ANESTHESIOLOGY

Positive End-expiratory Pressure and Postoperative Atelectasis

A Randomized Controlled Trial

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EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- Positive end-expiratory pressure (PEEP) is used during anesthesia to prevent atelectasis, but its impact during emergence from anesthesia is uncertain.

What This Article Tells Us That Is New

- Thirty patients undergoing nonabdominal surgery under general anesthesia were randomized to maintained (7 or 9 cm H_2O) or zero PEEP before being given 100% oxygen for emergence preoxygenation. Postoperative atelectasis (assessed by computed tomography) was small with no effect on oxygenation, whether or not PEEP was used during emergence.

ABSTRACT

Background: Positive end-expiratory pressure (PEEP) increases lung volume and protects against alveolar collapse during anesthesia. During emergence, safety preoxygenation preparatory to extubation makes the lung susceptible to gas absorption and alveolar collapse, especially in dependent regions being kept open by PEEP. We hypothesized that withdrawing PEEP before starting emergence preoxygenation would limit postoperative atelectasis formation.

Methods: This was a randomized controlled evaluator-blinded trial in 30 healthy patients undergoing nonabdominal surgery under general anesthesia and mechanical ventilation with PEEP 7 or 9 cm H_2O depending on body mass index. A computed tomography scan at the end of surgery assessed baseline atelectasis. The study subjects were thereafter allocated to either maintained PEEP (n = 16) or zero PEEP (n = 14) during emergence preoxygenation. The primary outcome was change in atelectasis area as evaluated by a second computed tomography scan 30 min after extubation. Oxygenation was assessed by arterial blood gases.

Results: Baseline atelectasis was small and increased modestly during awakening, with no statistically significant difference between groups. With PEEP applied during awakening, the increase in atelectasis area was median (range) 1.6 (−1.1 to 12.3) cm^2 and without PEEP 2.3 (−1.6 to 7.8) cm^2. The difference was 0.7 cm^2 (95% CI, −0.8 to 2.9 cm^2; $P = 0.400$). Postoperative atelectasis for all patients was median 5.2 cm^2 (95% CI, 4.3 to 5.7 cm^2), corresponding to median 2.5% of the total lung area (95% CI, 2.0 to 3.0%). Postoperative oxygenation was unchanged in both groups when compared to oxygenation in the preoperative awake state.

Conclusions: Withdrawing PEEP before emergence preoxygenation does not reduce atelectasis formation after nonabdominal surgery. Despite using 100% oxygen during awakening, postoperative atelectasis is small and does not affect oxygenation, possibly conditional on an open lung during anesthesia, as achieved by intraoperative PEEP.

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General anesthesia commonly induces pulmonary atelectasis.[1] In addition to increasing the risk of hypoxemia during anesthesia, it has been proposed that atelectasis forms the pathophysiologic basis of postoperative pulmonary complications.[2,3]

The main mechanism behind atelectasis formed after anesthesia induction is reduced lung volume with airway closure and subsequent gas absorption from preoxygenated alveoli.[4] For healthy patients undergoing nonabdominal surgery, early applied moderate positive end-expiratory pressure (PEEP) seems sufficient to essentially prevent or reverse atelectasis.[5] PEEP increases the end-expiratory lung volume and counteracts airway closure by having a dominant effect in dependent lung regions.[6] Although this has been shown to be beneficial during the maintenance phase of anesthesia, the physiologic effects of PEEP during awakening have been scarcely investigated. After completion of surgery, a second preoxygenation routinely precedes emergence from anesthesia and extubation.[7,8] PEEP is normally maintained during this phase, facilitating the entrance of highly absorbable oxygen in the dorsal lung regions. However, PEEP is discontinued at the moment of extubation. Still, the newly operated patient may not restore functional residual capacity, due to remaining effects of anesthetic drugs and possibly pain.[9,10] Therefore, airway closure and yet again formation of atelectasis may follow.

Few studies have reliably quantified early postoperative atelectasis.[11–14] Notably, atelectasis observed at a time point

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postoperatively can comprise a mix of lung tissue collapsed during the anesthesia and later in conjunction with the awakening procedure. Thus, it may be difficult to specify the contribution from the awakening procedure itself. Still, in one study, postoperative atelectasis was measured with computed tomography in a group of patients after a vital capacity maneuver before emergence, making it likely that the observed atelectasis had developed during awakening.[11] Although computed tomography has been used extensively in studies comparing atelectasis before and after induction of anesthesia, there is no published report on computed tomography scans performed both before and after emergence. Neither has the effect of PEEP been studied during this specific phase of anesthesia.

The primary aim of this study was to test the hypothesis that withdrawing PEEP just before emergence preoxygenation would attenuate postoperative atelectasis formation and thus improve oxygenation. Additionally, by performing computed tomography scans just before and after emergence, we wanted to further elucidate the contribution from the awakening procedure to the amount of early postoperative atelectasis.

Materials and Methods

This was a single-center, randomized controlled, evaluator-blinded trial with a two-arm parallel design. The study protocol was approved by the local Radiation Safety Committee and the Regional Ethics Committee in Uppsala, Sweden (Dnr 2017/267). It was prospectively registered at ClinicalTrials.gov (NCT03351946, principal investigator Erland Östberg, registration date August 11, 2017). The study was conducted in accordance with the ethical principles of the 1964 Declaration of Helsinki and its later amendments and performed at Köping County Hospital in Köping, Sweden.

Study Population

Patients scheduled for day-case surgery in supine position were screened for inclusion and contacted by phone a week before the surgery to obtain preliminary consent. We included 30 American Society of Anesthesiologists class I and II patients between 40 and 75 yr of age undergoing elective hernia repair or orthopedic extremity surgery, for whom interscalene or supraclavicular plexus block was not planned as part of the anesthetic regimen. The exclusion criteria were a body mass index greater than or equal to 30kg/m^2, ischemic heart disease, obstructive pulmonary disease, and smokers or previous smokers with a history of more than 6 pack yr. Written informed consent was obtained from all participants upon arrival at the day-case unit. A final eligibility check was done by ensuring a normal spirometry result and peripheral oxygen saturation (Sp_{O_2}) above 95% when breathing room air. The corresponding author (E.Ö.) enrolled all the participants.

Anesthesia and Monitoring

No patient received sedating premedication. An arterial catheter was placed under local anesthesia in the radial artery to enable blood gas sampling and invasive blood pressure monitoring. Further monitoring consisted of three-lead electrocardiography and pulse oximetry (Masimo Rad-5; Masimo Corporation, USA).

Preoxygenation, without any continuous positive airway pressure, was undertaken for 3 min with an inspired oxygen fraction (F_{IO_2}) of 1.0 in a 15- to 20-degree head-up position. The induction and maintenance of anesthesia were standardized and identical for all patients with target-controlled infusions of propofol and remifentanil (Injectomat TIVA Agilia; Fresenius Kabi AB, Sweden). After the loss of spontaneous breathing, the patients were bag mask–ventilated with F_{IO_2} 1.0, without PEEP. Rocuronium was used to facilitate endotracheal intubation, which was performed 6 min after starting preoxygenation. Mechanical ventilation was undertaken with the portable Hamilton-T1 (Hamilton Medical, Switzerland) in a volume-controlled mode with adaptive inspiratory pressure. The ventilatory settings in both groups were F_{IO_2}, 0.35; tidal volume, 7 ml/kg ideal body weight[15]; inspiratory to expiratory ratio, 1:2; PEEP, 7 or 9 cm H_2O, with the higher setting in case the body mass index was above or equal to 25kg/m^2. The PEEP levels were chosen because they recently, in a similar patient group, were shown to result in minimal atelectasis at the end of surgery without compromising hemodynamics.[5] The respiratory frequency was set to 10 breaths/min and further adjusted to maintain end-tidal carbon dioxide pressure between 35 and 40 mmHg. Recruitment maneuvers were not used.

Phenylephrine or ephedrine was administered as required to maintain mean arterial blood pressure above 60 mmHg. A balanced crystalloid solution with 2.5% glucose was given as maintenance at a maximum of 500 ml during anesthesia. All the study subjects were anesthetized by the same investigators (E.Ö. and L.E.).

Postoperative pain relief consisted of oral paracetamol or ibuprofen in conjunction with local anesthesia. No opioids were administered, except for the remifentanil used during surgery.

Emergence from Anesthesia

After the completion of surgery, the patients, still anesthetized, were transported to the radiology department located below the operating room. Because a portable ventilator was used from the start of anesthesia, transportation was possible without disconnecting or changing ventilator settings. After the first computed tomography scan, the study subjects were randomized to their respective allocation group. In the control group, PEEP was maintained throughout emergence preoxygenation with F_{IO_2} 1.0. In the intervention group, with the F_{IO_2} still at the maintenance level, the PEEP level was set to zero (zero PEEP), and 2 min were allowed for

the lungs to establish equilibrium with the new ventilator setting. Thereafter, emergence preoxygenation was started with the same F_{IO_2} 1.0 as in the control group. Awakening was initiated in both groups during transportation from the radiology department to the postoperative care unit. A peripheral nerve stimulator was used to ensure satisfactory recovery from neuromuscular blockade by a train-of-four ratio above 0.9. Suctioning of the upper airways was performed through an oropharyngeal airway before extubation, which took place when the patients were awake.

Computed Tomography Scans

The primary outcome was change in atelectasis area from before awakening to after extubation. The first computed tomography scan was done before awakening, and the second was done approximately 30 min after tracheal extubation. From earlier experience, the timing of the second scan was chosen to ensure a cooperative patient being able to hold his breath for a few seconds during scanning.[12,13] For the second scan, the patients, remaining in a supine position with a 15- to 20-degree head-up tilt, were transported from the postoperative care unit back to the radiology department. To allow flexibility and minimum interference with ordinary elective and acute radiology activity, we used either of the two computed tomography scan machines available: the GE LightSpeed VCT XTe machine (GE Healthcare, USA) and the Toshiba Aquilion PRIME (Canon Medical Systems, USA). The scanning was done with the study subjects in a supine position. First, we obtained a frontal scout view at end-expiration to locate the diaphragm. A single-sliced transverse scan was then performed approximately 5 mm above the right diaphragm dome, at end-expiration. Because each examination was restricted to one slice, the radiation dose received by each participant was limited to a total 0.6 mSv. In comparison, the radiation exposure from a full thoracic computed tomography scan is typically 5.0 mSv (Swedish Radiation Safety Authority, 2017).

Irrespective of the type of scanning machine used, Sectra RIS and PACS systems (version 17.1.21, Sectra, Sweden) were used for the computed tomography scan assessments, and all measurements were done using the same workstation software (AW Server 2.0; GE Healthcare, USA). In the obtained computed tomography slice, we first measured the total lung area in cm^2 by carefully delineating the contours of both lungs. The pulmonary hilus vessels were excluded from the lung region of interest. The atelectasis region was then outlined posteriorly as close to the pleura as possible but with some margin ventrally beyond the radiologic appearance of atelectasis and lung parenchyma haziness, using a separate region of interest technique. Any vascular structures 3 mm or larger were identified and manually excluded from the particular region of interest. Finally, we used the histogram functional view to calculate the actual atelectasis area, which was defined as −100 to +100 Hounsfield units.[1] Areas of different aeration were measured using the same technique described above and by setting the histogram parameters between −1,000 and −901, −900 and

−501, and −500 and −101 Hounsfield units for over aeration, normal aeration, and poor aeration, respectively.[16,17] The total lung area is generally smaller in the awake state without PEEP. Therefore, all areas were primarily expressed in cm^2 for adequate comparisons between areas detected during anesthesia (with PEEP) and areas observed after extubation. However, atelectasis areas are often expressed as the percentage of the total lung area in the basal slice; therefore these values were also reported. All assessments and measurements were performed by the same radiologist, who was blinded to the group assignment and patient outcome.

Arterial Blood Gases and Oxygenation

The secondary outcome was change in oxygenation, from before emergence to after extubation. Blood gas samples were drawn from the arterial line with the participants in a 15- to 20-degree head-up position. In addition to the baseline sample drawn before anesthesia and at room air, two more blood gases were analyzed. The first sample was drawn at the end of surgery during anesthesia with F_{IO_2} 0.35. The second sample was drawn during the first 45 min after extubation, however, not earlier than 15 min after extubation, assuming this delay would be sufficient for the study subjects to achieve the steady-state breathing of room air instead of pure oxygen. All blood gas samples were analyzed immediately using the Radiometer ABL800 Flex (Radiometer Medical, Denmark). Oxygenation was assessed by calculating the ratio of the arterial oxygen partial pressure to the inspired oxygen fraction, Pao_2/F_{IO_2} ratio.

Randomization

An independent statistician performed the randomization using the procedure PROC PLAN in SAS version 9.4 (SAS Institute Inc., USA). The treatment allocation sequence was generated using permuted-block randomization (with a fixed block size of four) stratified by body mass index, creating two strata (less than 27 and from 27 to 29.9 kg/m²). Sequentially numbered, sealed, and opaque envelopes were prepared containing treatment allocations until randomization. The corresponding author allocated the patients to their respective group by opening the envelopes immediately before starting the awakening procedure.

Statistical Analysis

The study was designed as a superiority trial. From the limited earlier data, we expected the control group to have an increase in atelectasis area of $4.5 cm^2$ with a SD of $2.2 cm^2$. With a two-sided α set to 0.05 and 1-β to 0.8, we calculated that 30 study subjects would be sufficient to detect a clinically relevant reduction of 50% in the primary outcome measure. Because we did not expect our outcome data to be normally distributed, the results were reported as the median (range), and for both primary and secondary outcomes, we used the Mann–Whitney U test for comparisons between groups.

Fisher's exact test was used in the case of binary outcomes, and the related samples were analyzed using the Wilcoxon signed-rank test. For all tests, a two-sided *P* value of less than 0.05 was considered significant. A *post hoc* sensitivity analysis to the primary outcome analysis was performed using a linear regression model, after log transformation of data, with inclusion of baseline atelectasis area as a covariate in the model. CI values were derived by the percentile bootstrap method. Data analysis was performed with the IBM SPSS Statistics version 24 software (IBM Corporation, USA) and R version 3.5.1 (https://www.r-project.org; accessed January 8, 2019). The stratification used during randomization was not considered in the analysis. The existence of outliers were considered, but no action was taken, and all data were included in the analysis.

Results

In total, 116 patients were assessed for eligibility between December 2017 and August 2018. The 30 included patients all received their allocated treatment and were included in the analysis (fig. 1); there were no missing data. Baseline characteristics, ventilatory data, and time data were similar in the two groups (table 1). Except for one patient who had upper extremity surgery, all patients had inguinal or umbilical hernia repair. All patients were able to comply with the breathing instructions during the second computed tomography scan. No patient received continuous positive airway pressure or supplemental oxygen to maintain SpO_2 greater than or equal to 94% after extubation. No complications were observed.

After surgery and ventilation with PEEP, there was no statistically significant difference between the groups in baseline atelectasis. The atelectasis area was median (range) 3.7 (0.2 to 9.8) cm^2 in the group allocated to receive PEEP during awakening and 2.7 (1.0 to 6.4) cm^2 in the group allocated to zero PEEP during awakening; the difference was 1.0 cm^2 (95% CI, −0.1 to 2.3 cm^2; $P = 0.120$; fig. 2). For the groups combined, the atelectasis area before awakening was median 3.3 cm^2 (95% CI, 2.5 to 3.9 cm^2), corresponding to median 1.3% (95% CI, 1.1 to 1.6%) of total lung area. Atelectasis increased in both groups during awakening, but there was no difference between the groups regarding the primary outcome, *i.e.*, change in atelectasis from before awakening to after extubation, median (range) 1.6 (−1.1 to 12.3) cm^2 for the PEEP group and 2.3 (−1.6 to 7.8) cm^2 for the zero PEEP group; the difference was 0.7 cm^2 (95% CI, −0.8 to 2.9 cm^2; $P = 0.400$). The smaller baseline
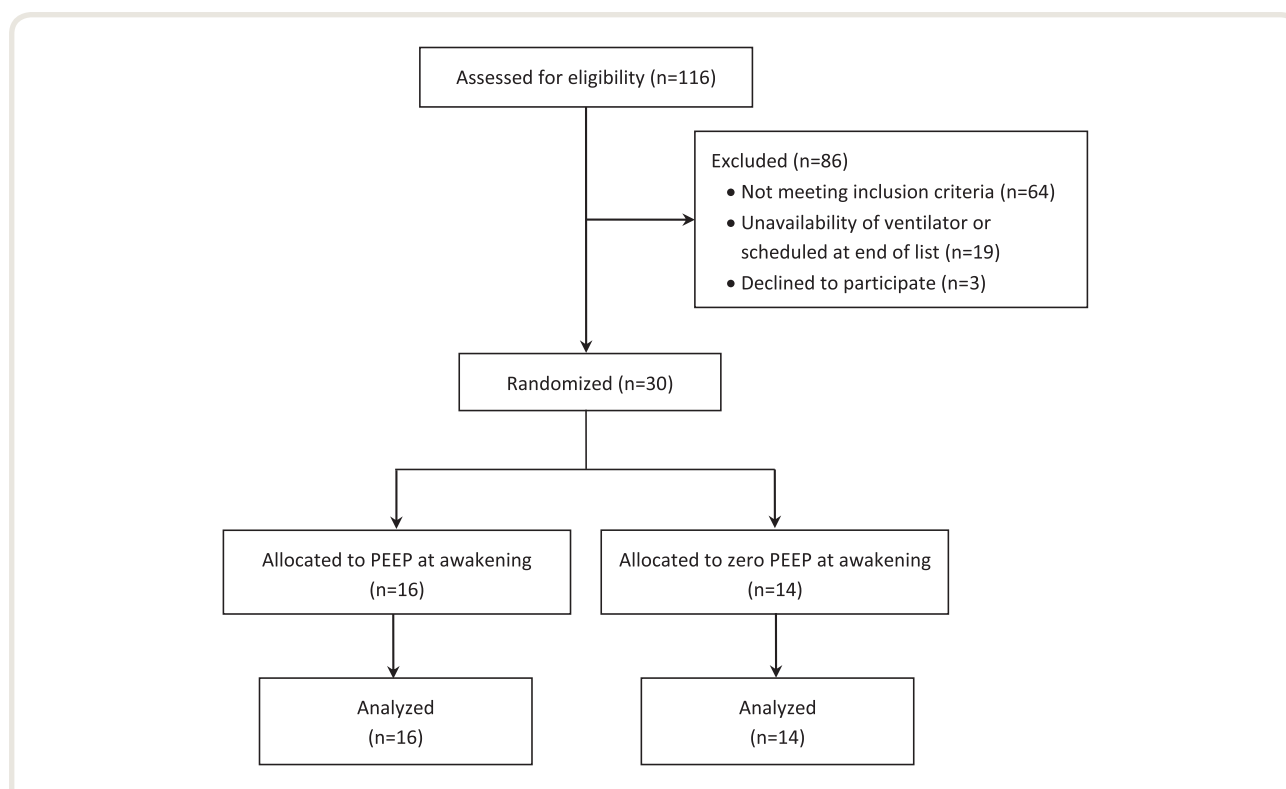

Fig. 1. Consolidated Standards of Reporting Trials diagram of the study. Of the excluded patients, 19 were for logistic reasons. The authors had only one portable ventilator and could therefore only study one patient at a time. In addition, patients scheduled at the end of the operation list were not included, as study participation would risk their discharge on time from the day-case unit. PEEP, positive end-expiratory pressure.

Table 1. Demographic, Ventilatory, and Time Data

	PEEP Group (n = 16)	Zero PEEP Group (n = 14)
Male/female, n	16/0	13/1
Age, yr	57 (41 to 73)	61 (48 to 75)
BMI, kg/m²	26.4 (21.2 to 29.3)	24.6 (18.9 to 29.0)
ASA physical status, I/II	10/6	9/5
Type of surgery, n		
Inguinal hernia	13	12
Umbilical hernia	3	1
Orthopedic upper extremity	0	1
Tidal volume, ml	480 (440 to 580)	520 (410 to 550)
Tidal volume, ml/kg IBW	7.0 (7.0 to 7.1)	7.0 (6.9 to 7.1)
PEEP during surgery		
7 cm H_2O, n	5	9
9 cm H_2O, n	11	5
PIP, cm H_2O	16 (12 to 19)	15 (13 to 18)
Duration of surgery, min	56 (21 to 86)	59 (34 to 112)
Time at first CT, min	106 (63 to 133)	106 (80 to 164)
Time at extubation, min	129 (87 to 169)	128 (100 to 190)
Duration of emergence preoxygenation, min	16 (10 to 29)	14 (8 to 20)
Time from extubation to second CT, min	29 (23 to 40)	32 (25 to 40)
Time from extubation to postoperative blood gas sampling, min	37 (19 to 46)	40 (17 to 42)

The values are numbers or the median (range).

ASA, American Society of Anesthesiologists; BMI, body mass index; CT, computed tomography; IBW, ideal body weight; PEEP, positive end-expiratory pressure; PIP, peak inspiratory pressure.

atelectasis in the zero PEEP group, although not statistically significant, prompted a *post hoc* sensitivity analysis that confirmed that there was no statistically significant difference in the primary outcome measure between the two groups, either with or without adjustment for baseline atelectasis areas. For the two groups combined, the median increase in atelectasis area was 2.1 cm² (95% CI, 1.2 to 2.9 cm²).

The postoperative atelectasis area was a median (range) of 5.2 (2.4 to 14.3) cm² in the PEEP group and 4.9 (3.0 to 12.7) cm² in the zero PEEP group; the difference was 0.3 cm² (95% CI, −1.5 to 2.0 cm²; *P* = 0.854; fig. 2). For all patients in the study, the median postoperative atelectasis area was 5.2 cm² (95% CI, 4.3 to 5.7 cm²), corresponding to a median of 2.5% (95% CI, 2.0 to 3.0%) of total lung area. The contribution from the awakening procedure to the total amount of postoperative atelectasis was median 39% (95% CI, 29 to 56%) for all study subjects. Two patients in each group deviated by having an increase in atelectasis area of 7 cm² or more. These four patients were also in the high range regarding postoperative atelectasis size. The measurements of areas with different aeration, before and after awakening, are displayed in table 2.

A mild decrease in oxygenation was observed in both the groups when calculating the change in oxygenation from before awakening to approximately 40 min after extubation.

The difference between the groups was not statistically significant (table 2). Postoperative oxygenation was unchanged in both groups when compared to oxygenation in the preoperative awake state.

Discussion

This study showed that in most healthy patients undergoing nonabdominal day-case surgery, despite using F_{IO_2} 1.0 during emergence, postoperative atelectasis is small and has no effect on oxygenation. We also demonstrated that withdrawing PEEP before emergence preoxygenation to avoid entrance of high oxygen concentration in susceptible lung units does not affect postoperative atelectasis formation in this type of patients.

Several factors associated with emergence from anesthesia may have contributed to our results. In contrast to the induction of anesthesia, where it is well known that end-expiratory lung volume decreases,[18] during and after emergence from anesthesia, it will gradually increase and be restored.[10] This process is likely faster in a normal-weight population undergoing nonabdominal surgery, such as in this study. Moreover, the concept of day-case surgery often features short-acting anesthetics, adequate pain control, and avoidance of long-lasting opioids and neuromuscular blocking agents. These factors all help the patient in restoring the end-expiratory lung volume soon after anesthesia. On the other hand, if more pronounced airway closure were present in the early postoperative phase, as after open abdominal surgery,[10] we may have observed larger atelectasis and possibly even more so in the group with maintained PEEP. Furthermore, the patients in this study were subjected to moderate PEEP levels. With higher PEEP levels, any negative effects of a maintained PEEP during emergence preoxygenation may be aggravated.

In addition to testing our hypothesis regarding PEEP during awakening, the study protocol enabled us to quantify the contribution from standard emergence procedure to the total amount of postoperative atelectasis. Although a 39% contribution might seem substantial, most patients started from very small atelectasis, and the total postoperative atelectasis area was thus limited, with median 2.5% of total lung area for the groups combined.

The only statistically significant differences observed between the two study groups were that the zero PEEP group exhibited a smaller median increase in poor aeration and a larger median area of lung tissue defined as over aeration postoperatively (table 2). This could possibly indicate more aerated lung tissue in the zero PEEP group and that the physiologic reasoning behind the study hypothesis is plausible. However, the analysis of areas with different aeration was a *post hoc* analysis, and we therefore suggest that these results should be interpreted with caution.

Two recent studies investigated the magnitude of postoperative atelectasis with computed tomography in patients similarly ventilated with a moderate PEEP intraoperatively.[12,13] In those studies, the nonsmoking study subjects
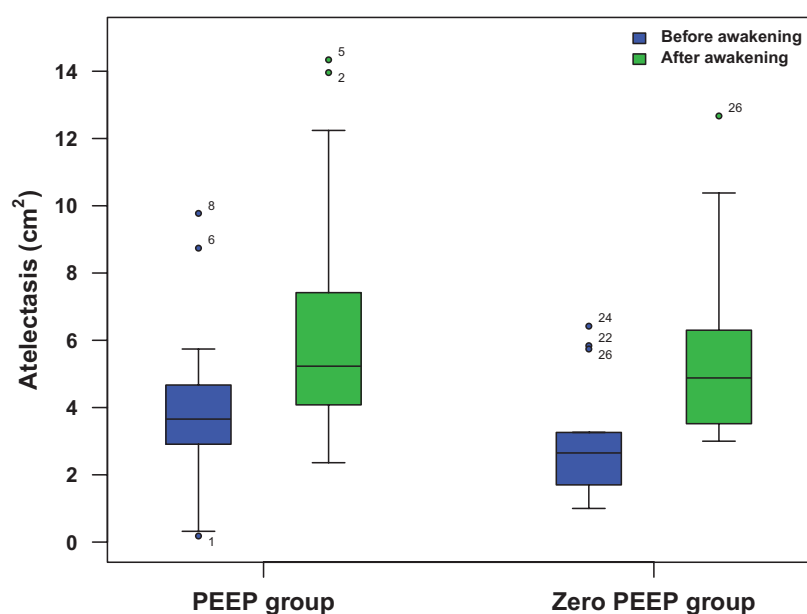
Fig. 2. Areas of atelectasis expressed as cm² before and after awakening, in the positive end-expiratory pressure (PEEP) group and the zero PEEP group. The first scan was done at the end of surgery still under anesthesia and mechanical ventilation with PEEP in both groups. The second scan was done at awake state, approximately 30 min after extubation. Computed tomography scans were performed at end expiration 5 mm above the right diaphragm dome. The data are presented as the median, interquartile range (*boxes*), and range (*whiskers*), except for observations that were considered outliers (indicated by individual study subject numbers in the two groups, respectively). $P = 0.120$ for the difference between groups in atelectasis before awakening. $P = 0.400$ for the difference between groups in change in atelectasis from before to after awakening. $P = 0.854$ for the difference between groups in postoperative atelectasis.

Table 2. Aeration and Oxygenation Data

	PEEP Group (n = 16)	Zero PEEP Group (n = 14)	*P* Value
Poor aeration, cm²			
Before awakening	19.4 (11.4 to 36.5)	18.7 (10.7 to 29.2)	0.400
After awakening	32.1 (17.1 to 52.0)	26.1 (12.3 to 40.5)	0.093
Change	9.6 (−1.2 to 20.7)	5.9 (−1.1 to 14.7)	0.047
Normal aeration, cm²			
Before awakening	175 (139 to 226)	174 (109 to 226)	0.984
After awakening	149 (110 to 213)	165 (106 to 207)	0.448
Change	−16.8 (−87.6 to 18.3)	−16.7 (−37.2 to 44.2)	0.552
Over aeration, cm²			
Before awakening	36.4 (10.3 to 81.3)	39.1 (21.6 to 70.4)	0.608
After awakening	7.3 (1.1 to 33.3)	13.5 (5.5 to 24.0)	0.015
Change	−22.6 (−66.9 to −7.7)	−21.7 (−53.2 to −13.7)	0.854
Pa_{O_2}/F_{IO_2} ratio, awake, mmHg	418 (337 to 482)	415 (328 to 550)	0.951
Pa_{O_2}/F_{IO_2} ratio, mmHg			
End of surgery	466 (364 to 561)	504 (317 to 581)	0.377
Postoperative	423 (308 to 561)	418 (349 to 582)	0.854
Change	−33 (−129 to 134)	−39 (−132 to 75)	0.552

The values are noted as the median (range). Computed tomography scans were performed at end expiration, 5 mm above the right diaphragm dome. The scans before awakening were obtained during anesthesia and ventilation with positive end-expiratory pressure in both groups. The scans after awakening were obtained approximately 30 min after extubation. Arterial blood gases for the ratio of arterial oxygen partial pressure to inspired oxygen fraction (Pa_{O_2}/F_{IO_2}), awake, were taken before anesthesia induction with the study subjects breathing room air. Arterial blood gases for the Pa_{O_2}/F_{IO_2} ratio, end of surgery, were taken during anesthesia with F_{IO_2} 0.35. Arterial blood gases for the Pa_{O_2}/F_{IO_2} ratio, postoperative, were taken approximately 40 min after extubation with the study subjects breathing room air. The change in Pa_{O_2}/F_{IO_2} is the median change in oxygenation between the blood gas at the end of surgery and the postoperative blood gas.

PEEP, positive end-expiratory pressure.

exhibited comparable amounts of atelectasis as in the present study, regardless of F_{IO_2} or continuous positive airway pressure used during and just after emergence. These earlier results are in accordance with the present findings that the emergence procedure seems to have limited importance in healthy patients undergoing this type of surgery.

In another study, also on patients undergoing nonabdominal surgery, emergence with F_{IO_2} 1.0 resulted in larger postoperative atelectasis areas of mean 8.3%.[11] However, contrary to our study, the patients did not receive PEEP during intraoperative mechanical ventilation, possibly resulting in larger atelectasis being present already before awakening. In the same study, an intervention group receiving both a vital-capacity maneuver and F_{IO_2} 0.4 during emergence exhibited similar small postoperative atelectasis areas as in our study. Unfortunately, small study groups of 10 patients, with only mean values reported and no information on smoking habits, make a detailed comparison with our study difficult. Still, we believe that using PEEP intraoperatively and F_{IO_2} 1.0 during emergence is safer and less time-consuming than a vital-capacity maneuver followed by F_{IO_2} 0.4 during emergence.

Our group recently showed that a moderate PEEP without recruitment maneuvers is sufficient to achieve a virtually open lung at the end of surgery in this type of patients.[5] The current data confirm these findings, with a median atelectasis area of only 1.3% of the total lung area just before emergence. Moreover, it indicates that if awakening starts with an open lung, emergence preoxygenation with F_{IO_2} 1.0 and PEEP is well tolerated, even without vital-capacity maneuvers or continuous positive airway pressure postoperatively.

Overall, in addition to the present study, a variety of interventions have been tested to decrease postoperative atelectasis formation in this patient group. It seems, however, difficult to achieve less atelectasis than what corresponds to 2.5% of total lung area in a basal computed tomography slice. These atelectases look small (fig. 3), and their impact on pulmonary function seem negligible, since our data show that oxygenation is unaffected. We believe that the findings in this study may well be interesting for clinicians handling the large group of healthy patients undergoing nonabdominal surgery: if a moderate PEEP is used during surgery and maintained during awakening, atelectasis is small both before and after awakening, despite using F_{IO_2} 1.0 for a maximum oxygen reserve at extubation.

Study Limitations

The Hamilton T1 ventilator lacks a pure volume-controlled mode. The ventilation mode that was used in this study is very similar but automatically adjusts the peak inspiratory pressure to the lowest level possible while still maintaining the target tidal volume. Although the set PEEP level is maintained at all times, occasionally, this mode can deliver slightly higher or lower tidal volumes. We believe it is unlikely to have influenced the results of the study, because the patients in both groups were ventilated with the same ventilator.
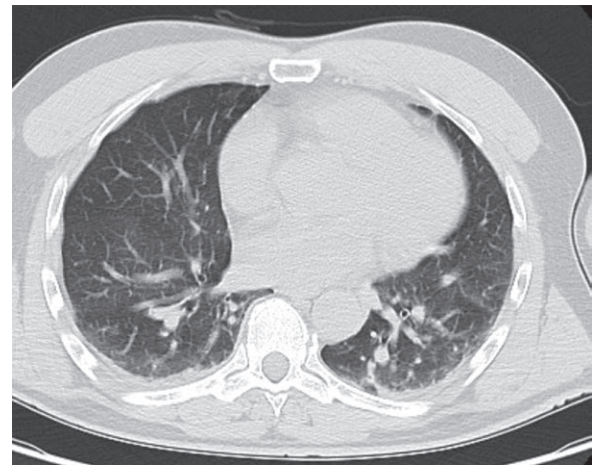

Fig. 3. Example of a postoperative computed tomography scan. The area of atelectasis in this patient, 4.6 cm^2 (2.5% of total lung area), corresponds to the median area of postoperative atelectasis in all participating subjects. Computed tomography scan was performed at end expiration, 5 mm above the right diaphragm dome approximately 30 min after extubation.

This was an explanatory study aimed at securing a better understanding of the mechanisms underlying the formation of postoperative atelectasis. The study required two computed tomography scans. Still, the local Radiation Safety Committee deemed the health risks for the study participants as very small, because radiation exposure was kept to a minimum by restricting each scanning to only one slice. A healthy study population undergoing day-case surgery was chosen to have minimal interference from other potential factors on pulmonary physiology than anesthesia itself. Thus, the results cannot be extrapolated to major abdominal surgery and/or patients with higher risks of pulmonary complications. A relevant next step is to investigate the hypothesis under such circumstances. Moreover, although most patients exhibited limited postoperative atelectasis, in analogy with previous studies, a few outliers displaying larger atelectasis were identified in each group (fig. 2). Except for one patient with aggravated coughing before extubation,[19] demographic, ventilatory, or time data did not reveal any apparent explanation for these extremes. In the absence of obvious reasons, our current understanding is limited as to why some patients seem more prone to developing atelectasis. With increased understanding of explanatory factors, patients at risk should ideally be identified before anesthesia to assure an individualized ventilatory strategy, comprising PEEP and possibly both recruitment maneuvers and continuous positive airway pressure, to minimize their risk of developing postoperative atelectasis and pulmonary complications.[2,14,20,21]

Conclusions

In most healthy day-case surgery patients, postoperative atelectasis formation is limited without affecting oxygenation.

A moderate PEEP during intraoperative ventilation ensures an open lung at the end of surgery. We recommend maintaining PEEP during subsequent emergence preoxygenation using F_{IO_2} 1.0 for maximum safety margins.

Acknowledgments

Research Support

Competing Interests

Reproducible Science

Full protocol available at: erland.ostberg@regionvastmanland.se. Raw data available at: erland.ostberg@regionvastmanland.se.

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ANESTHESIOLOGY REFLECTIONS FROM THE WOOD LIBRARY-MUSEUM

From Piles of Fortune to Piles of Wood: Bangor's William E. Mann and "Ko-Kane"

Advocating topical anesthetic use of cocaine, the W. E. Mann City Drug Store of Bangor, Maine, advertised its proprietary "KO-KANE" as curing "instantly…all local pains, headache, toothache, neuralgia, etc., by merely applying to the spot that aches." After he relinquished full control of his drugstore in 1884, the year that Koller discovered cocaine anesthesia, William Edward "Doctor" Mann (1841 to 1926) turned his attention from "instant relief for itching piles" to generating piles of wood. He successfully patented a "reciprocating gang saw mill" for expanding his father-in-law's lumber business. Three decades after following his only child, a banker, to Boston, "Doctor" suffered a "long and painful illness"—apparently unrelieved by his namesake company's "KO-KANE." (Copyright © the American Society of Anesthesiologists' Wood Library-Museum of Anesthesiology.)

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