The impact of ultrasound-guided recruitment maneuvers on the risk of postoperative pulmonary complications in patients undergoing general anesthesia

Jolanta Cylwik[1], Natalia Buda[2]

[1] *Anesthesiology and Intensive Care Unit, Mazovia Regional Hospital in Siedlce, Poland*
[2] *Department of Internal Medicine, Connective Tissue Diseases and Geriatrics, Medical University of Gdansk, Poland*

Correspondence: Natalia Buda, Department of Internal Medicine, Connective Tissue Diseases and Geriatrics, Medical University of Gdansk, Gdansk, Poland; email: natabud@wp.pl

Abstract

Introduction: Postoperative pulmonary complications are among the most frequent problems in perioperative care. The risk of their development depends not only on the parameters associated with the patient's initial clinical condition, but also on the employed anesthesia technique, the method of mechanical ventilation, and the type and technique of the surgical procedure. Atelectasis is the most common complication, affecting nearly 90% of the patients undergoing general anesthesia. **Aim:** The aim of this study was to determine whether it was possible to positively impact the postoperative period and reduce the frequency of postoperative pulmonary complications via patient-based intraoperative ultrasound-guided recruitment maneuvers. **Methodology:** The course of the postoperative period was analyzed in two groups of patients. One of them comprised 100 patients in whom no recruitment maneuvers were performed during general anesthesia. The other group (100 patients) consisted of patients in whom patient-based ultrasound-guided pulmonary recruitment maneuvers were performed. **Results:** In the recruitment group, the postoperative hospitalization was statistically significantly shorter ($p = 0.003$) and the risk of intensive care treatment significantly lower. Additionally, the need for prolonged postoperative mechanical ventilation was reduced, as was the risk of respiratory tract infections. **Conclusions:** Intraoperative ultrasound-guided recruitment maneuvers reduce the frequency of postoperative pulmonary complications.

Introduction

Postoperative pulmonary complications (PPCs) are among the most common problems in perioperative care. The most frequent complications include respiratory failure, atelectasis, pneumothorax, pleural effusion, pneumonia, and acute respiratory distress syndrome (ARDS)[1]. Numerous risk factors predisposing a patient to the development of anesthesia-induced respiratory failure have been reported – a significant correlation has been evidenced with such risk factors as age over 60 years, class 2 or higher according to the ASA (American Society of Anesthesiologists) Physical Status Classification System, chronic obstructive pulmonary disease (COPD), heart failure, and reduced exercise tolerance[2]. Additionally, the risk of PPCs is affected by factors associated with the employed surgical technique, the surgical site (mainly surgeries involving the chest and epigastrium), the anesthesia technique, and the method of mechanical ventilation used during the procedure[3–5].

It has been found that nearly 90% of patients undergoing general anesthesia (intubated with the use of neuromuscular blocking agents) who had been ventilated with positive pressures developed atelectasis, i.e., a pulmonary aeration disturbance[6,7]. In the majority of patients, the areas affected by atelectasis are clinically insignificant and become normally aerated upon a return to sufficient spontaneous respiration. In some patients, however, intraoperative atelectasis may be a predisposing factor for postoperative complications. Recruitment maneuvers are commonly employed for reducing pulmonary atelectasis. Various techniques for performing them have been described in the relevant literature[8–12].

Tab. 1. *Clinical characteristics of the study group and control group*

Variable	Study group (*n* = 100)	Control group (*n* = 100)	Result
Age *M (SD)*	63.90 (11.34)	64.17 (14.03)	*p* = 0.881
BMI *M (SD)*	28.31 (5.08)	29.61 (5.75)	*p* = 0.173
Gender *n* (%)			
Females	66 (66.0)	50 (50.0)	*p* = 0.022
Males	34 (34.0)	50 (50.0)	
ASA Score *n* (%)			
1	1 (1.0)	4 (4.0)	*p* = 0.152
2	27 (27.0)	20 (20.0)	
3	66 (66.0)	63 (63.0)	
4	6 (6.0)	13 (13.0)	
MRC Score *n* (%)			
0	49 (49.0)	48 (57.8)	*p* = 0.056
1	40 (40.0)	20 (24.1)	
2	11 (11.0)	15 (18.1)	
Coexisting chronic disease *n* (%)			
Hypertension	55 (55.0)	66 (66.0)	*p* = 0.112
Ischemic heart disease	13 (13.0)	17 (17.0)	*p* = 0.428
COPD	1 (1.0)	3 (3.0)	*p* = 0.621
Asthma	6 (6.0)	2 (2.0)	*p* = 0.279
Diabetes	24 (24.0)	18 (18.0)	*p* = 0.298
Atherosclerosis	12 (12.0)	15 (15.0)	*p* = 0.535
Number of comorbidities *n* (%)			
0	26 (26.0)	24 (24.0)	*p* = 0.635
1	26 (26.0)	35 (35.0)	
2	24 (24.0)	23 (23.0)	
3	19 (19.0)	13 (13.0)	
4	5 (5.0)	5 (5.0)	
Type of surgery *n* (%)			
Elective	90 (90.0)	87 (87.0)	*p* = 0.506
Emergency	10 (10.0)	13 (13.0)	
Surgery duration *n* (%)			
<2 h	45 (45.0)	43 (43.0)	*p* = 0.467
2–4 h	44 (44.0)	40 (40.0)	
>4 h	11 (11.0)	17 (17.0)	
BMI – body mass index; ASA – American Society of Anesthesiologists (ASA) physical status classification system, MRC – modified Medical Research Council Dyspnea Scale			

The effectiveness of conventional recruitment methods in preventing PPCs has not been proven[13]. Moreover, they are associated with the risk of developing respiratory complications (barotrauma, volumotrauma, biotrauma) and may lead to hemodynamic destabilization due to significant intrapleural pressure changes during their performance. Their disadvantage is the lack of patient-based customization: irrespective of the extent of pathology and the response of the lungs to performed maneuvers, they are conducted identically in all patients.

As claimed by some authors (Tusman, Cylwik, Park), the application of lung ultrasound for monitoring the recruitment process appears to be of significant benefit for patients. Owing to the continuous ultrasound assessment of the pulmonary tissue affected by atelectasis during the recruitment process, it is possible to decrease ventilation pressures necessary to achieving a good effect in reducing atelectasis, while at the same time limiting potential complications associated with the procedure[14–16].

The aim of this study was to determine whether it was possible to positively impact the postoperative period and reduce the frequency of postoperative pulmonary complications (PPCs) via patient-based intraoperative ultrasound-guided recruitment maneuvers. The 7-day postoperative period was assessed, with particular emphasis on the length of hospitalization after surgery, the need for prolonged mechanical ventilation, the duration of stay in the postoperative ward, and the incidence of pneumonia.

Material and methods

Ethical statement

The study was approved by the Bioethics Committee of the Regional Medical Chamber in Warsaw (No. KB/1154/19).

Patient enrolment

For the study, we enrolled adult patients (over 18 years of age) undergoing general anesthesia during elective and emergency surgery. All eligible patients provided their

written consent to participation in the study. Exclusion criteria included: age less than 18 years, risk of ASA 5, pregnancy, and increased intracranial pressure. The patients who were undergoing cardiac surgery and cardiothoracic surgery were also excluded.

In total, 200 patients undergoing general anesthesia in one research center were included in the study. They were randomly divided into 2 groups consisting of the same number of participants. In both groups, clinical data concerning the postoperative period in terms of PPC development were collected. The assessment period encompassed 7 postoperative days.

Intraoperative mechanical ventilation

Following the induction of anesthesia, its type and technique being dependent on the patient's age and comorbidities (the induction of anesthesia not protocolized), mechanical ventilation in the volume control ventilation (VCV) mode was performed with Philips IntelliSave AX700 (USA) anesthesia workstation. The fraction of inspired oxygen (FiO_2) was 0.35. Nitrous oxide was not provided during anesthesia. Initially, the frequency of respiration was set physiologically, and during anesthesia it was modified to achieve the end-tidal CO_2 ($EtCO_2$) at a level of 35–40 mmHg. Tidal volume (Vt) was always 7 ml/kg of body mass. For all patients, the initial positive end-expiratory pressure (PEEP) value was set at 5 cm H_2O.

In the non-recruitment patient group, mechanical ventilation was performed during the entire anesthesia procedure with the PEEP value set at a constant level of 5 cm H_2O. In the group of patients who underwent intraoperative ultrasound-guided recruitment, once the maneuver was completed, the PEEP value was retained at a level consistent with the one determined during the procedure.

Ultrasound-guided recruitment procedure

In the study group, the recruitment maneuvers were performed in conformity with the adopted protocol once the indications for such procedures were determined. The indications included atelectasis detected during preoperative ultrasound assessment or during such assessment after the induction of general anesthesia. If atelectasis was not visualized at these stages, ultrasound reassessment was performed when oxygen saturation (SaO_2) dropped to a level of 94% or when static compliance decreased by 15%. The recruitment protocol has been previously described by Cylwik and Buda[15]. The procedure involves an incremental increase of the PEEP value with a simultaneous continuous ultrasound assessment of areas affected by atelectasis. Depending on the dynamics of changes in the ultrasound image, the decision to increase mechanical ventilation pressure values was made, and end-expiratory pressure preventing the formation of new areas affected by atelectasis was determined.

Statistical analysis

The collected clinical data were analyzed statistically with IBM SPSS Statistics 25.0 software. Pearson's chi-squared test was used to compare the two groups for qualitative data. Fisher's exact test was used when the expected number was smaller than 5. The level of significance was assumed to be α = 0.05. The Kolmogorov-Smirnov test was used to determine whether the values of the analyzed variable were normally distributed. A normal distribution was found for age, hence a parametric test (the independent samples t-test) was employed to compare the two groups. The remaining quantitative variables were not normally distributed, so the Mann-Whitney U test was used for group comparison.

Results

Analysis of the study group and the control group

The group in which ultrasound-guided recruitment was performed, henceforth termed the study group, comprised 100 patients. The control group also consisted of 100 patients, in whom no intraoperative recruitment maneuvers were performed. In both groups, the average age of the patients was about 64 years. The study group comprised significantly more women (66%). In the control group, the number of females and males was identical (50% of each gender). The BMI of patients in both groups was similar and amounted to about 28–29. The percentages of ASA and MRC (dyspnea scale according to Medical Research Council) scores were similar in both groups – in the ASA score the most frequent value was 3, and in the MRC score – 0. The most frequent chronic coexisting disease was arterial hypertension (55% of patients in the study group and 66% in the control group) (Tab. 1).

Effect of ultrasound-guided recruitment maneuver

In the group of patients for whom ultrasound lung (LUS) assessment was performed during anesthesia, areas affected by atelectasis were visualized in 89 cases (89%). After ultrasound-guided recruitment, aeration of the areas affected by atelectasis was achieved in 79 patients (91.9% of patients selected for the procedure)[15]. Figure 1 demonstrates a sample ultrasound image of the procedure.

Clinical outcomes of intraoperative ultrasound-guided recruitment maneuvers

In order to assess the impact of the proposed intraoperative procedure on the final clinical outcome, data concerning hospitalization were compared in both groups (Tab. 2). The postoperative hospitalization period was significantly shorter in the patients who underwent patient-based recruitment maneuvers ($p = 0.003$). Those patients less
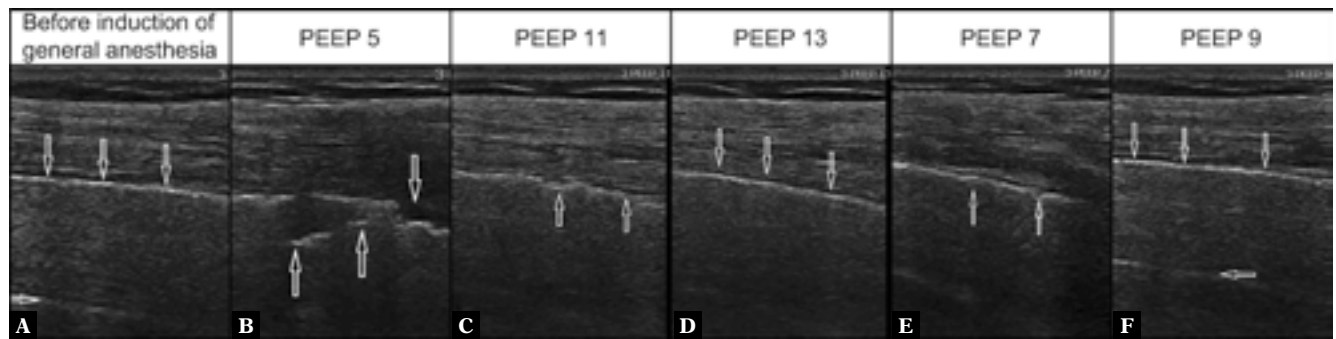
Fig. 1. *Recruitment process with a good ultrasound effect:* **A.** *LUS image before anesthesia – normal, hyperechoic pleural line (↓) and A-line artifacts (→), normal image;* **B.** *control assessment during anesthesia, at PEEP 5 cm H_2O – blurred, fragmented pleural line (↓), with small, hypoechoic subpleural consolidations (↑), image typical of atelectasis;* **C.** *when increasing PEEP to 11 cm H_2O – persistent ultrasound features of atelectasis with a visible reduction of subpleural consolidations (↑);* **D.** *when achieving PEEP value of 13 cm H_2O – normal, hyperechoic pleural line visible again (↓);* **E.** *when reducing pressures, PEEP 7 cm H_2O – segmental disturbances in the pleural line continuity (↑) visible again – initial image of atelectasis;* **F.** *after increasing end-expiratory pressure by 2 cm H_2O, disturbances in lung aeration reversed and normal pleural line and A-line artifacts were visualized*

frequently required prolonged mechanical ventilation (2 patients (2%) in the study group, 8 patients (8%) in the control group). Additionally, the mean number of hours of postoperative mechanical ventilation was statistically significantly smaller in the study group: on average 15 minutes versus nearly 3 h in the control group (the symptoms of respiratory failure, despite the lack of neuromuscular block, necessitated prolonged mechanical ventilation). The patients who underwent recruitment less frequently ($p = 0.022$) required treatment in the Intensive Care Unit (ICU) (4 patients from the study group vs. 13 from the control group). No postoperative respiratory tract infections occurred in the study group, whereas in the control group 4 patients developed postoperative pneumonia (given the small number of patients in each group, the difference was not statistically significant).

Discussion

PPCs constitute a serious problem in perioperative care. Appropriate preoperative management (e.g., introduction of respiratory rehabilitation), and then optimally performed anesthesia procedure, including protective ventilation, and intensive postoperative care may reduce the risk of PPC development. Recruitment maneuvers are one of the constituents of optimal intraoperative ventilation[17]. Their effectiveness has been extensively discussed in literature; however, even based on large meta-analyses the most optimal procedure for performing them has not

been determined thus far[18,19]. Because of the risk of both respiratory and circulatory complications (mainly hypotension), it is justified to closely monitor their course, also with the application of imaging techniques. A number of studies have reported the usefulness of computed tomography[20,21] and electrical impedance tomography[22,23] for recruitment monitoring. However, these methods cannot be employed in the operating theater during general anesthesia. Ultrasonography is a universally available imaging method that can be easily used in the operating theatre in the bedside mode, without emitting adverse radiation. Its great advantage lies in the possibility of reexamination as often as the clinical situation dictates.

The major aim of this study was to determine whether it was possible to positively impact on the postoperative period of patients undergoing general anesthesia via patient-based optimized intraoperative ultrasound-guided recruitment maneuvers. To this end, available relevant literature was analyzed. A search of scientific databases was conducted, which yielded a total of 127 publications that were further examined (key words: lung ultrasound, recruitment maneuvers). Out of the selected publications, 101 papers were excluded since they were not directly relevant to the topic. Six studies were devoted to ultrasound-guided recruitment monitoring in patients with ARDS, 12 referred to ultrasound-guided monitoring of the conventional procedure, and 3 papers only evaluated PEEP. Finally, only 5 publications were identified that directly related to the discussed topic (Tab. 3).

Tab. 2. *Assessment of the postoperative period in both groups*

Variable	Study group (*n* = 100)	Control group (*n* = 100)	Result
Hospitalization duration up to 10 days *n* (%)	85 (85.0)	67 (67.0)	$p = 0.003$
Hospitalization duration more than 10 days *n* (%)	15 (15.0)	33 (33.0)	
Respiratory tract infection *n* (%)	0 (0)	4 (4.0)	$p = 0.121$
Prolonged mechanical ventilation *n*(%)	2 (2.0)	8 (8.0)	$p = 0.052$
Number of hours of prolonged mechanical ventilation *Me (IQR, min-max); M (SD)*	0 (0; 0–20); 0.25 (2.06)	0 (0; 0–96); 2.96 (13.33)	$p = 0.049$
Admission to ICU *n* (%)	4 (4.0)	13 (13.0)	$p = 0.022$
Deaths *n* (%)	3 (3.0)	5 (5.0)	$p = 0.721$

Tab. 3. *List of publications devoted to ultrasound-guided recruitment maneuvers during general anesthesia*

Author (year of publication)	Study population	Number of participants (study group/control group)	Employed transducers	Ultrasound-guided recruitment	Detected incidence of atelectasis	Incidence of atelectasis after RM
Cylwik, Buda (2021)	adults	100/0	convex, linear	yes	87%	16%
Park *et al.* (2021)	adults	20/20	convex	yes	100%	ND
Elshalzy *et al.* (2020)	adults	20/20	convex	yes	ND	ND
Song *et al.* (2018)	pediatric	61/61	linear	yes	21%	13%
Song *et al.* (2016)	pediatric	20/20	linear	yes	50%	30%
RM – recruitment maneuvers; ND – no data						

Elshalzy *et al.* [24], who examined the application of intraoperative bedside lung ultrasound in optimizing PEEP settings in obese patients undergoing laparoscopic bariatric surgeries, reported a significant reduction of developing PPCs. These conclusions are consistent with our results. What needs to be stressed, though, is that in the Elshalzy *et al.* study, the postoperative follow-up period as regards the development of postoperative complications was only 24 h, which may be definitely too limited for infectious complications.

In their study, Park *et al.* [16] compared the efficacy of conventional lung recruitment maneuvers and ultrasound-guided procedure in reducing areas affected by atelectasis. They revealed a lower incidence of atelectasis in the ultrasound-guided recruitment group with a persistent postoperative effect. These authors also analyzed the postoperative period – no episodes of desaturation were revealed in the intraoperative ultrasound-guided recruitment group, while in the conventionally performed recruitment group desaturation occurred in 10% of patients. No statistically significant differences were revealed between the groups as regards the period spent in the postanesthesia care unit and total hospitalization. Out of 40 patients, only one from the ultrasound-guided recruitment group developed PPC. In this study, similarly to the previously discussed one, the follow-up period was relatively short and amounted to 48 h. Our results indicate a more evidently pronounced positive tendency concerning the postoperative period. This may be, however, correlative to a different research methodology. In our study, the control group consisted of patients for whom no intervention was performed, while in the study by Park *et al.* the control group underwent conventional recruitment. Additionally, the number of participants is of relevance in both these studies – 40 vs. 200 patients, which may also be the reason for the dissimilarity of the findings.

A good clinical effect of reducing atelectasis with ultrasound-guided alveolar recruitment maneuvers during general anesthesia was reported by Song *et al.* [18,25]. These studies involved a pediatric population characterized by a different physiology of the respiratory system and much lower lung compliance as compared to adults. Therefore, the results of these studies cannot be comparatively interpreted with our study, but the positive effect of ultrasound-guided recruitment maneuvers in pediatric patients is nevertheless worth noting.

In our study published in 2021 [15], we reported that owing to ultrasound-guided recruitment maneuvers it was possible to achieve the persistent effect of reducing intraoperative atelectasis and determine patient-based PEEP values that prevented the recurrence of lung aeration disturbances. To our knowledge, this is the only study in which a significant reduction of pressures in the respiratory system necessary for the alveolar recruitment was revealed, resulting in the absence of respiratory tract complications.

In the present study, we observed a reduced need for prolonged postoperative mechanical ventilation in the group of patients who underwent ultrasound-guided pulmonary recruitment during general anesthesia, as well as a slightly reduced postoperative hospitalization period, and a smaller number of ICU admissions due to postoperative complications. We believe these results, despite their lack of statistical significance, to be very advantageous both for the patients involved and the hospital (economic factors, better capacity of departments). This positive effect concerns not only the recruitment procedure *per se*, but also applies the holistic ultrasound image of the organs within the chest (assessment of both the lungs and the heart). Pathologies such as atelectasis and pulmonary congestion can be detected ultrasonographically before the occurrence of clinical symptoms [26–28]. The detection of a pathology may influence decisions made by the anesthesiologist, for instance, decisions concerning fluid therapy intra- and postoperatively [29–34]. The persistence of atelectasis, despite performing the recruitment process, resulted in the administration of high-flow nasal oxygen therapy after extubation, which definitely affected the results.

Study limitations

One of the basic limitations of our study was the absence of a double control group (where one control group would consist of patients undergoing conventional recruitment maneuvers without ultrasound-guided monitoring, and the other – patients who would undergo no intervention). Being familiar with the advantages of ultrasound-guided recruitment, we decided not to create a group undergoing a conventional recruitment procedure (in order to avoid the risk of hyperinflation or hemodynamic complications). Another limitation concerns the possibility of overlapping pathologies during the postoperative period, e.g., exacerbation of heart failure with secondary pneumonia. The results presented in our study concern patients who did not present symptoms of respiratory failure preoperatively. Consequently, these findings cannot be directly extrapolated to patients who exhibited symptoms of respiratory failure before the anesthesia.

Conclusion

Ultrasound-guided intraoperative recruitment maneuvers have a favorable effect on the postoperative period and reduce the incidence of PPCs.

Conflict of interest

Authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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