two equally sized groups via randomly mixed sealed envelope assignment at the start of the procedure in the operating theatre.

Statistical Analysis:

For details on the statistic methods used the reader is referred to the respectivestudies I-IV.In brief, data analyses were as follows:

In all studies an initial power analysis was performed to estimate the numberof observations needed to achieve a power over 0.8 at $P < 0.05$.All statistical analysis was performed with SPSS for Windowsdata is presented as mean valuesand variability quantified with SD. Data was analyzed with a two-tailed t-test.During examination of not normally distributed continuous or categoricaldata, data is presented as median and variability quantified with inter quartilerange. Data was analyzed with a non-parametric method (Mann-Whitney-Utest).For change of values over time, two-way analysis of variance (ANOVA) forrepeated measurements was used.A *P*-value < 0.05 was considered to indicate statistical significance.

Results:

For demographic data please see **Table 1.** No intraoperative problems were notedduring the studies. All patients recovered from anaesthesia and left thepostoperative unit in accordance with the routines assigned for the varioussurgical procedures.

Table - 1:Patient Data

Groups		No. of Patients	Female / Male	Age (years)	BMI ($kg\ m^{-2}$)
Study I	NV_T	30	6/24	63 (57-68)	28 (24-32)
	IV_T	31	9/22	61 (53-68)	26 (24-30)
Study II	NV_T	10	5/5	69 (60-82)	23 (19-26)
	IV_T	10	5/5	65 (41-71)	22 (19-24)
Study III	NV_T	10	6/4	63 (51-77)	30 (26-32)
	IV_T	10	5/5	63 (53-67)	27 (26-16)
Study IV	NV_T	15	5/10	64 (59-71)	27 (25-26)
	IV_T	15	5/10	57 (46-73)	27 (26-32)

Table – 2:Values are M ± SD,Except lung compliance value ,which are median.*denotes stastically significant (p<0.05)

Groups		PET Co_2 (kPa)	Pa Co_2 (kPa)	Pa-PET Co_2 (kPa)	Lung Compliance (ml cm H_2o^{-1})
Study I	NV_T	4.3 ± 0.1	4.9 ± 0.23	0.61 ± 0.2	30 (27-38)
	IV_T	4.4 ± 0.2	4.6 ± 0.24*	0.29 ± 0.2*	41 (36-49)

Study II	NV_T	4.3 ± 0.06	5.5 ± 0.36	1.07 ± 0.34	30 (27-33)
	IV_T	4.3 ± 0.12	4.7 ± 0.26*	0.40 ± 0.25*	43 (32-47)
Study III	NV_T	4.2 ± 0.21	5.3 ± 0.30	1.0 ± 0.29	26 (20-30)
	IV_T	4.3 ± 0.06	4.8 ± 0.19*	0.50 ± 0.20*	40 (30-51)
Study IV	NV_T	4.3 ± 0.07	5.4 ± 0.49	1.0 ± 0.50	38 (33-42)
	IV_T	4.3 ± 0.06	5.0 ± 0.54*	0.6 ± 0.50*	40 (35-48)

Table – 3:Comparison of Values for Fi O2,SaO2 and PaO2 between normal and tidal volume group (NVT) and increased tidal volume group (IV T) .*denotes stastically significant (p<0.05)

Groups			05 min	60 min
Study I	FiO_2 (%)	NV_T	36 ± 4.7	33 ± 0.8
		IV_T	35 ± 3.2	33 ± 1.6
	S_aO_2 (%)	NV_T	99 (97-100)	100 (99-100)
		IV_T	99 (97-100)	100 (99-100)
	P_aO_2 (kPa)	NV_T	15 ± 4.5	14 ± 4.7
		IV_T	17 ± 3.9	15 ± 3.9
Study II	FiO_2 (%)	NV_T	32 ± 1.8	34 ± 1.3
		IV_T	33 ± 0.5	33 ± 0.6
	S_aO_2 (%)	NV_T	99 (96-99)	99 (97-100)
		IV_T	99 (99-100)*	100 (99-100)*
	P_aO_2 (kPa)	NV_T	17 ± 5.0	1.4 ± 4.2
		IV_T	20 ± 3.1	21 ± 4.8*
Study III	FiO_2 (%)	NV_T	33 ± 2.0	35 ± 5.4
		IV_T	33 ± 0.9	33 ± 0.4
	S_aO_2 (%)	NV_T	96 (92-98)	94 (91-98)
		IV_T	100 (99-100)	99 (98-100)*
	P_aO_2 (kPa)	NV_T	1.0 ± 3.7	09 ± 2.6
		IV_T	15 ± 2.9*	14 ± 4.2*
Study IV	FiO_2 (%)	NV_T	33 ± 0.82	33 ± 0.69
		IV_T	35 ± 0.9	33 ± 0.45
	S_aO_2 (%)	NV_T	98 (97-98)	98 (97-99)
		IV_T	98 (97-99)*	99 (98-99)*
	P_aO_2 (kPa)	NV_T	13 ± 2.3	14 ± 2.7
		IV_T	15 ± 3.3*	18 ± 3.2*

Carbon dioxide:

In all studies mean $P_{ET}CO_2$were similar between the two groups **(Table 2).** MeanP_aCO_2 was statistically significantly lower in the IVT group throughout theobservation period ($P < 0.05$, Table 2) except in study IV where the difference did20not reach statistical significance. The difference between P_aCO_2 and $P_{ET}CO_2$ was,however, statistically significantly smaller in the IV_T group compared to the NV_Tgroup in all studies ($P < 0.05$, Table 2).

Discussion:

In our system for controlled ventilation with low flow anaesthesia, we used aflexible corrugated hose between the Y-piece of the anaesthesia circle system andthe endotracheal tube, a safe and simple technique described by Luttropp andJohansson.(12) The flexible corrugated tube allows adjustment of the apparatus deadspace volume and the rebreathing of carbon dioxide enabling isocapnic ventilationwith constant respiratory frequency despite variations in VT.

Ventilating obese patients is becoming a frequent challenge since the prevalence of obesity is steadily increasing and reaching epidemic proportions worldwide [13,14].

We have in four papers, studied if large VT achieved this way, affects eliminationof carbon dioxide and/or uptake of oxygen and anaesthetic gas. The studiesincluded both normal- and overweight patients with and without PEEP. In theabsence of PEEP the difference between P_aCO_2 and $P_{ET}CO_2$ was lower in thegroups with the larger VT and in three of four studies the uptake of both oxygenand sevoflurane was higher. We found a smaller effect on cardiac output by theventilation mode in patients ventilated with large tidal volumes than in patientsventilated with PEEP.

Influence of tidal volume on carbon dioxideelimination:

In study I-III, the analysis of P_aCO_2, demonstrates lower values in the groups withlarger VT which resulted in a decrease in the P_aCO_2- $P_{ET}CO_2$ difference. In studyIV, PEEP of 10 cm H_2O was applied to the NVT group in order to prevent regionswith abnormal ventilation/perfusion. In this study the difference between theP_aCO_2 and $P_{ET}CO_2$ values in the groups did not reach statistical significance andthe P_aCO_2 value did not change from baseline in either group.

The findings in the IVT groups (studies I-III) could be the result of a decreasedshunt due to recruitment of lung tissue. In study IV, the P_aCO_2 value after 60 mindid not differ from baseline in either group but in study III we found a greaterreduction in the P_aCO_2 value. These findings may be explained, at least in part, bythat in study IV mean VT in the IVT group was 8.6 ml kg-1 body weight comparedto 9 - 11 ml kg-1 in the other three studies resulting in a smaller CO2 elimination instudy IV. This may be a shortcoming in our method using an increase in plateaupressure in order to increases the tidal volume instead of using a fixed ml kg-1.Because of a probably smaller chest wall compliance our approach may result inlower VT increase in overweight patients compared to normal weight patients.

Tsuman and colleagues showed a decrease in the P_aCO_2– $P_{ET}CO_2$ gradient in pigsafter application of PEEP, an observation also made in humans (15-17). This suggeststhat the P_aCO_2- $P_{ET}CO_2$ difference is dependent on the FRC. Thus, indirectevidence for an increase in FRC in the group with larger VT compared to the NVTgroup comes from the fact that the arterial-end tidal CO2 difference was smaller inall patients ventilated with larger VT which is in line with previous studies(18-19).Influence of tidal volume on oxygen uptake. In study II-IV, all patients had similar initial SaO2 and PaO2 levels. However, after5 minutes after the application of the different ventilator modes, both PaO2 andSaO2 were significantly increased in the IVT group compared to the NVT group.As discussed above, the CO_2 data strongly suggests recruitment of ventilated lungtissue in the IVT group. The recruitment increases FRC.

In overweight patients FRC is lower than in patients with normal weight(3). A lowFRC increases atelectasis development, which is a plausible explanation for theexistence of regions with low ventilation/perfusion ratio during anaesthesia(20,21).Hedenstierna and colleagues concluded that airway closure and therebyventilation to perfusion mismatch can be prevented with increasing FRC withPEEP (13). However, Futier and colleagues recently showed that although PEEPimproves the end-expiratory lung volume after anaesthesia induction PaO2remains unchanged (22). The effect of added PEEP alone in obese patients iscontroversial, since several studies have demonstrated that in order to improveoxygenation a recruitment manoeuvre is needed before the application of PEEP(23-26).Edmark and colleagues showed that preoxygenation with 100% O_2 results in anincreased formation of atelectasis (27). To preoxygenate our patients we used 100%oxygen for 3-4 minutes with a fresh gas flow of 5 liters minute-1. Lower FiO_2during preoxygenation or a recruitment manoeuvre after intubation mighteliminate the differences in oxygenation between our groups in study IV, wherePEEP was found to be inferior to large VT concerning oxygenation.

In the study I, we found a trend towards increased arterial oxygenation levelswhich, however, was not statistically significant. These small differences ofarterial oxygenation in the first study may be due to patient selection and/or thatstudy methodology differed from the other studies. The patients were mostlymale, anaesthetised for urological surgery. It is unlikely though that the differencein oxygenation depends on the patient selections or on a Type II error. The reason could be a higher initial FiO_2 in this study. Consequently, the value of SaO_2 in theNVT group in study I is slightly higher than in the NVT groups in study II-III.The patients ventilated with large VT had lower P_aCO_2 levels. This causes aleftward shift of the oxygen-haemoglobin dissociation curve, which enhances thebinding of oxygen to haemoglobin. Together with higher PaO2 this effect of CO_2could contribute to the statistically significantly higher SaO_2 in patients of the IVTgroups.

Influence of tidal volume on airway pressure:

The patients in the IVT group, in all studies received a tidal volume of 9.7 ± 2.0ml kg-1 (mean ± SD) total weight corresponding to 11 ± 1.3 ml kg-1 predictedweights according to Lemmens formula for estimating of ideal body weight (19). Thepatients in the NVT groups received an average tidal volume of 5.4 ± 0.80 ml kg-1total weight (6.4 ± 0.83 ml kg-1 predicted weight).In overweight patients ventilated without PEEP (study III) plateau pressure didnot differ statistically significantly between the NVT and IVT groups but medianairway pressure was higher in the IVT group compared with the NVT group.

These obese patients presented greater initial (before study protocol) V_T and peak and plateau airway pressures. However, the outcomes associated with ARDS were not significantly different between obese and normal-weight patients. Therefore, a greater awareness for appropriate selection of low V_T in obese patients is highly recommended, but further investigations are needed to determine the ideal V_T (and other ventilatory) settings for obese patients. Obese patients present specific lung physiology and mechanics characteristics, frequent respiratory comorbidities and increased risk of postoperative pulmonary complications. Intraoperatively, lung protective ventilation with low tidal volumes, recruitment maneuvers with greater PEEP levels and the judicious use of oxygen concentrations are recommended.

Interestingly, in study IV in which the NVT group had a PEEP of 10 cmH2Oapplied, the relationship in mean airway pressure was reversed. Gammon andcolleagues as well as Anzueto and colleagues found that even using normalventilation mode to ventilate patients with lung diseases, barotrauma (e.g.pnemothorax) could develop (28, 29). Furthermore, Boussarsar and colleagues foundthat the risk of barotrauma in patients with lung injury increases with higherpulmonary plateau pressures and/or decreased lung compliance. They also founda weak correlation with increased VT. Eisner and colleagues demonstrated anassociation between barotrauma and high inspiratory airway pressure both withand without PEEP. Several other studies have addressed the influence of VT onpulmonary inflammatory response but taken together the results areinconclusive(30-33).

In overweight patients ventilation with large VT created similar pulmonary plateaupressures as with normal VT without PEEP but lower in the presence of PEEP. Itthus cannot be excluded that at least in our patients, who had no signs ofpulmonary disease, a moderate increase of VT in fact constitutes a lower risk ofbarotrauma than application of 10 cmH_2O PEEP.

Conclusion:

The major findings of the present studies comparing patients without pulmonaryand cardiovascular disease ventilated with normal tidal volumes with patientsventilated with larger tidal volumes with isocapnia accomplished with anincreased apparatus dead space are:
Larger tidal volumes decrease the arterial-endtidal carbon dioxide gradient,and improve the oxygen and sevoflurane uptake into arterial blood in normaland overweight patients.Larger tidal volumes result in lower airway plateau and mean pressurescompared to normal tidal volumes with added PEEP in overweight patients.Larger tidal volumes preserve cardiac output better compared to normal tidalvolumes with added PEEP in overweight patients.Further research is needed to identify the ideal perioperative respiratory care needed to enhance the outcomes and minimize postoperative pulmonary complications of obese surgical patients.

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