J Surg Med. 2021;5(9):964-968.
DOI: 10.28982/josam.1001166

Journal of Surgery and Medicine
e-ISSN=2602-2079

The effect of recruitment maneuver on the development of expansion defect and atelectasis after lobectomy: A double-blind randomized controlled trial

Kadir İdin

Intensive Care Unit, Anesthesiology Department, School of Medicine, Istanbul Medipol University, Istanbul, Turkey

ORCID ID of the author(s)
Kİ: 0000-0002-1936-9153

Abstract

Background/Aim: In pulmonary lobectomy operations, the operation is performed with one-lung ventilation by collapsing the related lung. Postoperative expansion failure on the deflated side is a critical issue. We aimed to correct the expansion failure and atelectasis with the recruitment maneuver performed at the end of the operation.

Methods: A total of 61 cases who underwent elective lobectomy under one-lung ventilation were included in this double-blind and prospective study. They were randomized into two groups comprising thirty and thirty-one cases. The first group included patients in whom the cycling recruitment maneuver (cRM) was performed, and the second group comprised patients who underwent the manual recruitment maneuver. Both groups were ventilated similarly during the one-lung ventilation period. After switching to double-lung ventilation, a standardized cycling recruitment maneuver was performed in the first group, and a high-volume manual recruitment maneuver with an anesthetic reservoir bag was used in the second group. Preoperative and postoperative inspiratory and hemodynamic parameters, wakefulness level, pain scores, developments of complications and durations of the hospitalization were noted. Expansion failure and atelectasis were evaluated both with chest radiography and thorax computerized tomography.

Results: There was no statistically significant difference among the two groups in terms of age, smoking, duration of operation, preoperative forced expiratory volume in 1 second (FEV1), SpO2 levels, respiratory and hemodynamic parameters noted during the operation, invasive arterial pressure monitoring results, electrocardiogram (ECG) findings, modified Aldrete score (MAS), and visual analogue scores (VAS) (P>0.05 for all). The gender distribution and types of operations performed were also similar. No complications were observed. Expansion failure was seen in 23.3% and 48.8% (P=0.042) of the patients in the cRM and mRM groups, respectively. Additional procedures were needed in 4 patients (13.3%) in the cRM group and in 11 patients (35.5%) in the mRM group. The duration of hospital stay was significantly shorter in the cRM group (P=0.045). Regression analysis revealed a 3.08-times increase in the incidence of expansion failure in the mRM group compared to group cRM.

Conclusion: In pulmonary lobectomy operations, we observed that with the utilization of the recruitment maneuver which is performed after switching to double-lung ventilation, the rate of expansion failure, the need for additional procedures and duration of hospital stay decreased.

Keywords: Atelectasis, Cycling recruitment management, Expansion defect, Lobectomy

Corresponding Author
Kadir İdin
Intensive Care Unit, Anesthesiology Department, School of Medicine, Istanbul Medipol University, Istanbul, Turkey
TEM Avrupa Otoyolu Göztepe Çıkışı No: 1 Bağcılar 34214, İstanbul, Turkey
E-mail: drkadiridin@yahoo.com

Ethics Committee Approval
Bezmialem Foundation University's Clinical Research Ethics Committee, B.300.2.BAV.0.05.05/267, 22.02.2012
All procedures in this study involving human participants were performed in accordance with the 1964 Helsinki Declaration and its later amendments.

Conflict of Interest
No conflict of interest was declared by the authors.

Financial Disclosure
The authors declared that this study has received no financial support.

Published
2021 September 30

How to cite: İdin K. The effect of recruitment maneuver on the development of expansion defect and atelectasis after lobectomy: A double-blind randomized controlled trial. J Surg Med. 2021;5(9):964-968.

Introduction

Pulmonary complications are common after surgery and cause an increase in mortality and morbidity [1, 2]. The development of postoperative pulmonary complications depends on the anesthetic agents, surgical technique, and patient characteristics [3]. Major morbid complications may develop after lung resection operations, such as independently developing expansion defect and atelectasis along with prolonged air leak (PAL) [4-7]. The incidence of atelectasis and PAL varies depending on the underlying disease, lung structure and type of resection [5]. PAL is usually caused by the lung parenchyma after lobectomy [7]. Air leak usually ends in 2-3 days when the lung re-expands [8]. Prevention of the development of prolonged air leak requires a meticulous surgical technique. Naturally, the remaining lung can be filled by bringing the costae closer together, healing the mediastinum on the operative side, raising the diaphragm, or somehow ensuring that the lung on the operative side remains open [8-10]. In the postoperative period, negative intrapleural aspiration, chest tube insertion and respiratory physiotherapy contribute to the expansion of the lung and the prevention of atelectasis [9-11]. For the treatment of an expansion defect or residual air space, stapler use during surgery, suture line-support structures, fibrin adhesive use, decortication of the thickened pleura, separation of the inferior pulmonary ligament, pleural awning and pneumoperitonium can be considered [9, 12, 13]. The incidence of PAL in large series is 15.2%. The residual air gap ratio is between 10-30%. Eighty percent are usually reabsorbed within 4 weeks. Ninety percent may also be monitored for a year. Of these, 9% persist from 1 year to 10 years, and 5% of those with persistent air leaks are also infected [1, 8, 9].

These complications may be reduced thanks to the use of low tidal volume (Vt) during surgery, lower fractionated inspiratory oxygen (FiO_2) and end-expiratory positive pressure (PEEP), "Preventive Ventilation Strategy" [14, 15] and postoperative care including early mobilization, respiratory physiotherapy, and postoperative continuous positive airway pressure (CPAP) [1, 9, 16-19].

It is a routine practice to continue the operation by deflating the lung to be operated on, inserting a double lumen tube and performing single lung ventilation. Intrapulmonary shunting is observed in 15-40% due to complete deflation of the operated lung during single lung ventilation performed in the lateral position [12]. Atelectasis in the compressed zones of the lung is also shown by computed tomography (CT) [1, 12, 17]. Atelectatic zones and hypoventilated areas in the ventilated lung lead to ventilation/perfusion (V/Q) disorders and contribute to an increase in the shunt seen in the deflated lung [1, 12]. Atelectasis is a predisposing factor for ventilator-induced lung injury (VILI), the development of pneumonia, prolonged oxygen demand with hypoxemia, antibiotic treatment and even mechanical ventilation need [1, 14, 15]. For complete and uncomplicated recovery in the postoperative period, the remaining lung section after resection must completely fill the ipsilateral hemithorax as it re-expands. The necessity of additional procedures such as bronchoscopy, CPAP, respiratory physiotherapy performed to provide expansion after expansion defects and atelectasis in the postoperative period in both the deflated and ventilated lung increase the length of hospital stay and the treatment costs [1].

The recruitment maneuver is often used in the intensive care unit and in the peroperative period due to its positive contribution to gas exchange. In this study, a standardized cycling recruitment maneuver (cRM) and manual recruitment maneuver (mRM) were used. Mechanical ventilation began with 10 cmH_2O PEEP, 20 cmH2O PEEP-over pressure. After the PEEP value was increased to 15 and 20 cmH_2O at 1-minute intervals, it was waited for 1 minute at each step and decreased by 2 cmH_2O. This maneuver, which reduced PEEP to 8 cmH_2O, took a total of 9 minutes. With this prospective, randomized and double-blind study, the effects of these maneuvers on postoperative expansion defect, atelectasis development, the need for additional procedures and hospital stay were investigated.

Materials and methods

Patient characteristics

Sixty-one volunteers aged between 18-70 years in the ASA (American Society of Anesthesiologists) 1-2 category who underwent elective lobectomy were included in this double blind randomized controlled trial. The volunteers were randomly assigned numbers (RANDOM.ORG: True Random Number Service). Two groups consisting of 30 and 31 patients were created. Patients who required emergency operation, were uncooperative, had any contraindications for PEEP, those who received pleural awning, were given sub-diaphragmatic air, had contraindications to the drugs to be used, or were known to have atelectasis before elective lobectomy were excluded from the study. Group I consisted of patients who underwent cRM and Group II consisted of those who underwent high-volume uncontrolled mRM with an anesthetic reservoir bag.

Technique of anesthesia

No premedication was performed on the patients before surgery. A thoracic epidural catheter was inserted through T7 – T8 in all cases during preoperatively. The catheter was advanced epidurally about 6-8 cm and 10 mL of bolus bupivacaine (0.25%) was administered after a 2.5 mL-test dose (15 µg of adrenaline+20 mg of Lidocaine). Immediately afterwards, patient-controlled epidural analgesia was started in continuous mode with bupivacaine and fentanyl (1mg-2µg/ml). Before epidural catheterization, 500 mL of colloid solution, an intravascular volume extender (Voluven^{TM}), was administered, and fluid maintenance was continued with ringer lactate at 8 mL/kg/h. Epidural analgesia is the best pain relief method in thoracotomies. Using this method of analgesia, it was aimed to prevent the pain of patients with a low pain threshold from interfering with their mobilization and coughing in the postoperative period. After providing sedation with midazolam (0.03 mg/kg), 100% FiO_2 was given as an inhaler for 3 minutes. 2 µg/kg fentanyl, 1.5-2mg/kg propofol, 0.1 mg/kg vecuronium were administered as slow bolus during induction of anesthesia. A double-lumen endobronchial tube was inserted into the trachea of all patients. Anesthesia was maintained with a Draeger Primus® (Draeger AG, Lübeck, Germany) anesthesia device with sevoflurane (0.5-2%) and 50% N_2O. When it was clinically necessary, a bolus dose of vecuronium (0.015 mg/kg) was administered.

All patients were given 0.5 FiO_2 in volume control mode, with a Vt of 6-8ml/kg, PEEP of 6cm H_2O, RR (respiratory rate) of 12/min, I/E (Inspiratory/Expiratory time ratio) of 1/2. When thoracotomy began, the lung to be operated on was deflated. Ventilation continued with a Vt of 3-4 ml/kg, a PEEP of 6 cmH2O, a RR of 12-15 to keep $EtCO_2$ between 30-40 during single-lung surgery.

Study plan

The following ventilatory settings were followed when switching to double lung ventilation in the cRM group: Pressure Controlled Ventilation (PCV) mode, FiO_2: 1, RR: 12/min, I/E: 1/1, PEEP-overpressure: 20 cmH_2O, PEEP: 10 cmH_2O, and target peak inspiratory pressure (PIP) was adjusted to a maximum of 40 cmH_2O. Ventilated was performed in these settings for 1 minute. PEEP was increased to 15 cmH_2O and 20 cmH_2O every 1 min. Afterwards, the PEEP value was reduced by 2 cmH_2O each minute until 8 cmH_2O. Finally, when PEEP reached 8 cmH_2O and PEEP-overpressure reached 20 cmH_2O, after waiting for 1 minute, the patient was ventilated with both lungs in PCV mode with PEEP: 8 cmH_2O, PIP: Vt 6-8 ml/kg, FiO_2: 0, 5, RR: 12/min, I/E: ½. Ventilation was continued with the same settings until extubation. During this procedure, the hemodynamic parameters of patients were monitored with GE B30 Patient Monitor (GE Healthcare, USA) or peripheral oxygen saturation (SpO_2). If deterioration was observed, the procedure was stopped, and normal ventilation was switched to, and the patient was removed from the study. The recruitment maneuver took a total of 9 minutes.

At the end of the resection, which was performed to the patients included in the mRM group, double lung ventilation began, and the anesthesia reservoir bag was used for about 2 min with FiO_2: 1, Vt: 10-15 ml/kg, RR: and $PaCO_2$: 40 mmHg for continuous and high-volume ventilation. The post-maneuver settings in volume control mode were as follows: FiO2: 0.5 Vt: 6-8 ml/kg, PEEP: 6 cmH2O, RR (respiratory frequency): 12/min, I/E (Inspiration/Expiration time ratio): ½. Ventilation continued at these settings until extubation.

Intraoperative follow-up

Invasive arterial pressure, electrocardiogram (ECG), SpO_2, and hourly urine output monitoring were performed. At the beginning and the end of each hour, arterial blood gas (ABG) was analyzed and partial O_2 and CO_2 pressures (PaO_2 and $PaCO_2$) and pH values were noted. Hemodynamic parameters and SpO_2 values were recorded continuously. High FiO_2 need due to hypoxemia and sudden SpO_2 decrease that may develop during single lung ventilation were taken note of, along with the type of lung resection performed on the patient.

Postoperative follow-up method

The physicians and health personnel who followed the patients were blinded to the study groups. All patients had the following parameters noted at the end of the operation: Alertness level (Modified Aldrete Score), heart rate (CAD), arterial pressure (TA), SpO, respiratory and hemodynamic parameters in the recovery unit. The patients were transferred to the wards once stable. Postoperative analgesia was provided at hours 0-1-2-4-12-24-48 with bupivacaine and dentanyl (1.25 mg/ml + 5 µg/ml) via patient-controlled epidural analgesia. Pain was evaluated with the Visual Analogue Scale (VAS) at the 1st postoperative hour. The VAS was intended to be kept ≤3.

PA lung X-ray and Thorax CT were obtained the same night, approximately 1 hour after being transferred to the ward as part of the routine follow-up, and expansion defect was evaluated as either present or absent. This assessment was routinely performed by the same experienced thoracic surgery specialist. The thoracic surgeon who performed the evaluation did not know which group the patient belonged to, both during and after the operation. In addition to the radiological evaluation, the patients were also evaluated in terms of complications. Nasotracheal aspiration, tube thoracostomy, CPAP-BiPAP (Bilevel Positive Airway Pressure) and bronchoscopy procedures performed on the patient from the postoperative period until discharge were noted as additional procedures. As long as the patient was in the operating room, the follow-up was performed by the same anesthesia technician and the same anesthesiologist. The follow-up in the ward was performed by the thoracic surgery team. The data of each patient were recorded in the follow-up form.

Statistical analysis

The design and data collection of our study follow the The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statements. Power analysis was performed with the G power software, with an alpha value of 0.05 and a power of 80%. For 20% expansion failure in the group that underwent the cycling recruitment maneuver (cRM), and %40 expansion failure in the manual recruitment maneuver (cRM) group, at least 25 patients were needed. The data obtained in the study were evaluated with SPSS (Statistical Package for Social Sciences for Windows, Armonk, NY: IBM Corp.) v.22.0 with a 95% confidence interval and a significance level of $P<0.05$. Compliance with the normal distribution was assessed using the Kolmogorov Smirnov and Spiro-Wilk One-Sample tests. Since the data showed a normal distribution, parametric hypothesis tests were performed. Independent samples t-test was used for quantitative data among the independent groups, and Pearson chi-square test or Fisher's exact tests were used to assess qualitative data. To determine the effect of groups on the expression defect, logistic regression analysis was performed.

Results

The study included 61 lobectomy surgery patients who met the criteria for inclusion. According to the mode of double lung ventilation, the patients were divided into 2 groups. There was no significant difference between the groups in terms of age, duration of surgery, smoking, preoperative Forced expiratory volume in 1 second (FEV_1), SpO_2 values and the respiratory and hemodynamic parameters recorded during the preoperative period. The invasive arterial pressures and ECG monitoring findings were similar between the two groups. A decrease in the SpO_2 value was intervened with and brought to normal levels with FiO_2 increase. There was no significant difference between the groups in PaO_2 and $PaCO_2$ values in arterial blood gas analysis at the beginning of the operation and at the beginning of each hour. The groups were also similar in terms of pH values, alertness levels recorded with the Modified Aldrete Score in the first 30 minutes postoperatively, VAS assessment, gender distribution and the type of operation performed (Tables 1 and 2).

Table 1: Quantitative data and significance levels

	Group	N	Mean	SD	*P*-value
Age, years	cRM	30	59.90	9.12	0.10
	mRM	31	55.71	10.53	
Use of tobacco, n	cRM	30	35.43	26.27	0.49
	mRM	31	31.29	19.49	
Duration of operation, minutes	cRM	30	174.33	80.97	0.97
	mRM	31	173.35	80.01	
Oxygen saturation, %	cRM	30	94.87	4.18	0.60
	mRM	31	95.42	4.10	
FEV1, L	cRM	30	2350.4	480.37	0.91
	mRM	31	2430.5	601.20	
VAS0	cRM	30	8.83	0.46	0.96
	mRM	31	8.84	0.45	
VAS4	cRM	30	5.52	1.15	0.48
	mRM	31	5.29	1.30	
VAS8	cRM	30	4.34	1.45	0.82
	mRM	31	4.26	1.44	
VAS15	cRM	30	3.72	0.92	0.64
	mRM	31	3.61	0.92	
VAS24	cRM	30	3.34	0.55	0.94
	mRM	31	3.35	0.55	
Postoperative hospitalization, days	cRM	30	5.83	2.59	0.02*
	mRM	31	9.03	6.51	

* $P<0.05$ Independent Samples T test, n: number, SD: Standard deviation, cRM: group of cycling recruitment maneuver, mRM: group of manual recruitment maneuver, FEV1: Forced expiratory volume in 1 second, VAS: visual analogue scores

Table 2: Comparison of gender and performed surgery according to group

n(%)		Group			
		cRM	mRM	Total	*P*-value
Gender	Male	24(80%)	25(80.6%)	49(80.3%)	
	Female	6(20%)	6(19.4%)	12(19.7%)	0.949
Surgery	RUL	14(46.7%)	15(48.4%)	29(47.5%)	
	Others	16(53.3%)	16(51.6%)	32(52.5%)	0.893

* $P<0.05$, Pearson Chi-Square Test, cRM: group of cycling recruitment maneuver, mRM: group of manual recruitment maneuver, RUL: Right upper lobectomy

When evaluated for additional procedures performed to treat the resulting expansion defect, additional procedures were required in 4 patients (13.3%) in the cRM group, and 11 patients (35.5%) in the mRM group ($P<0.05$) (Table 3). The length of hospitalization was significantly shorter in the cRM group ($P<0.05$). There were no complications associated with the recruitment process.

Regression analysis revealed that the MRM group was 3.08 times more likely to have an expansion defect than the cRM group ($P<0.05$) (Table 4).

Table 3: Distribution of expansion defects and additional procedures by groups

		cRM n(%)	mRM n(%)	Total	*P*-value
Expansion defect and atelectasis	None	23 (76.7%)	16 (51.6%)	39(63.9%)	0.042*
	Exist	7(23.3%)	15(%48.8%)	22(36.1%)	
Additional procedure	None	26 (86.7%)	20 (64.5%)	46(75.4%)	
	Exist	4(13.3%)	11(35.5%)	15(24.6%)	0.045*

*$P<0.05$, Pearson Chi-Square Test, n: number, cRM: group of cycling recruitment maneuver, mRM: group of manual recruitment maneuver

Table 4: The logistic regression model

	B	*P*-value	O.R.	95.0% CI for Exp(B)	
				Lower	Upper
cRM	1.125	0.045*	3.080	1.024	9.262
Constant	0.065	0.857	1.067		

*$P<0.05$, Logistic regression, B: beta coefficient, OR: Odds ratio, CI: confidence interval, cRM: group of cycling recruitment maneuver

Discussion

In subtotal lung resection operations, the recruitment maneuver positively affects arterial oxygenation by contributing to alveolar gas exchange during the peroperative period [12, 13, 16, 20, 21]. Although almost all rehabilitation studies in the literature aim to reduce the complications experienced during the peroperative period. This study was conducted to evaluate the re-expansion of the lung in the postoperative period and differs from other studies.

Expansion defects can be caused by poor lung compliance [8]. In this study, since the average FEV_1 between the groups was similar, it can be said that the lung compliance of both groups was equal. With preoperative values, it is seen how close both groups are to each other in terms of many variables. Some expansion defects seen after lobectomy are caused by small damages to the lung parenchyma, and when the lung re-expands, this air leak mostly ends in 2-3 days [8]. It is of great importance that the lung is expanded in case of air leak. With the applied recruitment maneuver, immediate expansion is provided after the procedure, which leads to the air leak terminating earlier. According to the results of this study, the 2-3-day period required for re-expansion in the postoperative period is significantly shortened by cRM, which is a standardized recruitment maneuver.

Compression atelectasis develops in the dependent areas of the lung during single-lung ventilation [12]. However, we observed no atelectasis in both groups in the dependent lung, possibly because an optimal PEEP value was given stably throughout the operation [15]. In addition, due to the complete deflation of the nondependent lung in the lateral position, atelectatic areas were formed during the re-ventilation period. For complete and uncomplicated recovery in the postoperative period, it is necessary that both the parenchyma remaining after resection in the independent lung completely fills the same side hemithorax with re-expansion, and the atelectatic areas in the dependent lung are fully re-expansed. In this study, a complete and uncomplicated recovery was achieved at a statistically significant level thanks to the cycling recruitment method.

The prevention of complications that may occur after thoracotomy surgery and early recovery of respiratory function are the most important factors in postoperative pain control. The superiority of the administration of analgesics in the epidural space to other methods is known [4]. In this study, postoperative pain control was achieved at the desired level by inserting a catheter into the epidural space before the operation. The fact that there is no significant difference between the two groups in the postoperative VAS assessment suggests that pain control was sufficient.

Our rate of expansion defects in the remaining lung after resection was 48% in the mRM group and 23.3% in the cRM group, which was significantly different. The rates may be relatively high as they were detected with postoperative thorax CT. In the light of the available data, it can be said that the used cycling recruitment maneuver reduces the expansion defect.

Additionally, fewer additional procedures were performed on the patients in the cRM group versus the mRM group, which also shows that the cRM group yielded positive results in terms of expansion defect.

Two known surgical methods are the application of pleural awning and creation of pneumoperitoneum to prevent postoperative expansion defects [9, 11, 22]. With these methods, the pleural cavity is reduced, allowing the remaining lung to fully fill the corresponding hemithorax. When applied during the operation, a recruitment maneuver is known to contribute to gas exchange [13, 15-17, 20, 23-25]. In addition, in the mRM group, logistic regression model revealed that the probability of an expansion defect to be 3.08 times higher compared to the cRM group.

Its single-center design is the most prominent limitation of this study.

Conclusion

The cycling recruitment maneuver used when switching from single lung ventilation to double lung ventilation during the peroperative period results in significant reduction in expression defects, atelectasis development, the need for additional procedures. Also, hospitalization is significantly shorter, which lowers hospital costs.

References

1. Tusman G, Böhm SH, Warner DO, Sprung J. Atelectasis and perioperative pulmonary complications in high-risk patients. Curr Opin Anaesthesiol. 2012 Feb;25(1):1-10.
2. Handy JR Jr, Denniston K, Grunkemeier GL, Wu YX. What is the inpatient cost of hospital complications or death after lobectomy or pneumonectomy? Ann Thorac Surg. 2011 Jan;91(1):234-8.
3. Canet J, Gallart L, Gomar C, Paluzie G, Vallès J, Castillo J, et al. Prediction of postoperative pulmonary complications in a population-based surgical cohort. Anesthesiology. 2010;113:1338-50.
4. Stolz AJ, Lischke R, Schutzner J, Petrik E, Harustiak T, Pafko P. Predisposing factors of atelectasis following pulmonary lobectomy. Acta Chir Belg. 2009 Jan-Feb;109(1):81-5.
5. Uramoto H, Nakanishi R, Fujino Y, Imoto H, Takenoyama M, Yoshimatsu T, et al. Prediction of pulmonary complications after a lobectomy in patients with non-small cell lung cancer. Thorax. 2001 Jan;56(1):59-61.
6. Uzieblo M, Welsh R, Pursel SE, Chmielewski GW. Incidence and significance of lobular atelectasis in thoracic surgical patients. Am Surg. 2000 May;66(5):476-80.
7. Abholda A, Liu D, Brooks A, Burt M. Prolonged air leak following radical upper lobectomy. Chest. 1998 Jun;113(6):1507-10.
8. Akkaş Y, Yazıcı Ü. Postoperative Complications In: Yüksel M, Balci AE, editors. Thoracic Surgery. Istanbul: Nobel Medical Bookstores; 2015. p. 203-11
9. Toker A, Dilege S, Bostancı K, Kalaycı G. Perioperative Pneumoperitoneum to Prevent Space and Air Leak after Lobectomy Operations. Thorac Cardiovasc Surg. 2003 Apr;51(2):93-6.
10. Rice TW, Kirby TJ. Prolonged air leak. Chest Surg Clin North Am 1992 Feb;23(2):803-11.
11. Handy JR, Judson MA, Zellner JL. Pneumoperitoneum to treat air leaks and spaces after lung volume reduction operations. Ann Thorac Surg. 1997 Dec;64(6):1803-5.
12. Tusman G, Böhm SH, Sipmann FS, Maisch S. Lung recruitment improves the efficiency of ventilation and gas exchange during one-lung ventilation anesthesia. Anesth Analg. 2004 Jun;98(6):1604-9.
13. Tusman G, Böhm SH, Suarez-Sipmann F, Turchetto E. Alveolar recruitment improves ventilatory efficiency of the lungs during anesthesia. Can J Anaesth. 2004 Aug-Sep;51(7):723-7.
14. Kilpatrick B, Slinger P. Lung protective strategies in anaesthesia. Br J Anaesth. 2010 Dec;105 Suppl 1:i108-16.
15. Inomata S, Nishikawa T, Saito S, Kihara S. "Best" PEEP during one-lung ventilation. Br J Anaesth. 1997 Jun;78(6):754-6.
16. Tusman G, Böhm SH, Vazquez de Anda GF, do Campo JL, Lachmann B. The 'alveolar recruitment strategy' improves arterial oxygenation during general anaesthesia. Br J Anaesth. 1999 Jan;82(1):8-13.
17. Lumb AB, Greenhill SJ, Simpson MP, Stewart J. Lung recruitment and positive airway pressure before extension does not improve oxygenation in the post-anaesthesia care unit: a randomized clinical trial. Br J Anaesth. 2010. May;104(5):643-7.
18. Stock MC, Downs JB, Gauer PK, Alster JM, Imrey PB. Prevention of postoperative pulmonary complications with CPAP, incentive spirometry, and conservative therapy. Chest. 1985 Feb;87(2):151-7.
19. Sentürk NM, Dilek A, Camci E, Senturk E, Orhan M, Tugrul M, et al. Effects of positive end-expiratory pressure on ventilatory and oxygenation parameters during pressure-controlled one-lung ventilation. J Cardiothorac Vasc Anaesth. 2005 Feb;19(1):71-5.
20. Hoftman N, Canales C, Leduc M, Mahajan A. Positive end expiratory pressure during one-lung ventilation: selecting ideal patients and ventilator settings with the aim of improving arterial oxygenation. Ann Card Anaesth. 2011 Sep-Dec;14(3):183-7.
21. Tusman G, Böhm SH, Melkun F, Staltari D, Quinzio C, Nador C, et al. Alveolar recruitment strategy increases arterial oxygenation during one-lung ventilation. Ann Thorac Surg. 2002 Apr;73(4):1204-9.
22. Carbognani P, Spaggiani L, Solli P, Rusca M. Pneumoperitoneum for prolonged air leaks after lower lobectomies. Ann Thorac Surg. 1998 Aug;66(2):604-5.
23. Jung JD, Kim SH, Yu BS, Kim HJ. Effects of a preemptive alveolar recruitment strategy on arterial oxygenation during one-lung ventilation with different tidal volumes in patients with normal pulmonary function test. Korean J Anesthesiol. 2014 Aug;67(2):96-102.
24. Unzueta C, Tusman G, Suarez-Sipmann F, Böhm S, Moral V. Alveolar recruitment improves ventilation during thoracic surgery: a randomized controlled trial. Br J Anaesth. 2012 Mar;108(3):517-24.
25. Park SH, Jeon YT, Hwang JW, Do SH, Kim JH, Park HP. A preemptive alveolar recruitment strategy before one-lung ventilation improves arterial oxygenation in patients undergoing thoracic surgery: a prospective randomised study. Eur J Anaesthesiol. 2011 Apr;28(4):298-302.

This paper has been checked for language accuracy by JOSAM editors.
The National Library of Medicine (NLM) citation style guide has been used in this paper.