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REVIEW ARTICLES

Ventilation strategies in obese patients undergoing surgery: a quantitative systematic review and meta-analysis†

M. Aldenkortt[1*], C. Lysakowski[1], N. Elia[1,3], L. Brochard[2,4] and M. R. Tramèr[1,4]

[1] Division of Anaesthesia and [2] Department of Anaesthesia, Clinical Pharmacology and Intensive Care, Geneva University Hospitals, Rue Gabrielle-Perret-Gentil 4, 1211 Geneva 14, Switzerland

[3] Institute of Social and Preventive Medicine, Faculty of Medicine and [4] Faculty of Medicine, University of Geneva, Geneva, Switzerland

* Corresponding author. E-mail: marc.aldenkortt@hcuge.ch

Editor's key points

- In this meta-analysis, the authors have looked for evidence of effective strategy for intraoperative ventilation in obese patients.
- Thirteen studies met inclusion criteria for analysis on the mode of ventilation or recruitment manoeuvres (RM).
- No difference in the outcomes was seen on comparing pressure-controlled and volume-controlled modes of ventilation.
- Importantly, RM with PEEP maintained better intraoperative oxygenation and lung compliance compared with PEEP alone.

Background. Pathophysiological changes due to obesity may complicate mechanical ventilation during general anaesthesia. The ideal ventilation strategy is expected to optimize gas exchange and pulmonary mechanics and to reduce the risk of respiratory complications.

Methods. Systematic search (databases, bibliographies, to March 2012, all languages) was performed for randomized trials testing intraoperative ventilation strategies in obese patients (BMI $\geq$30 kg m^{-2}), and reporting on gas exchange, pulmonary mechanics, or pulmonary complications. Meta-analyses were performed when data from at least three studies or 100 patients could be combined.

Results. Thirteen studies (505 obese surgical patients) reported on a variety of ventilation strategies: pressure- or volume-controlled ventilation (PCV, VCV), various tidal volumes, and different PEEP or recruitment manoeuvres (RM), and combinations thereof. Definitions and reporting of endpoints were inconsistent. In five trials (182 patients), RM added to PEEP compared with PEEP alone improved intraoperative $Pa_{O_2}/F_{I_{O_2}}$ ratio [weighted mean difference (WMD), 16.2 kPa; 95% confidence interval (CI), 8.0–24.4] and increased respiratory system compliance (WMD, 14 ml cm H_2O^{-1}; 95% CI, 8–20). Arterial pressure remained unchanged. In four trials (100 patients) comparing PCV with VCV, there was no difference in $Pa_{O_2}/F_{I_{O_2}}$ ratio, tidal volume, or arterial pressure. Comparison of further ventilation strategies or combination of other outcomes was not feasible. Data on postoperative complications were seldom reported.

Conclusions. The ideal intraoperative ventilation strategy in obese patients remains obscure. There is some evidence that RM added to PEEP compared with PEEP alone improves intraoperative oxygenation and compliance without adverse effects. There is no evidence of any difference between PCV and VCV.

Keywords: anaesthesia, general; obesity; ventilation, mechanical

The number of obese patients undergoing surgery, either bariatric or non-bariatric, is steadily increasing.[1] These patients have *a priori* healthy lungs. However, the pathophysiological changes induced by obesity make these patients prone to perioperative complications, such as hypoxaemia, hypercapnia, and atelectasis.[2] Immediately after the induction of general anaesthesia, atelectasis develops, leading to a reduction in both ventilation–perfusion ratio and pulmonary compliance, even in non-obese patients.[3–5] Obesity is characterized by several alterations in the mechanics of the respiratory system that tend to further exaggerate impairment of gas exchange.[2] [6] 7 It has been demonstrated that in anaesthetized patients, arterial partial pressure of oxygen (Pa_{O_2}) is inversely related to BMI.[2] Finally, intraoperative respiratory changes may extend to the postoperative period and may subsequently necessitate the use of supplementary oxygen. It may also delay discharge from the post-anaesthesia care unit, increase the need for respiratory physiotherapy or non-invasive ventilation, and also increase the probability of intensive care unit admission. Furthermore, it has been demonstrated that obesity is a risk factor for postoperative tracheal re-intubation, morbidity, and mortality.[8]

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Several trials have tested different intraoperative ventilation strategies in these patients, for instance, various ventilation modes, PEEP, or recruitment manoeuvres (RM) which is the application of a sustained increase in positive pressure to the airway in order to reopen collapsed alveoli. However, the ideal ventilation strategy in obese patients undergoing surgery under general anaesthesia has not yet been established. This ventilation strategy would be expected to optimize gas exchange and pulmonary mechanics, and to minimize the risk of postoperative respiratory complications. We have performed a systematic review and meta-analysis to determine the impact of different intraoperative ventilation strategies on these endpoints in obese patients undergoing surgery.

Methods

We followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) working group (http://www.prisma-statement.org/).[9]

Eligibility criteria

All published full reports of randomized, controlled trials in obese patients (BMI $\geq$30 kg m^{-2}, according to the World Health Organization's definition)[10] undergoing surgery under general anaesthesia comparing different ventilation strategies (e.g. PEEP, RM, various ventilation modes), and reporting on intraoperative gas exchange, pulmonary mechanics, or postoperative respiratory complications were included. We did not consider animal studies or abstracts.

Information sources and search strategy

We searched in MEDLINE, the Cochrane Central Register of Controlled Trials (CENTRAL), and Excerpta Medica Database (EMBASE) using the terms 'obese', 'obesity', 'bariatric', 'ventilation', 'lung', 'oxygenation', 'atelectasis', 'pneumonia', and combinations of those, without language restriction up to March 2012. Additional studies were identified through screening of bibliographies of retrieved reports. Authors of original studies were contacted and asked to provide additional information of their studies if necessary.

Study selection

Two of us (M.A., C.L.) conducted the systematic search independently. One author (M.A.) screened the abstracts of retrieved articles and excluded reports that did not fulfil the inclusion criteria. He then examined the full reports and confirmed their eligibility. Any doubt concerning the inclusion of a trial was resolved by discussion with a third author (M.R.T.).

Data extraction process and data items

One author (M.A.) extracted information on the number of patients, type of surgery, BMI, ventilation strategies, pulmonary mechanics, gas exchange, postoperative pulmonary complications, and intervention-related adverse effects. Extracted data were checked by another author (C.L.). If data reporting was incomplete, or unclear, we contacted the original authors and asked for further data.

Risk of bias in individual studies

We applied a modified five items, seven-point Oxford scale to assess the quality of data reporting.[11] As we included only randomized trials, the minimum score was one. One author (M.A.) scored all the studies. The scores were independently checked by another author (C.L.). Any disagreement was resolved through discussion with a third author (M.R.T.).

Synthesis of results

There was an arbitrary pre-hoc decision to perform meta-analyses only when data from at least three studies or 100 patients could be combined. We estimated weighted mean differences (WMDs) with 95% confidence intervals (CI) using data from the original reports. If the data were homogenous ($P\geq0.1$), we applied a fixed effect model. If the data were heterogeneous ($P<0.1$), we applied a random effects model.

Analyses were conducted using Microsoft Excel 11.3 for Mac, and Review Manager [RevMan (computer program) version 5, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration].

Results

Study selection

Four hundred and thirty-nine reports were identified and screened for inclusion (Fig. 1). Of those, 417 were excluded for a variety of reasons; 28 were potentially relevant but did not have a randomized study design. Twenty-two potentially relevant randomized trials were evaluated for inclusion. Of those, eight were performed in non-obese patients, and one reported on outcomes that could not be extracted for meta-analysis.[12] Finally, 13 randomized trials (reporting on 15 comparisons), including relevant data from 505 obese surgical patients, fulfilled all inclusion criteria (Table 1).[13–25]

Study characteristics

Studies were published between 1978 and 2011, and came from 10 different countries: France (three), Belgium (two), and Argentina, Brazil, Denmark, Germany, Lebanon, Saudi Arabia, Sweden, and USA (one each). The average group size was 17 patients (range, 5–34). The trials reported on a large variety of different interventions: pressure-controlled ventilation (PCV), volume-controlled ventilation (VCV), pressure support ventilation, large tidal volumes (increase in normal tidal volume by 35%), different levels of PEEP, different alveolar RM, and multiple combinations thereof (Table 1). The median of all average BMI was 43 kg m^{-2} (range, 32–53); in one trial, average body weights were 121 and 129 kg.[17]

Patients underwent laparoscopic bariatric surgery in eight trials (284 patients),[13 15 18–22 24] open bariatric surgery in four (133 patients),[14 16 17 19] open colectomy in one (30 patients),[23] and non-abdominal surgery in one (68 patients).[25]

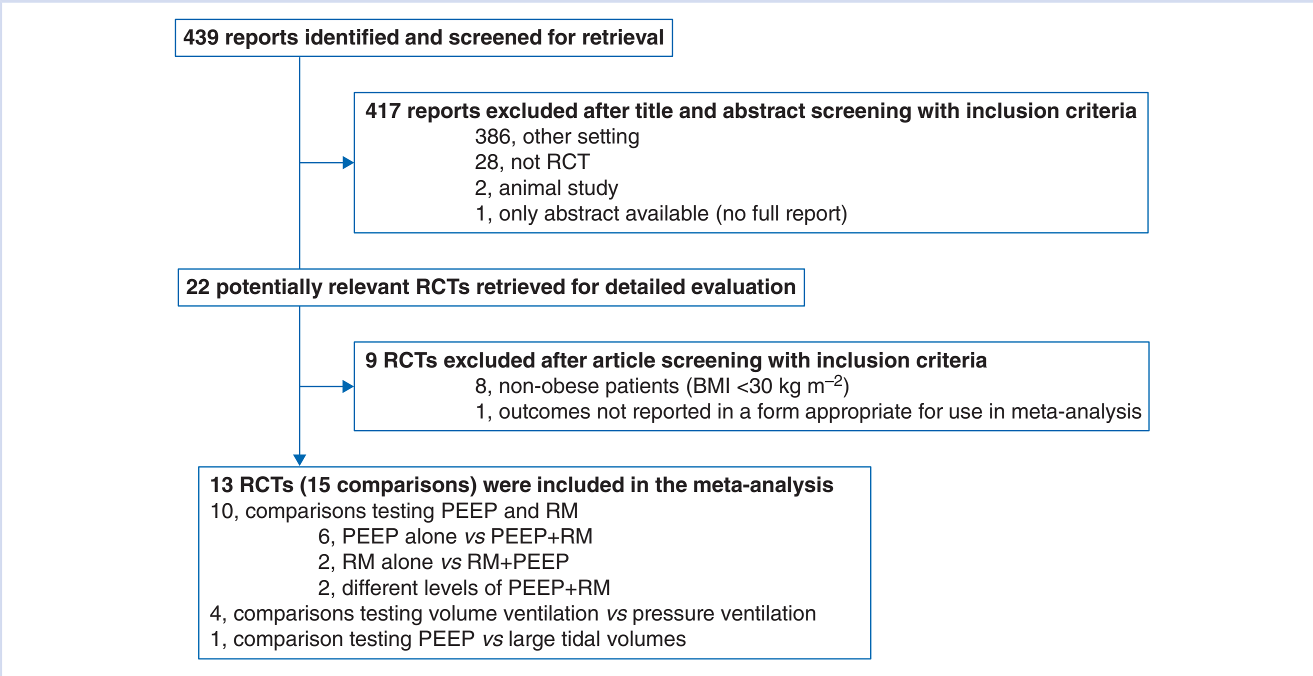


Fig 1 Study selection process. RCT, randomized controlled trial; PEEP, positive end-expiratory pressure; RM, recruitment manoeuvre.

The median modified Oxford quality score was 3 (range, 1–5). Additional information on specific outcomes was provided upon request by the original authors of two reports;[18 19] these could subsequently be included in our analyses.

Results of individual studies and synthesis of results

There were enough relevant data to warrant meta-analyses for two comparisons only: PEEP alone *vs* PEEP associated with RM, and PCV compared with VCV. In these two subgroups, all patients underwent open or laparoscopic bariatric surgery.

PEEP alone *vs* PEEP plus recruitment manoeuvre

Six randomized trials compared PEEP alone with PEEP plus RM (Table 2). From five of those (182 patients), outcome data could be extracted and combined.[14 16 18 20 21] PEEP levels varied from 5 to 10 cm H_2O. RM regimens included inspiratory pressure of 40 cm H_2O for 40 s,[14 18] of 55 cm H_2O for 10 s,[20] or of 40 cm H_2O plus PEEP (20 cm H_2O) for 3 min,[21] and progressive or sudden increase in PEEP from 5 to 20 or 30 cm H_2O for 2 min.[16]

Adding RM to PEEP improved intraoperative Pa_{O_2}/F_{IO_2} ratio (WMD, 16.2 kPa; 95% CI, 8.0–24.4) (Fig. 2A) and increased respiratory system compliance (WMD, 14 ml cm H_2O^{-1}; 95% CI, 8–20) (Fig. 2B) but did not affect intraoperative mean arterial pressure (Fig. 2C).

Barotrauma was sought in two studies. In one, none of 52 patients who were ventilated with PEEP 8 cm H_2O with or without additional RM (40 cm H_2O for 15 s) was reported to suffer from barotrauma after operation.[14] In the other, none of 66 patients who were ventilated with RM (inspiratory pressure of 40 cm H_2O for 7 to 8 s) with or without PEEP 5 or 10 cm H_2O was reported to suffer from barotrauma after operation.[22]

There were not enough data on other outcomes to draw any meaningful conclusions.

Pressure-controlled *vs* volume-controlled ventilation

Four randomized trials compared PCV with VCV (Table 1). From three of those (100 patients), outcome data could be extracted and combined.[13 15 19] One study included 40 patients in a crossover design; the number of eventually analysed patients was 79.[19] The authors provided individual patient data on request, which enabled us to integrate them into meta-analyses.

In the PCV modes, inspiratory pressure was set to achieve a tidal volume of 10 ml kg^{-1} ideal body weight, with an inspiratory over expiratory ratio 0.5, F_{IO_2} 0.5, and with PEEP 5 cm H_2O,[15] or without PEEP,[19] or was set to achieve a tidal volume of 8 ml kg^{-1} ideal body weight, with an inspiratory over expiratory ratio 0.5, F_{IO_2} 0.6, and PEEP 5 cm H_2O.[13] In each trial, VCV and PCV were always matched (i.e. identical tidal volume, PEEP, respiratory rate or F_{IO_2}).

There was no evidence of any difference between ventilation modes in terms of intraoperative Pa_{O_2}/F_{IO_2} ratio, intraoperative tidal volume, or mean airway pressure (Fig. 3A–C). There was no evidence either of any difference in mean arterial pressure (Supplementary material SA) or mean heart rate (Supplementary material SB).

There were not enough data on other outcomes to draw any meaningful conclusions.

Table 1 Included randomized controlled trials. Randomization (0–2): 0, none; 1, mentioned; 2, described and adequate; concealment of allocation (0–1): 0, none; 1, yes; intraoperative blinding (0–1): 0, none; 1, yes; postoperative blinding (0–1): 0, none; 1, yes; drop-outs (0–2): 0, not described; 1, described but incomplete; 2, described and adequate. VCV, volume-controlled ventilation; LTV, large tidal volumes; RM, recruitment manoeuvre; NPPV, non invasive positive pressure ventilation; PCV, pressure-controlled ventilation; PSV, pressure support ventilation; BMI, body mass index. *In this trial, only average body weights per group were reported

Study	Comparisons [no. of analysed patients] {comparison not considered} PEEP values in cm H_2O	Surgery	BMI (kg m^{-2}), mean (SD)	Randomization	Concealment	Intraoperative blinding	Postoperative blinding	Drop-outs
Cadi and colleagues[13]	1. VCV [18] 2. PCV [18]	Laparoscopic gastric banding	1. 44 (5) 2. 44 (5)	2	0	0	0	1
Chalhoub and colleagues[14]	1. PEEP 8+single RM [26] 2. PEEP 8 [26]	Open bariatric	1. 44.4 (3.7) 2. 45 (5.3)	1	1	0	0	0
De Baerdemaeker and colleagus[15]	1. VCV [12] 2. PCV [12]	Laparoscopic gastric banding	1. 41.1 (4.5) 2. 38.6 (3.6)	1	0	0	0	1
de Souza and colleagues[16] 2009	1. PEEP 5+single progressive RM [17] 2. PEEP 5+single sudden RM [16] 3. PEEP 5 [14]	Open Roux-en-Y bypass	1. 50.5 (7.2) 2. 46.3 (3.5) 3. 49.2 (6.3)	1	0	0	0	0
Eriksen and colleagues[17]	1. LTV (normal tidal volume+35%) [5] 2. PEEP 10 [5]	Open bariatric	1. 121.0 kg* 2. 128.9 kg	1	0	0	0	1
Futier and colleagues[18]	1. PEEP 10+RM+NPPV [22] 2. PEEP 10+NPPV [22] 3. PEEP 10 [22]	Laparoscopic sleeve gastrectomy or Roux-en-Y bypass	1. 45 (5) 2. 46 (2) 3. 46 (4)	2	1	0	0	2
Hans and colleagues[19]	1. VCV [20] 2. PCV [20] crossover design	Laparoscopic and open Roux-en-Y bypass	All patients 41.7 (5.8)	2	0	0	0	1
Reinius and colleagues[20]	1. PEEP 10+single RM [10] 2. PEEP 10 [10] 3. Single RM [10]	Laparoscopic bariatric Roux-en-Y bypass	1. 45 (5) 2. 44 (3) 3. 45 (4)	1	0	1	0	1
Tafer and colleagues[21]	1. PEEP 10+single RM [13] 2. PEEP 10 [13]	Laparoscopic gastric banding	1. 44 (7) 2. 45 (5)	1	1	0	0	1
Talab and colleagues[22]	1. PEEP 5+single RM [22] 2. PEEP 10+single RM [22] 3. Single RM [22]	Laparoscopic bariatric	1. 44.5 (7.0) 2. 38.3 (6.9) 3. 41.8 (7.9)	1	0	0	0	2
Tusman and colleagues[23]	1. PEEP 5+single RM [10] 2. PEEP 10+single RM [10] {3. BMI<30+RM [10] not randomized}	Open colectomy	1. 33 (2) 2. 35 (4) {3. 25 (1)}	1	0	0	0	1
Whalen and colleagues[24]	1. PEEP 4 [10] 2. PEEP 12+single progressive RM [10]	Laparoscopic bariatric Roux-en-Y bypass	1. 53 (11) 2. 48 (6)	2	1	0	0	1
Zoremba and colleagues[25]	1. PSV [34] 2. PCV [34]	Different non-bariatric	1. 32 (2) 2. 32 (2)	2	0	0	1	2

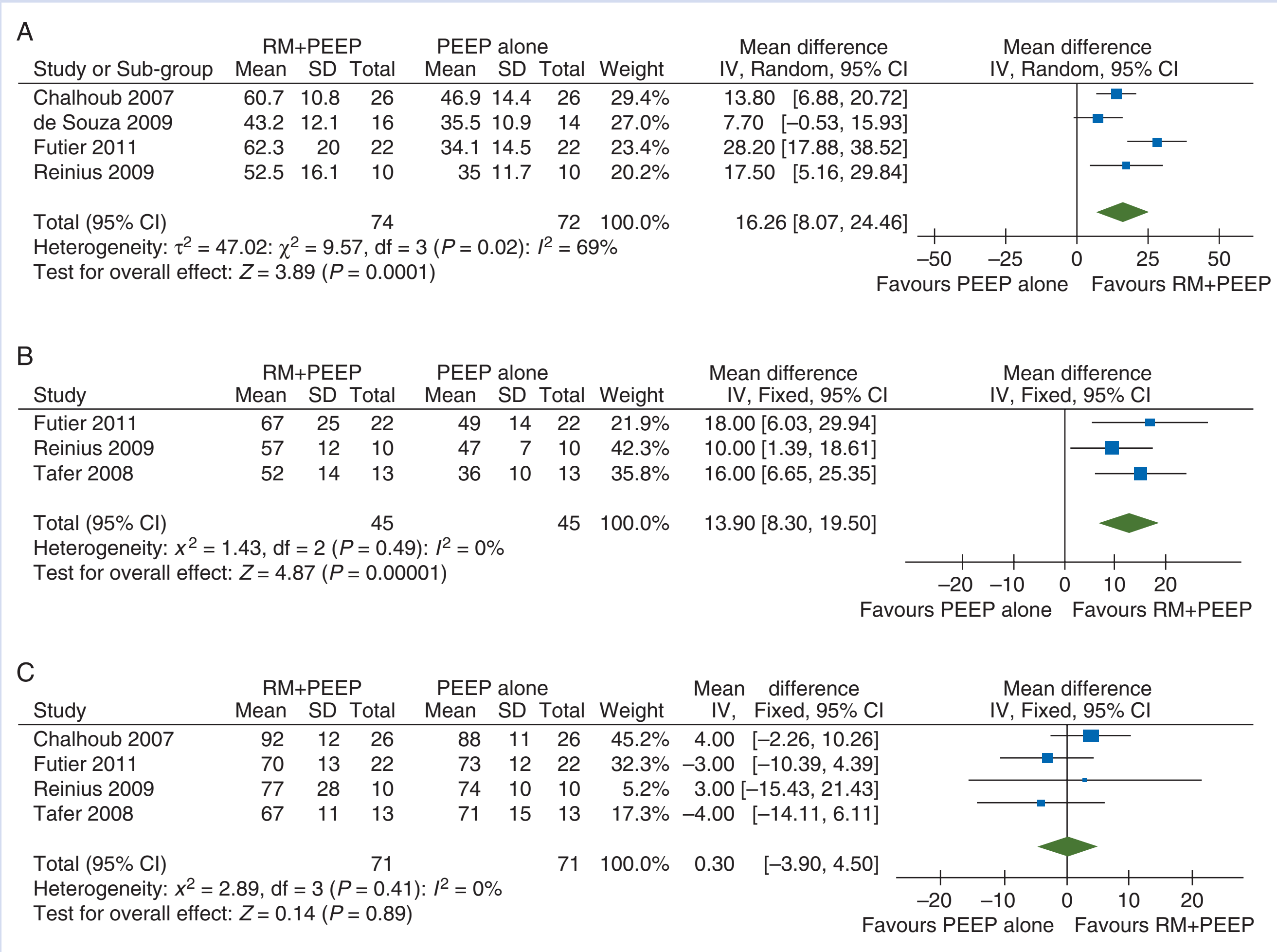
Table 2 Characteristics of studies testing RM. RM, recruitment manoeuvre; NPPV, non-invasive positive pressure ventilation; Pa_{O_2}, partial pressure of oxygen; PIP, peak airway pressure; Vt, tidal volume

Study	Comparisons and airway pressures (cm H_2O)	Frequency	Timing of RM	Details of RM (all pressures in cm H_2O)	Timepoint of measurement of endpoint
Studies comparing PEEP+RM *vs* PEEP alone					
Chalhoub and colleagues[14]	1. PEEP 8+RM 40 2. PEEP 8	Single	After abdominal opening	Positive inspiratory pressure of 40 for 15 s	Before abdominal closure
de Souza and colleagues[16]	1. PEEP 5+RM 20	Single	After suture of abdominal aponeurosis	Progressive: increase in PEEP from 5 to 10–15–20 for 2 min each	Immediately after RM
	2. PEEP 5+RM 30			Sudden: increase in PEEP from 5 to 30 for 2 min	
	3. PEEP 5				
Futier and colleagues[18]	1. PEEP 10 +NPPV+RM 40 2. PEEP 10+NPPV 3. PEEP 10	Single	After induction	Sudden inspiratory pressure of 40 for 40 s	5 min after RM
Reinius and colleagues[20]	1. PEEP 10+RM 55 2. PEEP 10 3. RM 55	Single	After induction	Inspiratory pressure 55 for 10 s	40 min after induction of anaesthesia
Tafer and colleagues[21]	1. PEEP 10+RM 40 2. PEEP 10	Single	After induction	Inspiratory pressure 40 with PEEP 20, respiratory frequency 7 bpm for 3 min	Immediately after RM
Other comparisons					
Talab and colleagues[22]	1. PEEP 5+RM 40 2. PEEP 10+RM 40 3. RM 40	Single	After induction	Inspiratory pressure 40 for 7–8 s	Immediately after RM and at the end of surgery
Tusman and colleagues[23]	1. PEEP 5+RM 30 2. PEEP 10+RM 30	Single	45 min after abdominal opening	Progressive increase in PEEP from 5 to 10–15–20, each over 3 cycles. PIP 40+PEEP 20 for 10 cycles	Immediately after RM
Whalen and colleagues[24]	1. PEEP 4 2. PEEP 12+RM 50	At 5, 30, and 60 min and at the end of surgery	After pneumoperitoneum	Unchanged Vt, increasing PEEP 10 (over 3 cycles), PEEP 15 (3 cycles), PEEP 20 (10 cycles). PIP max 50	Immediately after RM and at the end of surgery

Discussion

In obese patients undergoing surgery under general anaesthesia, a large variety of different ventilation strategies have been tested in a limited number of randomized trials. Unfortunately, the great variety of the tested ventilation interventions yielded very little convincing evidence. Indeed, a gold standard in terms of intraoperative ventilation strategy for obese patients does not exist. Consequently, trialists do not know against what an experimental, potentially useful ventilation method shall be compared. Randomized studies reporting on the same comparison and the same endpoints were uncommon and therefore combining data for meta-analysis was difficult and often not feasible. Despite these limitations, some conclusions can be drawn.

First, RM plus PEEP compared with PEEP alone added both a statistically significant and clinically relevant effect on intraoperative oxygenation and increased respiratory system compliance, although it remained unclear how long these benefits were lasting and whether they extended into the postoperative period. However, the studies by Reinius and colleagues[20] and Whalen and colleagues[24] suggested that the beneficial effect of RM was maintained during 30–40 min intraoperatively; unfortunately, the postoperative period was not studied. It has been well demonstrated that RM can improve oxygenation. Some authors have also suggested that RM may improve compliance by reversing atelectasis formation.[26 27] However, most relevant studies have been conducted in the critical care setting in patients with acute lung injury (ALI) or acute respiratory distress syndrome (ARDS).[28–31] Some trials have been performed in the surgical setting but with normal weight patients.[32–34] New knowledge from our systematic review is that RM in the presence of PEEP, and compared with PEEP alone, has a beneficial effect on oxygenation and compliance in obese patients undergoing surgery. The mechanism by which the combination of RM and PEEP exerts its positive effect could be that RM opens the collapsed alveoli and PEEP keeps them open. This hypothesis finds support in the studies by Dyhr and colleagues.[35 36] Whether RM alone, in the absence of PEEP, and compared with no RM, also improves respiratory function remains obscure. There is



A

Study or Sub-group	RM+PEEP Mean	SD	Total	PEEP alone Mean	SD	Total	Weight	Mean difference IV, Random, 95% CI
Chalhoub 2007	60.7	10.8	26	46.9	14.4	26	29.4%	13.80 [6.88, 20.72]
de Souza 2009	43.2	12.1	16	35.5	10.9	14	27.0%	7.70 [−0.53, 15.93]
Futier 2011	62.3	20	22	34.1	14.5	22	23.4%	28.20 [17.88, 38.52]
Reinius 2009	52.5	16.1	10	35	11.7	10	20.2%	17.50 [5.16, 29.84]
Total (95% CI)			74			72	100.0%	16.26 [8.07, 24.46]

Heterogeneity: $\tau^2 = 47.02$: $\chi^2 = 9.57$, df = 3 ($P = 0.02$): $I^2 = 69\%$
Test for overall effect: $Z = 3.89$ ($P = 0.0001$)

B

Study	RM+PEEP Mean	SD	Total	PEEP alone Mean	SD	Total	Weight	Mean difference IV, Fixed, 95% CI
Futier 2011	67	25	22	49	14	22	21.9%	18.00 [6.03, 29.94]
Reinius 2009	57	12	10	47	7	10	42.3%	10.00 [1.39, 18.61]
Tafer 2008	52	14	13	36	10	13	35.8%	16.00 [6.65, 25.35]
Total (95% CI)			45			45	100.0%	13.90 [8.30, 19.50]

Heterogeneity: $x^2 = 1.43$, df = 2 ($P = 0.49$): $I^2 = 0\%$
Test for overall effect: $Z = 4.87$ ($P = 0.00001$)

C

Study	RM+PEEP Mean	SD	Total	PEEP alone Mean	SD	Total	Weight	Mean difference IV, Fixed, 95% CI
Chalhoub 2007	92	12	26	88	11	26	45.2%	4.00 [−2.26, 10.26]
Futier 2011	70	13	22	73	12	22	32.3%	−3.00 [−10.39, 4.39]
Reinius 2009	77	28	10	74	10	10	5.2%	3.00 [−15.43, 21.43]
Tafer 2008	67	11	13	71	15	13	17.3%	−4.00 [−14.11, 6.11]
Total (95% CI)			71			71	100.0%	0.30 [−3.90, 4.50]

Heterogeneity: $x^2 = 2.89$, df = 3 ($P = 0.41$): $I^2 = 0\%$
Test for overall effect: $Z = 0.14$ ($P = 0.89$)

Fig 2 PEEP plus RM *vs* PEEP alone. (A) Impact on intraoperative Pa_{O_2}/FI_{O_2} ratio (kPa). (B) Impact on intraoperative respiratory compliance (ml cm H_2O^{-1}). (C) Impact on intraoperative mean arterial pressure (mm Hg).

some limited evidence based on a previous study showing that RM only improves intraoperative oxygenation and respiratory compliance transiently.[12]

Secondly, RM plus PEEP compared with PEEP alone did not impair mean arterial pressure. We do not know whether, and to what extent, mean arterial pressure was impaired through PEEP alone as no trial randomized patients to PEEP *vs* no PEEP. However, it may be inferred that in obese patients who are ventilated with PEEP, additional RM does not further increase haemodynamic instability. As only data on arterial pressure and heart rate were reported in these studies, we cannot exclude that RM decreased cardiac output. In critical care patients, RM was shown to lead to a significant reduction in cardiac output.[29 37]

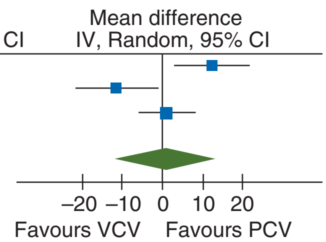
Thirdly, although barotrauma remains a major concern in patients treated with RM, only two randomized trials reported on this complication, and both analysed the effect of RM plus PEEP. In those, 92 patients were ventilated with different RM regimens and none was reported to suffer from barotrauma.[14 22] This does not exclude the risk of barotrauma in obese surgical patients who are ventilated with RM. However, these data are consistent with those from the intensive care setting, suggesting that barotrauma was not a major issue in critically ill patients who were ventilated with RM.[31 33 34 38] Interestingly, all these studies from the intensive care setting were conducted in ALI or ARDS patients, and even in these vulnerable patients, RM did not increase the risk of barotrauma. It may be inferred from these data that RM is a reasonably safe procedure both in the intensive care and the obese surgical patient.

Fourthly, RM modes varied widely among studies, ranging from a single sustained increase in inspiratory pressure to a progressive increase in PEEP with fixed driving pressure. However, the pragmatic question here is not what mode of RM is the most efficient in preventing pulmonary complications in obese patients, but whether RM *per se*, independently of the mode, makes any difference. Previous studies have shown that an inspiratory pressure of 30 cm H_2O was required to reduce atelectasis to half the initial extent while it was assumed that a pressure of 40 cm H_2O and a minimum duration of 15 s were necessary for complete reopening of all collapsed lung tissue.[32 39] Interestingly, the

A

Study or Subgroup	PCV Mean	PCV SD	PCV Total	VCV Mean	VCV SD	VCV Total	Weight	Mean difference IV, Random, 95% CI
Cadi 2008	37.5	14.3	18	26.5	10.3	18	32.8%	11.00 [2.86, 19.14]
De Baerdemaeker 2007	31.6	10.5	12	41.7	11.9	12	31.5%	−10.10 [−19.08, −1.12]
Hans 2007	36.4	13.5	39	35.5	14.4	40	35.7%	0.90 [−5.25, 7.05]
Total (95% CI)			69			70	100.0%	0.75 [−9.99, 11.48]

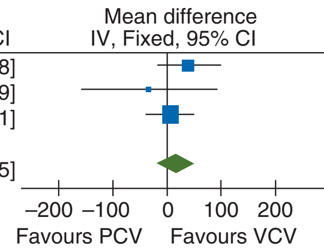
Heterogeneity: $\tau^2 = 74.21$; $\chi^2 = 11.66$, df = 2 ($P = 0.003$); $I^2 = 83\%$
Test for overall effect: $Z = 0.14$ ($P = 0.89$)



B

Study or Subgroup	PCV Mean	PCV SD	PCV Total	VCV Mean	VCV SD	VCV Total	Weight	Mean difference IV, Fixed, 95% CI
Cadi 2008	613	91	18	573	81	18	36.1%	40.00 [−16.28, 96.28]
De Baerdemaeker 2007	612	170	12	645	138	12	7.5%	−33.00 [−156.89, 90.89]
Hans 2007	650	104	39	643	100	40	56.4%	7.00 [−38.01, 52.01]
Total (95% CI)			69			70	100.0%	15.93 [−17.88, 49.75]

Heterogeneity: $x^2 = 1.45$, df = 2 ($P = 0.48$): $I^2 = 0\%$
Test for overall effect: $Z = 0.92$ ($P = 0.36$)



C

Study or Subgroup	PCV Mean	PCV SD	PCV Total	VCV Mean	VCV SD	VCV Total	Weight	Mean difference IV, Fixed, 95% CI
Cadi 2008	12	1	18	12	2	18	25.4%	0.00 [−1.03, 1.03]
De Baerdemaeker 2007	11.6	0.6	12	12	1.2	12	47.1%	−0.40 [−1.16, 0.36]
Hans 2007	7	2.2	39	7.3	2.3	40	27.5%	−0.30 [−1.29, 0.69]
Total (95% CI)			69			70	100.0%	−0.27 [−0.79, 0.25]

Heterogeneity: $x^2 = 0.38$, df = 2 ($P = 0.83$): $I^2 = 0\%$
Test for overall effect: $Z = 1.02$ ($P = 0.31$)

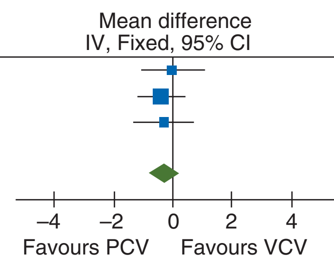


Fig 3 VCV *vs* PCV. (A) Impact on intraoperative Pa_{O_2}/FI_{O_2} ratio (kPa). (B) Impact on intraoperative tidal volume (ml). (C) Impact on intraoperative mean airway pressure (cm H_2O).

pressures used in the included randomized studies were in this range. Furthermore, the literature suggests that both the type of RM and the type of lung pathology have different effects on haemodynamic and respiratory parameters.[40 41] In an experimental animal study, a sustained inflation decreased cardiac output more than an incremental increase in PEEP.[41] This adverse haemodynamic effect was more pronounced in a pneumonia ALI model than in oleic acid injury or ventilator-induced lung injury. It may be speculated that the obese surgical patient with atelectasis was similar to the pneumonia ALI model. In the absence of convincing evidence, it seems reasonable to use a progressive, rather than a sudden, RM mode, assuming that it may have the least adverse effects.

Finally, intraoperative oxygenation, mean airway pressure, and mean arterial pressure were similar with PCV and VCV. This suggests that in the obese patient undergoing surgery, the ventilation mode *per se* does not seem to be a factor. This result was not unexpected as previous studies in ALI and ARDS patients,[42 43] or in non-obese patients undergoing thoracic surgery[44] failed to show a significant difference between these two ventilation modes. As suggested by Cereda and colleagues,[45] a theoretical risk of PCV in surgical patients is that the progressive decrease in compliance during anaesthesia and surgery may lead to a reduction in ventilation. These trials did not allow confirmation of this hypothesis.

Limitations of our study

Our analysis has several limitations. First, despite an extensive literature search, the number of retrieved valid randomized trials fulfilling the inclusion criteria remained low. Furthermore, the studies included a limited number of patients (average group size, 17); the total number of patients was 505 only. The evidence base drawn from such a small sample is therefore sparse. Variability in reported results may partially be explained through small trial size. For instance, three trials that compared PCV with VCV reported on largely contradictory data on intraoperative oxygenation. In one small study including 36 patients, the result was significant in favour of PCV.[13] In another small study including 24 patients, the result was significant in favour of VCV.[15] Finally, the largest of the three studies, including 40 patients, reported on equivalence (Fig. 3A).[19] It is well known that studies conducted with a limited number of participants tend to exaggerate the effect of an intervention.[46] A further limitation of small trials is the lack of valid information on risk. For instance, of a total of eight studies (193 patients) that investigated an RM strategy, only two reported on barotrauma.[14 22] We do not know whether in the other six, barotrauma was not sought or whether it happened but was not reported. Also, the absence of risk in a limited number of patients does not mean that the risk does not exist. Finally, despite the limited number of retrieved trials, we found an extraordinary variability of interventions and, consequently, of comparisons. In fact, more than 10 different interventions were tested in these 13 randomized studies. Also, definitions and reporting of outcomes varied widely. As a consequence, pooling of homogenous data from independent trials was rarely possible. The most likely reason for the large variability is the lack of a gold-standard intervention against which trialists may compare a potentially useful experimental intervention. Especially in subjects with healthy lungs, there is no consensus on the gold standard in mechanical ventilation. However, in the absence of a gold-standard intervention, we would expect to find mainly trials that compare an experimental intervention with nothing. Nevertheless, no randomized trial compared intraoperative PEEP with no PEEP (in the absence of RM). Previous studies did not unanimously show a beneficial effect of PEEP alone.[27 47–49] Thus, the widely believed beneficial effect of PEEP in obese surgical patients is still not based on strong evidence. Also, no randomized trial compared RM with no RM (in the absence of PEEP). As a consequence, the impact of each intervention alone, PEEP or RM, in obese patients undergoing surgery, remains obscure. This dilemma has been shown before in a similar setting.[50] Finally, due to the general lack of data, we were unable to compare ventilation strategies in different surgical settings, for instance, in open *vs* laparoscopic surgery. One small study only compared laparoscopy with open surgery.[19]

Our study sheds light on the currently used ventilation strategies in obese patients undergoing surgery under general anaesthesia. The research agenda should start with randomized comparisons of a single intervention with a no intervention control. Combinations of strategies should then be tested with interventions that have shown efficacy in no intervention-controlled trials. Standardized endpoint reporting is of importance. Ideally, reporting of surrogate endpoints should be avoided. Relevant clinical endpoints such as postoperative respiratory complications, atelectasis, and pneumonia should be reported; these would be more relevant for clinical decision-making as, for instance, intraoperative Pa_{O_2}. Atelectasis, pneumonia, delayed extubation, or need for re-intubation were reported in two trials only.[22 24] Finally, more relevant data are needed on intervention-related adverse effects.

Conclusion

There is some evidence from randomized trials that in obese patients undergoing surgery, alveolar RM in the presence of PEEP may improve intraoperative oxygenation and respiratory system compliance without adverse haemodynamic effects. There is a lack of evidence of any difference between PCV and VCV. The evidence base concerning the most efficacious intraoperative ventilation strategy in this specific patient population remains weak. Also, published trials report on a large variety of endpoints, and most of these are surrogate. A consensus on how to test ventilation strategies in obese patients undergoing surgery, and how to report data on efficacy and harm, is needed.

Supplementary material

Supplementary material is available at *British Journal of Anaesthesia* online and on the authors' institutional webpage (http://anesthesiologie.hug-ge.ch/data.htm).

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Declaration of interest

None declared.

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