Randomized Controlled Trial

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Positive Expiratory Pressure Therapy on Oxygen Saturation and Ventilation After Abdominal Surgery

A Randomized Controlled Trial

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Objective: To evaluate the immediate effects of positive expiratory pressure therapy on oxygen saturation and ventilation after abdominal surgery.

Background: Positive expiratory pressure therapy to treat postoperative hypoxia is widespread, despite a lack of evidence of effect.

Methods: This randomized, sham-controlled, crossover trial investigated adults 1–2 days after abdominal surgery at Umeå University Hospital, Sweden. The intervention was positive expiratory pressure of 10–15 cm H_2O. The control was a sham device. The investigations were ended with deep-breathing maneuvers. Outcomes were the gradient of changes in peripheral oxygen saturation and transcutaneous carbon-dioxide partial pressure ($PtcCO_2$).

Results: Eighty patients were included and randomized and 76 patients were analyzed. Oxygen saturation increased from a baseline mean of 92% to 95%, $P < 0.001$, during positive expiratory pressure breathing, while PtcCO2 decreased from a mean of 36 to 33 mm Hg, $P < 0.001$. This was followed by apnea, oxygen desaturations to a mean of 89%, $P < 0.001$, and increased $PtcCO_2$ before returning to baseline values. The changes in oxygen saturation and $PtcCO_2$ did not differ from sham breathing or deep-breathing maneuvers.

Conclusions: Positive expiratory pressure breathing after abdominal surgery improves oxygen saturation during the maneuver because of hyperventilation, but it is followed by apnea, hypoventilation, and oxygen desaturation. The effect is not different from the expiration to a sham device or hyperventilation. It is time to stop positive expiratory pressure therapy after abdominal surgery, as there is no evidence of effect in previous trials, apart from the adverse effects reported here.

INTRODUCTION

Globally, some 313 million operations are performed each year, complications occur in about 25% and 0.5%–5% of patients die after major surgery.[1,2] Postoperative hypoxia is the most common complication after abdominal surgery, and it is life-threatening when oxygen partial pressure falls below 60 mm Hg, corresponding to oxygen saturation below 90%.[3–5] One-hour episodes of oxygen saturation below 90% were found in 37% of patients after surgery, but these episodes were generally missed in clinical practice.[6] Recently, it was reported that patients with one or more postoperative pulmonary complications run an increased risk of early postoperative mortality, and the most common pulmonary complication was a need for prolonged oxygen therapy via a nasal cannula.[7] The risk factors for postoperative respiratory insufficiency include chronic hypoxia, chronic pulmonary disease, acute respiratory infection, upper abdominal surgery, emergency surgery, and surgery for over 2 hours.[3,8,9]

It is suggested that positive expiratory pressure breathing increases lung volume and prevents postoperative atelectasis and hypoxia.[10–12] Positive expiratory breathing devices are passive and require from the patient a forced exhalation against a resistance of 10–15 cm H_2O. It was introduced in 1918, using wind instruments to prevent pulmonary complications after thoracic surgery, and led to the development of blowing into surgical gloves, water bottles or fixed pressure valves, and incentive spirometry.[10,11,13] Incentive spirometry is commonly used in the United States and positive expiratory pressure valves in other countries. Patients are encouraged to take 3 sets of 10 breaths and expire into a passive pressure device every waking hour after waking up from abdominal surgery until discharge or full mobilization.[14]

We hypothesized that passive pressure valves are unable to improve lung expansion and oxygen saturation. Previous trials report no effect of positive expiratory pressure therapy on hypoxia and postoperative pulmonary complications.[11,15] The treatment is, however, still used worldwide because of a strong belief that it improves lung expansion and oxygen saturation. A lack of improvement in oxygen saturation during therapy would explain the lack of effect on hypoxia and postoperative

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pulmonary complications in previous trials. No previous study continuously measuring oxygen saturation and carbon-dioxide partial pressure during positive expiratory pressure therapy was found.

The present aims were to investigate the immediate effects of positive expiratory pressure breathing versus sham breathing after abdominal surgery on oxygen saturation and ventilation measured as changes in carbon-dioxide partial pressure. Another objective was to compare the effects of positive expiratory pressure breathing with deep-breathing maneuvers.

METHODS

The study was approved by the Regional Ethics Committee at Umeå University, Sweden (Dnr 2017-490-32M, 217-195-31M). It was conducted in accordance with the Declaration of Helsinki and all the participants gave their written informed consent. The study was registered at Clinicaltrials.gov NTC 03176589 with Karl Franklin as the principal investigator.

Trial Design and Patients

This was a randomized, sham-controlled, crossover trial on postoperative day 1 or 2 after abdominal surgery. Inclusion criteria were adult patients, aged 18 years or older who had undergone abdominal surgery at the Departments of Surgery, Urology, or Gynecology at Umeå University Hospital in Sweden. Exclusion criteria were the inability of using positive expiratory pressure therapy or not agreeing to participate in the trial.

Randomization and Masking

Participants were allocated a unique sequential number after signing the consent sheet. They were randomized in four blocks of 20 patients using a computer-generated random allocation list from http://www.randomization.com to start with either positive expiratory pressure breathing followed sham breathing, or to start with a sham breathing followed by positive expiratory pressure breathing. All patients performed deep breathing maneuvers at the end of the trial. Patients were breathing room air only, and without supplemental oxygen during the trial. The patients were told that we were aiming to test different methods of improving respiration after surgery. Neither the patients nor the investigator who performed the study were blinded. The outcome data were continuously stored in a computer during the investigations. The randomization was blinded during the analysis.

Intervention

The positive expiratory pressure device comprised either a device with fixed resistance of 10 or 15 cm H_2O (Wellspect Healthcare A/S, Mölndal, Sweden) or a 2-L plastic bottle filled with 10–15 cm of water and a 40-cm plastic tube with a 2 cm diameter for the underwater exhalation. A physical therapist or a trained nurse arranged the positive expiratory pressure device and educated the patients on its use. All the patients were instructed to inhale and then expire into the device in three sets of 10 breaths sitting in an upright position, huffing between sets to mobilize secretions, in accordance with the Swedish Care Manual.[14]

Control

The sham device was a plastic cylinder with an inner diameter of 2 cm and a length of 6 cm. The instructions to the patients were the same as during positive expiratory breathing, that is, to inhale and then expire into the sham device in three sets of 10 breaths, huffing between sets.

Deep Breathing

All the experiments ended with a deep-breathing maneuver, with the instruction to inhale deeply and then to exhale without any device in three sets of 10 breaths, huffing between sets.

Primary Outcomes

The primary outcomes were the gradient of changes in peripheral oxygen saturation and transcutaneous carbon-dioxide partial pressure levels during and after the interventions.

Arterial oxygen saturation was measured continuously using finger pulse oximetry (Nonin 3150 WristOx2 Model 3150 with Bluetooth, Nonin Medical Inc., MN).

Carbon-dioxide partial pressure was measured continuously using a transcutaneous capnometer attached beneath the clavicle (SenTec V-Sign System, Therwil BL, Switzerland).[16–19]

Secondary Outcomes

Secondary outcomes included peak expiratory flow and a numerical rating scale (NRS) for pain. Peak expiratory flow (PEF Mini-Wright, Clement-Clarke, Essex, United Kingdom) was recorded as the largest volume of three measurements before and after the study measurements. The participants rated pain on a numerical rating scale from 0 (no pain) to 10 (worst pain imaginable) before each intervention.

Procedures

Continuous monitoring was recorded using a Nox T3 recorder (Nox Medical, Reykjavik, Iceland). It included a nasal flow pressure sensor (Nox cannula with filter), a respiratory effort belt around the thorax and abdomen (XactTrace belt, Kanata, Canada), finger pulse oximetry (Nonin 3150 WristOx2 Model 3150 with Bluetooth, Nonin Medical Inc.) and a transcutaneous capnometer attached beneath the clavicle (SenTec V-Sign System, Therwil BL, Switzerland).[16–19] Any supplementary oxygen was ceased 30 minutes before the trial. The automatic calibration of the transcutaneous capnometer was performed at study start in every patient, with the sensor stored in the calibration chamber. Thirty minutes elapsed to allow for calibration of the capnometer and to establish a stable baseline over 5 minutes.

The participants performed the first interventions according to randomization, in 3 sets of 10 breaths. This was followed by a 15-minute wash-out period before the second intervention and another 15-minute wash-out period before the deep-breathing maneuvers. All the data were sampled and stored in the Nox T3 recorder. Apneas were scored according to the American Academy of Sleep Medicine guidelines.[20] A central apnea was defined as a reduction in airflow of at least 90% of the pre-event baseline for at least 10 seconds, without any inspiratory effort during apnea.

Statistical Analysis

It was estimated that 34 patients were needed to detect a mean ± SD difference in peripheral oxygen saturation of 1% ± 2% and to detect a difference in transcutaneous carbon-dioxide partial pressure of 4 ± 8 mm Hg with a significance of <0.05 and a power of 80%.

Summary measurements are represented as the mean and ±SD or as the median and interquartile range. Baseline values were calculated as the mean and 95% confidence interval of the mean values in each patient for 5 minutes before and

after each intervention. A mean and 95% confidence interval was calculated from the maximum and minimum of peripheral oxygen saturation and transcutaneous carbon-dioxide partial pressure recorded during each intervention. The t-test was used for paired samples to compare means within subjects, while the t-test for independent samples was used to compare when splitting the participants along intervention started with or the type of spirometer used. The mean differences are presented with 95% confidence intervals. Correlations were calculated using the Pearson correlation and were given as r values with two-tailed significance. Analyses were performed using SPSS (SPSS Statistics for Windows, Version 25.0.; IBM Corp., Armonk, NY).

RESULTS

Eighty patients were included and randomized to start with either positive expiratory breathing or sham breathing from

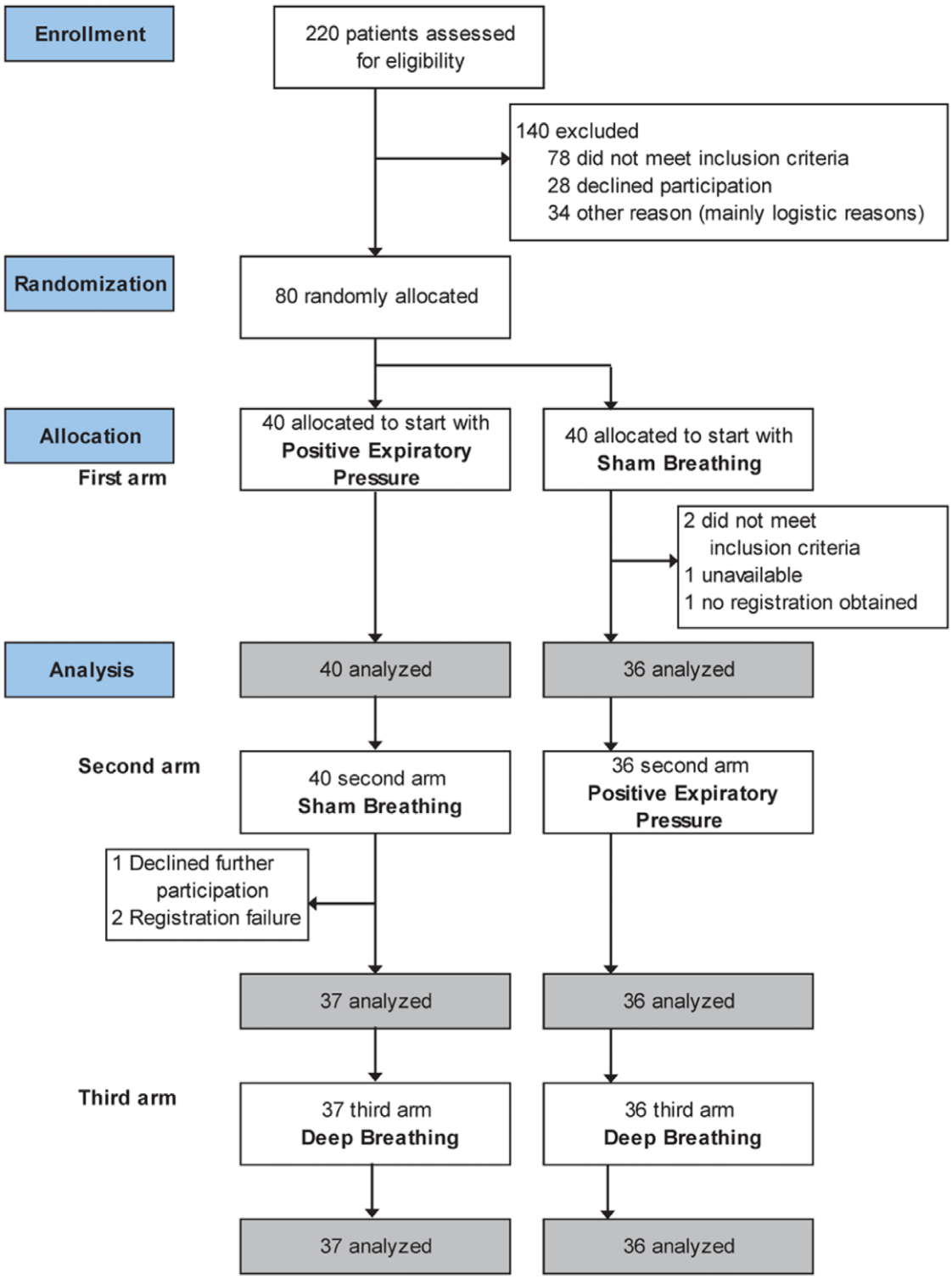

FIGURE 1. Consolidated Standards of Reporting Trials (CONSORT) flow diagram.

TABLE 1.

Baseline Characteristics

Age, years, mean ± SD	65.9 ± 14.1
Body mass index, kg/m^2, mean ± SD	27.2 ± 5.7
Operation time, hours, mean ± SD	3.8 ± 2.0
Women/men, n	45/33
Open/minimally invasive surgery, n	63/15
Elective/emergency surgery, n	56/22
Current smoking, n (%)	5 (6)
Pulmonary disease, n (%)	8 (10)
Colorectal surgery, n (%)	36 (46)
Upper gastrointestinal surgery, n (%)	29 (37)
Gynaecological surgery, n (%)	8 (10)
Urological surgery, n (%)	5 (6)

June 12 to August 25, 2017, and June 19 to October 5, 2018. Three patients were excluded from the trial, as it appeared that 2 patients did not meet the inclusion criteria and 1 patient was unavailable due to an emergent medical examination.

The recordings failed completely in 1 patient. One patient declined further participation after positive expiratory pressure registration and recordings failed in 2 patients during sham breathing in the second arm. Seventy-six patients were analyzed during positive expiratory breathing, 73 during sham breathing, and 73 during deep-breathing maneuvers (Fig. 1). The baseline characteristics are given in Table 1.

Primary Outcomes

At baseline, the peripheral oxygen saturation was 92% (95% confidence interval, 91%–93%), the transcutaneous carbon-dioxide partial pressure was 36 mm Hg (95% confidence interval, 35–38 mm Hg) and the respiratory rate was 18 breaths/min (95% confidence interval, 17–19 breaths/min). The baseline values for peripheral oxygen saturation, transcutaneous carbon-dioxide partial pressure and respiratory rate did not differ with regard to allocation before each intervention.

The treatment time for positive expiratory pressure therapy with 3 sets of 10 breaths lasted a mean of 3.46 minutes (95% confidence interval, 3.00–3.92 minutes). During positive expiratory pressure breathing, the mean peripheral oxygen saturation increased from baseline values to a maximum of 95% (95% confidence interval, 94%–95%, $P < 0.001$) at the end of the maneuver, followed by a rapid decrease to a minimum of 89% (95% confidence interval, 89%–90%, $P < 0.001$) compared with baseline at 1.6 minutes (95% confidence interval, 1.3–1.8 minutes) after termination of the maneuver. The peripheral oxygen saturation returned to baseline values within a minute (Fig. 2). The transcutaneous carbon-dioxide partial pressure was continuously reduced after the onset of positive expiratory breathing to a minimum of 33 mm Hg (95% confidence interval, 32–34 mm Hg, $P < 0.001$) at 30 seconds after the maneuver and it then increased continuously to baseline values (Fig. 3). Central apneas or hypopneas were recorded in 40 of 75 patients and reduced respiratory rate was recorded in another 20 patients immediately after the positive expiratory pressure breathing and before the oxygen desaturations (Fig. 4).

Sham-breathing maneuvers resulted in a similar pattern of changes in peripheral oxygen saturation and transcutaneous carbon-dioxide partial pressure with positive expiratory breathing (Figs. 2 and 3). The peripheral oxygen saturation increased slightly more from baseline during sham breathing versus positive expiratory pressure breathing, with a mean difference of 0.6% (95% confidence interval, 0.1%–1.1%, $P = 0.012$). Compared with baseline, there were no differences in the change between sham breathing and positive expiratory pressure breathing in minimum peripheral oxygen saturation, mean difference –1.0% (95% confidence interval, –2.0% to 0.1%, $P = 0.08$), and minimum transcutaneous carbon-dioxide partial pressure, difference –1 mm Hg (95% confidence interval, –2 to 0.2 kPa, $P = 0.11$).

Deep-breathing maneuvers also resulted in peripheral oxygen saturation and transcutaneous carbon-dioxide partial pressure similar with positive expiratory pressure breathing (Figs. 2 and 3). There were no differences in the change from baseline between deep breathing and positive expiratory breathing in maximum peripheral oxygen saturation, mean difference of 0.2% (95% confidence interval, –0.3% to 0.7%, $P = 0.44$), in minimum mean difference peripheral oxygen saturation of

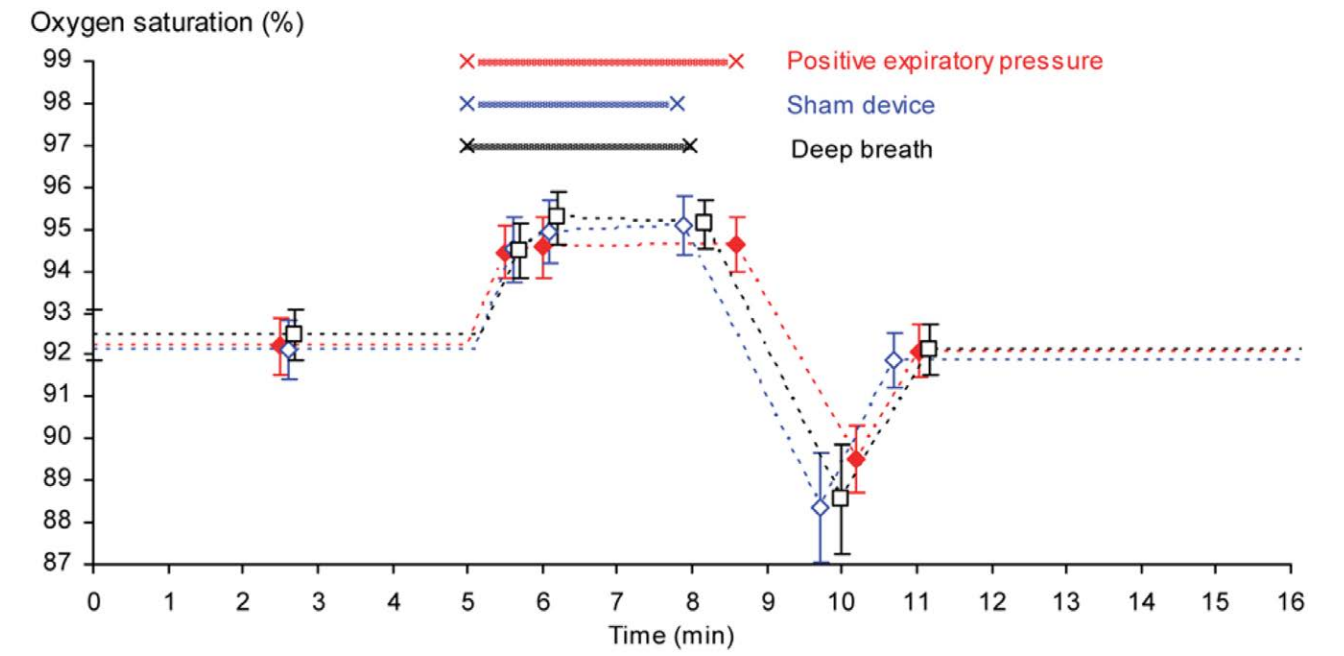

FIGURE 2. Oxygen saturation. Peripheral oxygen saturation during positive expiratory pressure therapy (red), during breathing into a sham device (blue), and during deep-breathing maneuvers (black).

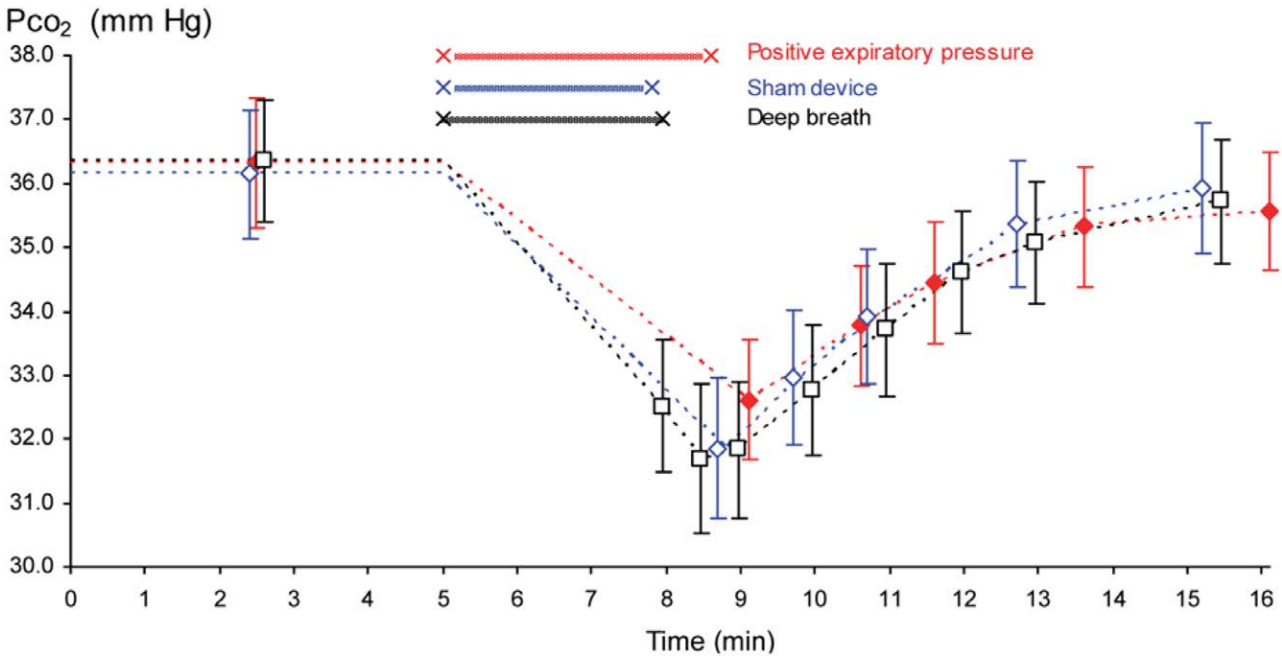

FIGURE 3. Transcutaneous carbon-dioxide partial pressure. Effect on transcutaneous carbon-dioxide partial pressure (PCO_2) during positive expiratory pressure therapy (red), during breathing into a sham device (blue), and during deep-breathing maneuvers (black).

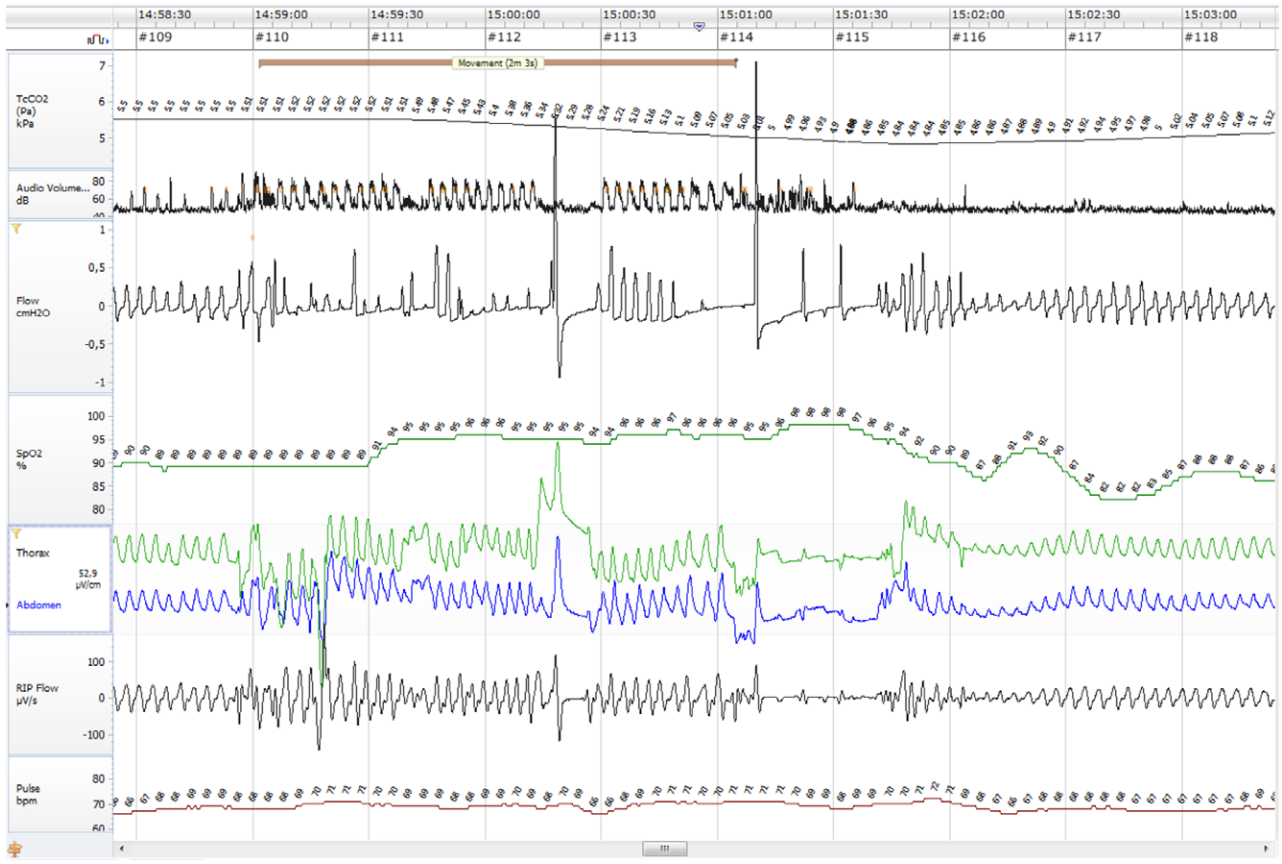

FIGURE 4. Five-minute recording during positive expiratory pressure therapy. A 76-year-old woman was investigated on postoperative day 1 after a robot-assisted anterior rectal resection. The recordings from top to bottom: timeline of positive expiratory pressure breathing, transcutaneous carbon-dioxide partial pressure, microphone, nasal airflow, peripheral oxygen saturation, thoracic respiratory movements, abdominal respiratory movements, rib flow, and heart rate.

–1.1% (95% confidence interval, –2.3% to 0.1%, $P = 0.07$) and in minimum transcutaneous carbon-dioxide partial pressure, mean difference of 0.0 mm Hg (95% confidence interval, –1 to 1 mm Hg, $P = 0.41$).

Additional Secondary Outcomes

The peak mean expiratory flow was 236 mL (95% confidence interval, 211–260 mL) at baseline and 227 mL (95% confidence interval, 204–251 mL, $P = 0.14$) after the experiments. The mean numerical rating scale for pain was 3.1 (95% confidence interval, 2.7–3.6) before and 3.1 (95% confidence interval, 2.7–3.5, $P = 0.82$) after the experiment. There was no correlation with the pain score and peripheral oxygen saturation.

DISCUSSION

There are 2 novel findings in this randomized controlled trial. First, the effect of exhaling into a passive pressure valve on oxygen saturation and carbon-dioxide partial pressure did not differ from exhaling into a sham device. Second, the breathing maneuver during positive expiratory pressure induced hyperventilation with increased oxygen saturation, followed by hypoventilation, central apnea, and oxygen desaturation, before returning to baseline values, with no lasting effects. The patients included in this study were slightly hypoxic at baseline and had a subnormal/slightly low transcutaneous carbon-dioxide partial pressure at baseline, indicating that they were hyperventilating even before the trial. The present results with hyperventilation followed by central apnea and hypoxia with no lasting effects on oxygen saturation challenge the use of positive expiratory pressure therapy, especially in people with chronic pulmonary diseases and people suffering from chronic hypoxia who run the risk of developing respiratory insufficiency after abdominal surgery.[3,8,9]

Positive expiratory pressure therapy was introduced and spread worldwide to reduce postoperative pulmonary complications after abdominal and thoracic surgery. Patients are encouraged to take a deep inspiration and exhale to a passive pressure valve. Instead of expiring to a pressure valve, Bartlett et al[10] in 1973 introduced incentive spirometry with visual feedback of the inspiratory flow or volume to increase lung inflation by long and deep breaths. However, both methods involve a risk for hyperventilation.[10]

PubMed was searched for randomized controlled trials and systematic reviews up to July 31, 2021, on the effects of positive expiratory pressure and incentive spirometry on respiratory insufficiency, hypoxia, atelectasis, lung function, or postoperative pulmonary complications after abdominal surgery. Single trials during the 1990s reported that positive expiratory pressure therapy was superior to deep breathing on lung volumes after upper abdominal surgery,[21] reduced the frequency of postoperative pulmonary complications after bariatric surgery,[22] and major abdominal surgery.[23] However, systematic reviews including Cochrane reviews consistently report the lack of effectiveness of positive expiratory pressure therapy and incentive spirometry after cardiac, thoracic, and abdominal surgeries.[11,13,24–27]

Positive expiratory breathing in different forms is currently used worldwide, despite a lack of evidence of its effect on hypoxia, lung function, atelectasis, or postoperative pulmonary complications. No previous study continuously measuring oxygen saturation and carbon-dioxide partial pressure during positive expiratory pressure therapy was found. This explains why the present observation of episodes of apnea and hypoxia after positive expiratory pressure therapy has not been reported.

There is a general misconception that passive valves used during positive expiratory pressure have the ability to expand the lungs, reduce atelectasis and thus improve oxygen saturation. A passive expiratory valve used during positive expiratory breathing is unable to expand the lungs, in contrast to an external airflow creating a positive end-expiratory pressure (PEEP) during mechanical ventilation or continuous positive airway pressure (CPAP) therapy. The external airflow will expand the lungs during the entire breathing cycle, from the start of inspiration to the end of expiration. CPAP and PEEP therefore have the potential to reduce atelectasis and improve oxygen saturation after surgery.[28] Positive expiratory breathing, on the other hand, consists of a passive valve without airflow. To overcome the resistance of a valve, expiratory muscles have to be used, which, by their very nature, compress the lung volume. Positive expiratory breathing is therefore unable to improve lung expansion, both during inspiration and during expiration, and the pressure at end-expiration will be zero. This is supported by the present results with no difference in oxygen saturation and carbon-dioxide partial pressure between positive expiratory pressure therapy and a sham device. Positive expiratory pressure therapy is a short-term treatment used for 3 times 10 breathing cycles an hour or about 3.5 minutes an hour. CPAP, on the other hand, can be used for hours and during the entire night.[28] In future research, we suggest focusing on the effect of CPAP or noninvasive ventilation to improve lung expansion and oxygen saturation after surgery rather than on positive expiratory pressure therapy.

One limitation of the present study is that carbon-dioxide partial pressure was measured using a transcutaneous capnometer and not by arterial gas samples. The transcutaneous capnometer is, however, a better option for measuring rapid changes in carbon-dioxide partial pressure and absolute values are reported to be about ±3 mm Hg when compared with arterial gas samples.[16–19]

In conclusion, positive expiratory pressure breathing after abdominal surgery improves oxygen saturation during the maneuver because of hyperventilation, but it is followed by apnea, hypoventilation, and oxygen desaturation. The effect is not different from the expiration to a sham device or hyperventilation. It is time to stop positive expiratory pressure therapy after abdominal surgery, as there is no evidence of effect in previous trials, apart from the adverse effects reported here.

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