

Rozprawa na stopień doktora nauk medycznych

**Ultrasonografia płuc w monitorowaniu
śródoperacyjnych manewrów rekrutacyjnych**

lek. Jolanta Cylwik

Oddział Anestezjologii i Intensywnej Terapii

Mazowiecki Szpital Wojewódzki w Siedlcach

Promotor

Dr hab. n. med. prof. nadzw. GUMed Wojciech Kosiak

Dissertation for the PhD Degree in Medical Sciences

**Lung Ultrasonography in the Monitoring of
Intraoperative Recruitment Maneuvers**

Jolanta Cylwik, MD

Anesthesiology and Intensive Care Unit

Mazovia Regional Hospital in Siedlce

Supervisor

***GUMed University Professor, Doctor Habilitated Wojciech
Kosiak***

SPIS TREŚCI / TABLE OF CONTENTS

WYKAZ PRAC WCHODZĄCYCH W SKŁAD ROZPRAWY DOKTORSKIEJ/ LIST OF PAPERS INCLUDED IN THE DOCTORAL DISSERTATION	4
WYKAZ DOROBKU NAUKOWEGO W LATACH 2020-2022 LIST OF SCIENTIFIC ACHIEVEMENTS FOR THE YEARS 2020-2022	6
STRESZCZENIE W JĘZYKU POLSKIM	9
1. SŁOWA KLUCZOWE	10
2. WPROWADZENIE	10
3. CEL PRACY	10
4. MATERIAŁY I METODY	10
5. WYNIKI	10
6. WNIOSKI	11
SUMMARY IN ENGLISH	12
1. KEYWORDS	13
2. INTRODUCTION	13
3. AIM OF THE STUDY	13
4. MATERIALS AND METHODS	13
5. RESULTS	13
6. CONCLUSIONS	14
OMÓWIENIE PUBLIKACJI WCHODZĄCYCH W SKŁAD ROZPRAWY DOKTORSKIEJ / DESCRIPTION OF PUBLICATIONS INCLUDED IN THE DOCTORAL DISSERTATION	15
PUBLIKACJE WCHODZĄCE W SKŁAD ROZPRAWY DOKTORSKIEJ/ PUBLICATIONS INCLUDED IN THE DOCTORAL DISSERTATION	20
WYKAZ CYTOWANEGO PIŚMIENNICTWA /REFERENCES	40
ZGODA KOMISJI BIOETYCZNEJ / CONSENT OF THE BIOETHICS COMMITTEE	50
OŚWIADCZENIA WSPÓŁAUTORÓW / STATEMENTS OF THE CO-AUTHORS	57

**WYKAZ PRAC WCHODZĄCYCH W SKŁAD
ROZPRAWY DOKTORSKIEJ**

**LIST OF PAPERS INCLUDED IN THE
DOCTORAL DISSERTATION**

1. Cylwik J, Buda N.

Lung Ultrasonography in the Monitoring of Intraoperative Recruitment Maneuvers.

Diagnostics (Basel). 2021 Feb 10;11(2):276.

Impact Factor 3,706

Punktacja Ministerialna 70.000

2. Cylwik J, Buda N.

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

J Ultrason 2022; 22: e6–e11

Impact Factor 0,0

Punktacja Ministerialna 20.000

Łącznie:

Impact Factor 3,706

Punktacja Ministerialna 90.000

**WYKAZ DOROBKU NAUKOWEGO W
LATACH 2020-2022**

**LIST OF SCIENTIFIC ACHIEVEMENTS FOR
THE YEARS 2020-2022**

Cylwik J, Buda N. The impact of ultrasound-guided recruitment maneuvers on the risk of postoperative pulmonary complications in patients undergoing general anesthesia.

J Ultrason 2022; 22: e6–e11

IF 0,0

Punktacja Ministerialna 20.000

Buda N, **Cylwik J**, Mróz K, Rudzińska R, Dubik P, Malczewska A, Oraczewska A, Skoczyński S, Suska A, Górecki T, Mendrala K, Piotrkowski J, Gola W, Segura-Grau E, Zamojska A, Welnicki M. Lung Ultrasound Examination in Patients with SARS-CoV-2 Infection: Multicenter Study. J Clin Med. 2021 Jul 23;10(15):3255. doi: 10.3390/jcm10153255.

IF 4,242

Punktacja Ministerialna 140.00

Buda N, Skoczylas A, Demi M, Wojteczek A, **Cylwik J**, Soldati G. Clinical Impact of Vertical Artifacts Changing with Frequency in Lung Ultrasound. Diagnostics (Basel). 2021 Feb 26;11(3):401. doi: 10.3390/diagnostics11030401.

IF 3,706

Punktacja Ministerialna 70.000

Cylwik J, Buda N. Lung Ultrasonography in the Monitoring of Intraoperative Recruitment Maneuvers. Diagnostics (Basel). 2021 Feb 10;11(2):276. doi: 10.3390/diagnostics11020276.

IF 3,706

Punktacja Ministerialna 70.000

Buda N, **Cylwik J**, Kwiecińska R. Similarity of Lung Ultrasound Image in Patients with COVID-19 and COVID-like Illnesses. Am J Respir Crit Care Med. 2021 Jan 6. doi: 10.1164/rccm.202008-3080IM.

IF 21,405

Punktacja Ministerialna 200.00

Cylwik J, Buda N. Possibilities of ultrasonography in diagnosing causes of dyspnea in palliative care cancer patients. Palliat Med Pract 2020;14(3):205-211.

DOI: 10.5603/PMP.2020.0024

Punktacja Ministerialna 20.000

Buda N, Segura-Grau E, **Cylwik J**, Wełnicki M. Lung ultrasound in the diagnosis of COVID-19 infection - A case series and review of the literature. Adv Med.Sci. 2020 Sep;65(2):378-385. doi: 10.1016/j.advms.2020.06.005.

IF 3.287

Punktacja Ministerialna 100.00

•POCUSy, ultrasonografia ratunkowa. Red. Małgorzata Rak, PZWL 2021, rozdział „Wykorzystanie ultrasonografii u pacjentów paliatywnych”

Łącznie:

Impact Factor 36,346

Punktacja Ministerialna 620.000

STRESZCZENIE W JĘZYKU POLSKIM

SŁOWA KLUCZOWE:

manewry rekrutacyjne, niedodma, niewydolność oddechowa, ultrasonografia klatki piersiowej, intensywna terapia

Wprowadzenie: Pooperacyjna niewydolność oddechowa jest poważnym problemem u pacjentów poddawanych znieczuleniu ogólnemu. U około 90% pacjentów wentylowanych mechanicznie w czasie zabiegu operacyjnego może rozwijać się niedodma będąca przyczyną powikłań okołoperacyjnych.

Cel: Celem badania jest określenie, czy przy pomocy przezklatkowej ultrasonografii płuc można optymalizować manewry rekrutacyjne, ograniczając ryzyko wystąpienia powikłań oddechowych u znieczulanych ogólnie pacjentów.

Metodologia: zastosowano metodę łagodnego, stopniowego zwiększania ciśnienia końcowydechowego (PEEP) u pacjentów wentylowanych mechanicznie z jednoczesną ciągłą oceną ultrasonograficzną. Efekt kliniczny oceniono porównując przebieg pooperacyjny chorych z grupy badanej z grupą kontrolną.

Wyniki: do badania włączono 100 pacjentów. Dzięki zastosowanej metodzie redukcję niedodmy uzyskano u 91,9% poddanych procedurze pacjentów. Ciśnienie PEEP potrzebne do zniwelowania ognisk niedodmy wyniosło średnio 17 cmH₂O, przy średnim ciśnieniu szczytowym 29 cmH₂O. Uśrednione ciśnienie PEEP zapobiegające powtórnemu powstawaniu niedodmy wyniosło 9 cmH₂O. Uzyskano istotną poprawę podatności płuc oraz saturacji. W grupie badanej wykazano istotne statystycznie skrócenie czasu hospitalizacji po operacji oraz znacząco mniejsze ryzyko koniczności leczenia w Oddziale Intensywnej Terapii. Dodatkowo wykazano redukcję częstości prowadzenia

przedłużonej pooperacyjnej wentylacji mechanicznej oraz zmniejszenie ryzyka infekcji układu oddechowego.

Wnioski: Manewry rekrutacyjne przeprowadzane pod kontrolą ultrasonografii umożliwiają indywidualizację procesu, dzięki czemu możliwa jest redukcja ciśnień wentylacji wymaganych do upowietrzenia ognisk niedodmy śródoperacyjnej, przy jednoczesnym zmniejszeniu ryzyka powikłań wynikających z wykonania procedury. Dzięki opisanej metodzie można ustalić indywidualny dla pacjenta PEEP zapobiegający powstawaniu niedodmy. Szczególną korzyść z proponowanego postępowania mogą odnieść pacjenci z grupy wysokiego ryzyka wystąpienia oddechowych powikłań pooperacyjnych.

SUMMARY IN ENGLISH

KEYWORDS:

recruitment maneuvers, atelectasis, respiratory failure, chest ultrasonography, intensive care

Introduction: Postoperative respiratory failure is a serious problem in patients who undergo general anesthesia. Approximately 90% of mechanically ventilated patients during the surgery may develop atelectasis that leads to perioperative complications.

Aim: The aim of this study is to determine whether it is possible to optimize recruitment maneuvers with the use of chest ultrasonography, thus limiting the risk of respiratory complications in patients who undergo general anesthesia.

Methodology: The method of incremental increases of positive end-expiratory pressure (PEEP) values with simultaneous continuous ultrasound assessments was employed in mechanically ventilated patients. The clinical outcome was assessed by comparing the postoperative period in the study group with controls.

Results: The study group comprised 100 patients. The employed method allowed for atelectasis reduction in 91.9% of patients. The PEEP necessary to reverse areas of atelectasis averaged 17cmH₂O, with an average peak pressure of 29cmH₂O. The average PEEP that prevented repeat atelectasis was 9cmH₂O. A significant improvement in lung compliance and saturation was obtained. The postoperative hospitalization period was statistically significantly shorter in the study group and the risk of treatment at the Intensive Care Unit significantly lower. Additionally, the necessity of prolonged postoperative mechanical ventilation was reduced as well as the risk of respiratory tract infections.

Conclusions: Ultrasound-guided recruitment maneuvers facilitate the patient-based adjustment of the process. Consequently, the reduction of ventilation pressures necessary to aerate intraoperative atelectasis is possible, with the simultaneous reduction of the risk of procedure-related complications. The described method allows for identifying the individual patient-based PEEP that prevents the development of atelectasis. The suggested procedure may be particularly beneficial for patients at a high risk of postoperative respiratory complications.

**OMÓWIENIE PUBLIKACJI WCHODZĄCYCH
W SKŁAD ROZPRAWY DOKTORSKIEJ**

Mimo dużego rozwoju technik anestezjologii regionalnej znieczulenie ogólne nadal jest niezbędne do przeprowadzenia części procedur zabiegowych. U około 90% pacjentów poddawanych zabiegom chirurgicznym u których stosowana była wentylacja dodatnimi ciśnieniami dochodzi do zaburzeń upowietrzenia płuc. Zjawisko to może przyczyniać się do występowania oddechowych powikłań śród- i pooperacyjnych. Powszechnie stosowaną metodą redukcji zaburzeń upowietrzenia płuc są manewry rekrutacyjne. W literaturze opisano wiele technik rekrutacji – jednak niezależnie od sposobu jej przeprowadzania jest ona obarczona ryzykiem wystąpienia powikłań (np. barotrauma, volumotrauma, destabilizacja hemodynamiczna). Ultrasonografia płuc jest doskonałym narzędziem umożliwiającym przyłóżkową, szybką, i pewną diagnostykę niedodmy podczas prowadzenia znieczulenia ogólnego.

Na rozprawę doktorską pt. **„Ultrasonografia płuc w monitorowaniu śródoperacyjnych manewrów rekrutacyjnych”** składają się dwa powiązane ze sobą tematycznie artykuły opublikowane w międzynarodowych i polskich czasopismach naukowych indeksowanych w bazie PubMed . Łączny Impact Factor prac wynosi 3,706, punktacja Ministerialna 90.000.

Pierwszy z artykułów pt. “Lung Ultrasonography in the Monitoring of Intraoperative Recruitment Maneuvers” (Diagnostics (Basel), 2021 Feb 10; 11(2):276) jest pracą oryginalną. Celem badania było określenie, czy przy pomocy przezklatkowej ultrasonografii płuc można optymalizować manewry rekrutacyjne (wyznaczenie indywidualnego dla pacjenta ciśnienia otwarcia niedodmowych pęcherzyków płucnych, jak i ciśnienia zapobiegającego ich ponownemu zapadaniu się). Do badania zrekrutowano 100 pacjentów

poddanych znieczuleniu ogólnemu, u których zastosowano metodę łagodnego, stopniowego zwiększania ciśnienia końcowowdechowego (PEEP) z jednoczesną ciągłą oceną ultrasonograficzną. Ciśnienie PEEP potrzebne do zniwelowania ognisk niedodmy wyniosło średnio 17 cmH₂O, przy średnim ciśnieniu szczytowym 29 cmH₂O. Uśrednione ciśnienie PEEP zapobiegające powtórному powstawaniu niedodmy wyniosło 9 cmH₂O. Uzyskano istotną poprawę podatności płuc oraz saturacji przy jednoczesnej znacznej redukcji ciśnień wentylacji w stosunku do klasycznych manewrów rekrutacyjnych. Dodatkowymi interesującymi wynikami tego badania jest stwierdzenie u 19% pacjentów (którzy nie manifestowali cech niewydolności oddechowej) istotnych patologii w przezklatkowym badaniu ultrasonograficznym płuc już w badaniu przedoperacyjnym. Osiem osób (8%) miało cechy zastoju w krążeniu płucnym (obustronnie, liczne artefakty linii B w polach dolnych). U 11 osób (11%) stwierdzono obecność obszarów niedodmy miąższu płucnego, w jednym przypadku z towarzyszącym bezechowym płynem w jamie opłucnej.

W drugim artykule wchodzącym w skład pracy doktorskiej, pt. „The impact of ultrasound-guided recruitment maneuvers on the risk of postoperative pulmonary complications in patients undergoing general anesthesia” (J Ultrason 2022; 22: e6–e11) dokonano oceny przebiegu okresu okołoperacyjnego u pacjentów u których wykonano w czasie znieczulenia ogólnego rekrutację niedodmowych obszarów płuc pod kontrolą ultrasonograficzną. Uzyskane wyniki porównano z grupą kontrolną (pacjenci u których nie wykonywano rekrutacji). W grupie chorych rekrutowanych wg. proponowanej metody wykazano istotne statystycznie skrócenie czasu hospitalizacji po operacji ($p = 0,003$) oraz

znacząco mniejsze ryzyko konieczności leczenia w oddziale intensywnej terapii. Dodatkowo wykazano redukcję częstości prowadzenia przedłużonej pooperacyjnej wentylacji mechanicznej oraz zmniejszenie ryzyka infekcji układu oddechowego. W artykule tym dodatkowo zamieszczono krótki przegląd piśmiennictwa – omówiono główne wnioski z pięciu dostępnych w bazach naukowych artykułów oryginalnych ściśle dotyczących tematu.

Opisywana w pracy metoda rekrutacji z ciągłą oceną ultrasonograficzną ma jednak ograniczenia. Śródoperacyjnie zazwyczaj nie ma dobrego dostępu do obszarów płuc najbardziej narażonych na niedodmę (u chorego leżącego na plecach tylne partie płuc), dodatkowo stosowane obłożenia chirurgiczne mogą utrudniać dostęp do klatki piersiowej. Interpretacja obrazu jest zależna od umiejętności i doświadczenia osoby wykonującej procedurę (z tego powodu zbieranie danych klinicznych było wykonywane przez jedną osobę). W czasie przeprowadzania badań korzystano z wentylacji mechanicznej w trybie objętościowo-zmiennym, w związku z czym nie było możliwości oceny ciśnienia plateau i driving pressure. Kolejnym ograniczeniem jest fakt, że badaniem ultrasonograficznym płuc nie jesteśmy w stanie wykryć hiperinflacji, do której mogą doprowadzić manewry rekrutacyjne (jak jednak wykazano ciśnienia szczytowe w opisywanej metodzie są niższe niż w tradycyjnych manewrach rekrutacyjnych, można więc przypuszczać, że ryzyko hiperinflacji jest stosunkowo niewielkie).

Mimo wymienionych ograniczeń opisywana metoda śródoperacyjnej rekrutacji płuc jest skuteczna klinicznie i pozwala w zindywidualizowany sposób niwelować powstałe z czasie znieczulenia obszary niedodmy mięszu płucnego. Dzięki opisanej technice można ustalić indywidualny dla pacjenta PEEP

zapobiegający powstawaniu niedodmy. Szczególną korzyść z proponowanego postępowania mogą odnieść pacjenci z grupy wysokiego ryzyka wystąpienia oddechowych powikłań pooperacyjnych.

**PUBLIKACJE WCHODZĄCE W SKŁAD
ROZPRAWY DOKTORSKIEJ**

**PUBLICATIONS INCLUDED IN THE
DOCTORAL DISSERTATION**

Article

Lung Ultrasonography in the Monitoring of Intraoperative Recruitment Maneuvers

Jolanta Cylwik¹ and Natalia Buda^{2,*}

¹ Anesthesiology and Intensive Care Unit, Mazovia Regional Hospital, 08-110 Siedlce, Poland; jolacylwik@o2.pl

² Department of Internal Medicine, Connective Tissue Diseases and Geriatrics, Medical University of Gdansk, 80-210 Gdańsk, Poland

* Correspondence: natabud@wp.pl

Abstract: Introduction: Postoperative respiratory failure is a serious problem in patients who undergo general anesthesia. Approximately 90% of mechanically ventilated patients during the surgery may develop atelectasis that leads to perioperative complications. Aim: The aim of this study is to determine whether it is possible to optimize recruitment maneuvers with the use of chest ultrasonography, thus limiting the risk of respiratory complications in patients who undergo general anesthesia. Methodology: The method of incremental increases in positive end-expiratory pressure (PEEP) values with simultaneous continuous ultrasound assessments was employed in mechanically ventilated patients. Results: The study group comprised 100 patients. The employed method allowed for atelectasis reduction in 91.9% of patients. The PEEP necessary to reverse areas of atelectasis averaged 17cmH₂O, with an average peak pressure of 29cmH₂O. The average PEEP that prevented repeat atelectasis was 9cmH₂O. A significant improvement in lung compliance and saturation was obtained. Conclusions: Ultrasound-guided recruitment maneuvers facilitate the patient-based adjustment of the process. Consequently, the reduction in ventilation pressures necessary to aerate intraoperative atelectasis is possible, with the simultaneous reduction in the risk of procedure-related complications.

Citation: Cylwik, J.; Buda, N. Lung Ultrasonography in the Monitoring of Intraoperative Recruitment Maneuvers. *Diagnostics* **2021**, *11*, 276. <https://doi.org/10.3390/diagnostics11020276>

Academic Editor: Byeong-Ho Jeong
Received: 6 December 2020
Accepted: 8 February 2021
Published: 10 February 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Keywords: atelectasis; intensive care; respiratory failure; chest ultrasonography

1. Introduction

Despite extensive advances in regional anesthesia methods, general anesthesia still remains indispensable for some surgical procedures—approximately 90% of surgical patients develop disturbances of lung aeration following positive pressure mechanical ventilation [1,2]. The risk of perioperative atelectasis depends on many factors, such as the type and duration of surgery, surgical technique and patient's general status (obesity, comorbidities). The manner of anesthesia administration and mechanical ventilation is also of significance [3–5]. The extent and severity of perioperative disturbances of lung aeration may vary from small and clinically insignificant local hypoventilation areas to the appearance of large areas of completely nonaerated lung tissue. This may contribute to the development of intra- and post-operative complications [4,6], including gas exchange pathologies (mainly hypoxia), and may potentially trigger a local inflammatory response leading to lung damage (VILI—ventilator-induced lung injury) [7–9]. Recruitment maneuvers are a routine procedure for reducing aeration disturbances. Many recruitment techniques have been described in the literature [10–14]. However, irrespective of how the recruitment is administered, this procedure involves the risk of complications (e.g., barotrauma, volutrauma, hemodynamic destabilization).

Lung ultrasonography is a modality facilitating bedside, quick and accurate diagnosis of atelectasis during general anesthesia [15–19]. The major advantage of ultrasound

assessment is that it can be done in the operating room, repetitively and noninvasively, without the necessity to transport the patient to the radiology unit.

The aim of the study is to determine whether the application of chest ultrasonography allows optimizing intraoperative recruitment maneuvers that reduce atelectasis in mechanically ventilated patients under general anesthesia. The question was asked whether it is possible to determine patient-specific pressure necessary to open collapsed alveoli and pressure that prevents repeat alveolar collapse, and further whether such a procedure allows reducing pressure during recruitment maneuvers (as compared to traditional methods), thus increasing the safety of the procedure both in the context of hemodynamic disturbances and the development of volutrauma.

2. Material and Methods

2.1. Ethic Statement

The study was approved by the Bioethical Committee of the Regional Medical Chamber in Warsaw (no KB/1154/19, approval date 19 September 2019).

2.2. Patient Qualification

Adult patients undergoing general anesthesia during elective and emergency surgery, who were able to provide their written informed consent for the participation in the study were qualified. They were assessed as ASA1, ASA2, ASA3 or ASA4 according to the ASA score (the American Society of Anesthesiologists physical status classification system). Exclusion criteria included: age below 18 years, risk of ASA5, pregnancy, patients with increased intracranial pressure and the inability to provide conscious informed consent for participation in the study. Patients undergoing chest surgeries were also excluded.

2.3. Ultrasound Technique and Settings

Ultrasound examinations were performed and recorded with Philips Sparq ultrasound unit (Philips, Bothell, WA, USA), with a convex transducer (2–6 MHz) and linear transducer (5–12 MHz). The type of transducer was individually selected depending on the patient's constitution. The examination was performed with the LUNG preset (characterized by speckle reduction, compound imaging, and tissue harmonic imaging filters switched off). The examination was performed by one anesthesiologist, with 10 years' experience in lung ultrasonography. Patients were always examined in the supine position. The transducer head was applied at 6 points over the anterior and lateral part of the chest, symmetrically at 3 assessment points on each side and evaluated repeatedly. The first point was localized subclavically in the midclavicular line; the second point was located at the level of the 4th intercostal space in the anterior axillary line, and the third point was in the posterior axillary line at the level of the costodiaphragmatic recess (Figure 1.)

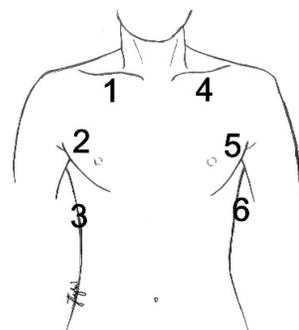


Figure 1. Lung ultrasound assessment points in the study.

The transducer head was preferably placed along the intercostal space to visualize the longest possible section of the pleura. The obtained image was qualified to a specific group (A profile—normal image, B profile—presence of B-line artifacts typical of the interstitial syndrome, C profile—subpleural consolidations characteristic for atelectasis, P profile—pleural effusion), and the result was recorded in the examination protocol, providing also current mechanical ventilation parameters and transcutaneous oxygen saturation levels (SaO₂).

2.4. Initial Mechanical Ventilation Parameters

All patients qualified for the study were monitored and administered with general anesthesia depending on age, comorbidities and the extent of surgery. After intubation, mechanical ventilation was performed in the volume control ventilation (VCV) mode in a uniform manner (Philips IntelliSave AX700 anesthesia machine). Tidal volume (V_t) was set at 7 mL/kg of body mass, and the frequency of breaths was regulated so that end-tidal CO₂ (EtCO₂) was at the level of 35–40 mm Hg. Additionally, FiO₂ was 0.35, and the initial positive end-expiratory pressure (PEEP) was always 5cmH₂O.

2.5. Intraoperative Ultrasound Assessment Protocol

The first ultrasound assessment was performed before the induction of general anesthesia, and the second 10 min after intubation and the beginning of mechanical ventilation. When features of atelectasis were detected during the first or second assessment, the patient was qualified for the recruitment maneuver to be administered as quickly as possible. When ultrasonographic features of atelectasis were absent during the initial assessment, depending on the patient's status during anesthesia and the results of taken measurements (transcutaneous blood gas monitoring, lung compliance), the decision concerning ultrasound reassessment was made. It was assumed that the decrease in transcutaneous oxygen saturation (SaO₂) below 94% or decrease in lung compliance by a minimum of 15% would indicate the necessity of repeated lung assessment for atelectasis (compliance determined automatically by the anesthesia machine).

When areas of atelectasis were visualized in the lungs, having excluded contraindications, the recruitment algorithm was introduced entirely guided by ultrasound. The patient's hemodynamic instability was the contraindication for the maneuver [20,21].

2.6. Recruitment Protocol in the Study Group

The suggested recruitment method involved an incremental increase in positive end-expiratory pressure (PEEP) with simultaneous continuous ultrasound assessments. During the entire procedure, the transducer head was placed over one point of the chest, selected by the operator, where the area of atelectasis was detected intraoperatively. After each increase in the PEEP value by 2cmH₂O, the area of atelectasis was observed for a minimum of 5 consecutive respiratory cycles. The PEEP value was increased until the aeration of the area of atelectasis (max. value of 19cmH₂O, which resulted from the limitations of the anesthesia machine) or until peak pressure values of 40cmH₂O were obtained. When the aim was achieved (i.e., aeration of the area of atelectasis was visualized in the ultrasound image), ventilation with patient-specific pressure was maintained for a minimum of 60 s, with a simultaneous monitoring of hemodynamic stability. Next, the PEEP was reduced by 2cmH₂O every 5 respiratory cycles until detecting the first features of atelectasis—then the last PEEP value was increased by 2cmH₂O and ventilation was continued at such pressure. The last ultrasound assessment was performed 2 h after extubation (Figure 2).

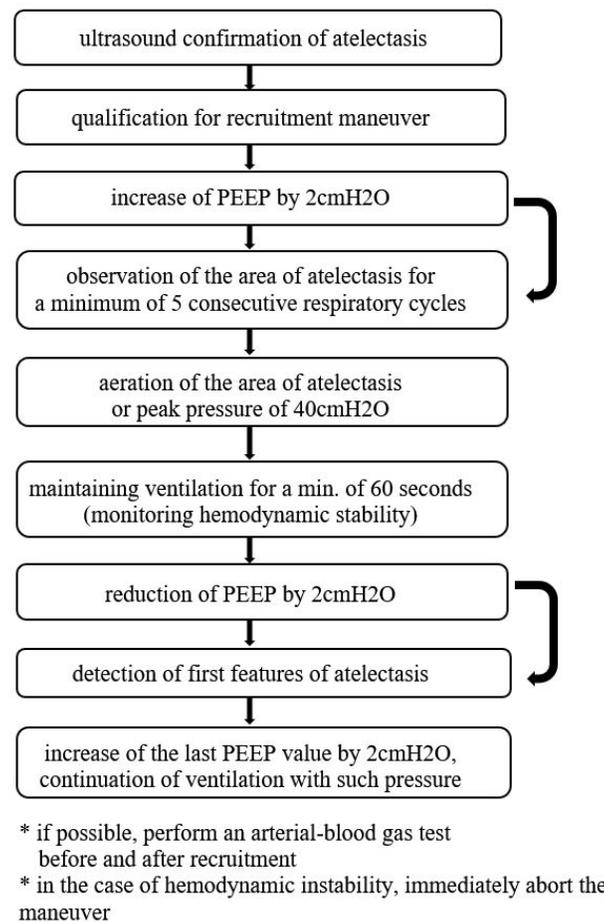


Figure 2. Recruitment maneuver algorithm employed in the study (modified Tusman’s protocol [22]).

2.7. Statistical Analysis

The collected data were analyzed statistically using IBM SPSS Statistics 25.0 software. To compare the two groups for qualitative data (nominal or categorical), Pearson’s chi-squared test was used, or Fisher’s exact test when the expected number was smaller than 5. For quantitative data, Student’s t-test was used for independent variables or Mann–Whitney U test when the numbers in the compared groups were different. To compare the results of lung ultrasound assessment at 6 points (normal vs. abnormal) during one assessment, Cochran’s Q test was employed. To establish correlations between quantitative/ordinal data, correlation analysis was performed with the use of Spearman’s rank correlation coefficient. To assess changes in compliance within the stages of assessments, repeated measures analysis of variance was performed, and to assess changes in saturation—its non-parametric equivalent—the Friedman test was used. The level of significance was $\alpha = 0.05$.

3. Results

3.1. Analysis of the Study Group and the Control Group

The study group was composed of 100 patients. The average age of patients was about 64 years, and the average BMI value was about 28. Arterial hypertension was the most frequent chronic coexisting disease (55% of patients). In the majority of cases, surgery was elective, and its duration usually did not exceed 4 h (Table 1).

Table 1. Clinical characteristics of study group.

Variable	Data (n = 100)
Gender n (%)	
Females	66 (66.0)
Males	34 (34.0)
Age M(SD)	63.90 (11.34)
BMI M(SD)	28.31 (5.08)
ASA Score n (%)	
1	1 (1.0)
2	27 (27.0)
3	66 (66.0)
4	6 (6.0)
MRC Score n (%)	
0	49 (49.0)
1	40 (40.0)
2	11 (11.0)
Coexisting chronic disease n (%)	
Hypertension	55 (55.0)
Ischemic heart disease	13 (13.0)
COPD	1 (1.0)
Asthma	6 (6.0)
Diabetes	24 (24.0)
Atherosclerosis	12 (12.0)
Type of surgery n (%)	
Elective	90 (90.0)
Emergency	10 (10.0)
Method n (%)	
Classic	82 (82.0)
Laparoscopy	18 (18.0)
Surgery duration n (%)	
<2 h	45 (45.0)
2–4 h	44 (44.0)
>4 h	11 (11.0)

3.2. Preoperative Ultrasound Assessment

In the preoperative ultrasound assessment, a normal lung image was obtained in 81 patients (81%). Eight patients (8%) had features of pulmonary congestion (bilaterally, multiple B-line artifacts in lower lung fields). The presence of atelectasis affecting areas of lung parenchyma was detected in 11 patients (11%) at this stage, in one case with the accompanying anechoic fluid in the pleural cavity. Additionally, decreased transcutaneous oxygen saturation when breathing air (93% or lower) was detected in nine patients (the lung image had features of abnormalities in six patients in this group).

3.3. Intraoperative Ultrasound Assessment

Perioperative atelectasis was found in ultrasound images of 87 patients (87%) in total. In 11 cases (11%), atelectasis was detected already in the preoperative assessment, in 14 patients (14%) it was visualized after 10 min of mechanical ventilation. Due to decreased values of transcutaneous oxygen saturation and/or decreased lung compliance by a minimum of 15% in relation to the initial value, ultrasound reassessment was performed in 62 patients.

In all cases, areas of atelectasis were revealed. Decreased saturation, as an isolated parameter qualifying for lung ultrasound reassessment, only occurred in two cases. In 13 patients (13%), the first two ultrasound assessments did not visualize areas of atelectasis, and decreased oxygen saturation and lung compliance were not observed during anesthesia.

Eventually, 86 patients were qualified for the ultrasound-guided recruitment maneuver. One patient, despite detected atelectasis accompanied with decreased compliance, was disqualified from the recruitment maneuver due to hemodynamic instability and the necessity to administer noradrenaline infusion. In all qualified patients (100%), areas of atelectasis were visualized. Decrease in saturation occurred in 12 patients (14%), and significant decrease in compliance in 77 patients (89.5%).

3.4. Effect of Ultrasound-Guided Recruitment Maneuver

Recruitment maneuvers followed the adopted protocol. In 79 patients (91.9%), the recruitment was effective, i.e., aeration of the areas of atelectasis was achieved. Completely normal lung ultrasound images were revealed in 29 patients (33.7%) (Figure 3, Figure 4). Improvement of aeration, but with persistent interstitial syndrome, was found in 50 patients (58.1%) (Figure 4), and lack of improvement, that is persistent atelectasis, was observed in 7 patients (8.1%). In six patients (7%), mild hypotension was observed during PEEP de-escalation. Due to the clinical status of these patients, recruitment protocol was modified.

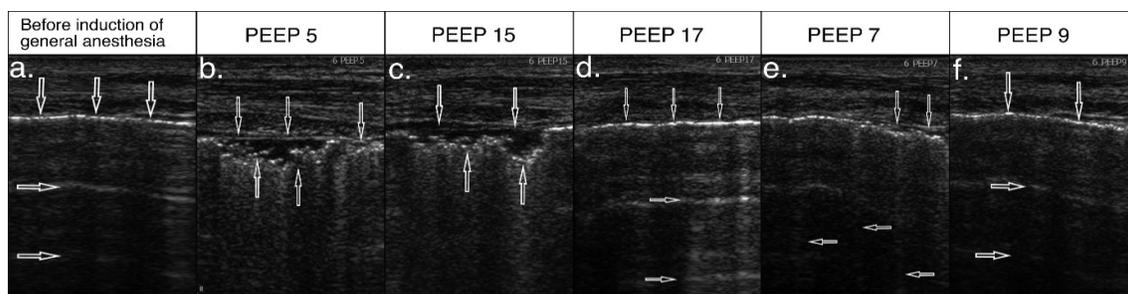


Figure 3. Recruitment process with a positive ultrasound effect. (a) Lung ultrasound (LUS) image before anesthesia—normal, hyperechoic pleural line (\downarrow) and A-line artifacts (\rightarrow), normal image; (b) control assessment during anesthesia, at positive end-expiratory pressure (PEEP) 5cmH₂O—abnormal, fragmented pleural line (\downarrow), subpleural consolidation (\uparrow), A-line artifacts not visible, image characteristic for atelectasis; (c) when increasing PEEP to 15cmH₂O—ultrasound features of atelectasis persist; (d) when achieving PEEP value of 17cmH₂O—normal, hyperechoic pleural line (\downarrow) and A-line artifact (\rightarrow) visible again; (e) when reducing pressures, PEEP 7cmH₂O—segmental disturbances in the pleural line continuity (\downarrow) visible again and vertical artifacts reappear (\leftarrow)—initial image of atelectasis; (f) after increasing end-expiratory pressure by 2cmH₂O, disturbances in lung aeration reversed and normal pleural line and A-line artifacts were visualized.

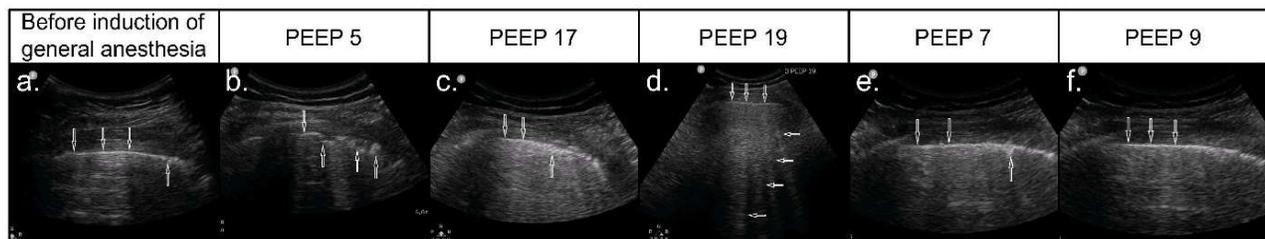


Figure 4. Recruitment process with an incomplete ultrasound effect. (a) LUS image before anesthesia—normal, hyperechoic pleural line (\downarrow) and small abnormalities within the pleural line (\uparrow) with small subpleural consolidations, as in segmental atelectasis; (b) control assessment after the induction of anesthesia, at PEEP 5cmH₂O—blurred fragmented pleural line (\downarrow) with hypoechoic subpleural consolidations (\uparrow), image typical of atelectasis; (c) when increasing PEEP to 17cmH₂O—persistent ultrasound features of atelectasis with a visible reduction in subpleural consolidations (\uparrow); (d) when achieving PEEP value of 19cmH₂O—continuous pleural line (\downarrow) with multiple B-Line artifacts B (\leftarrow); (e) when reducing pressures, PEEP 9cmH₂O—segmental disturbances in the pleural line continuity (\uparrow) visible again—initial image of atelectasis; (f) after increasing end-expiratory pressure by 2cmH₂O, to 9cmH₂O, improvement in the pleural line image and better lung aeration were achieved.

3.5. Postoperative Ultrasound Assessment

In postoperative ultrasound assessment, the lung image was normal in 52 patients (52%), in 43 patients (43%) interstitial syndrome was visible, and atelectasis was detected in only 13 patients (13%). The percentage distribution of ultrasound assessment results at consecutive stages of the procedure are presented in Figure 5.

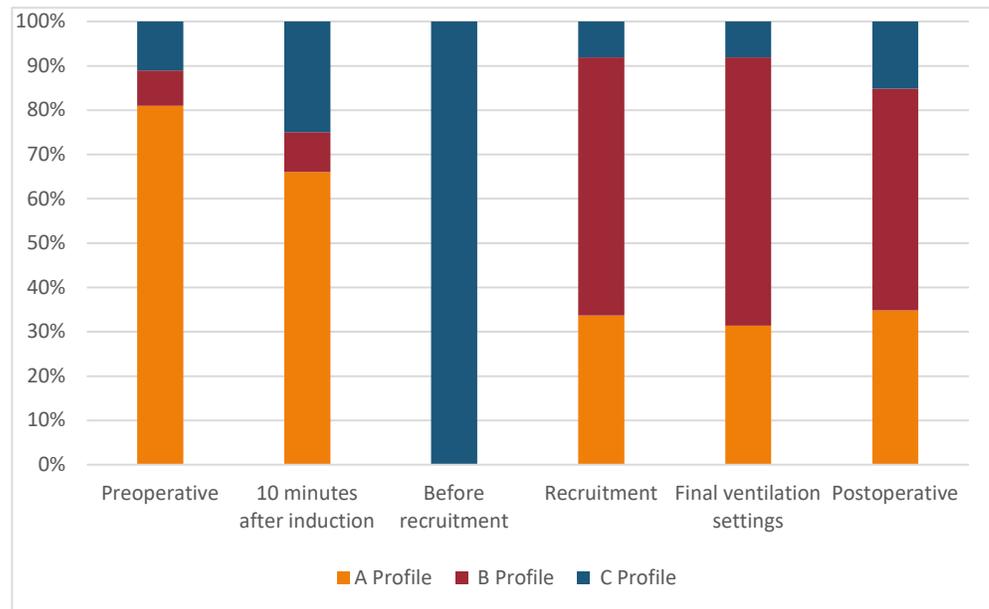


Figure 5. Percentage distribution of results at consecutive stages of lung ultrasound assessment.

The localization of the ultrasound-detected areas of atelectasis during the entire procedure was analyzed. Statistically, significantly more frequent abnormal results (areas of atelectasis) were found bilaterally in the lower fields of the lateral chest (assessment points 3 and 6) at each stage of the assessment as compared to the remaining points ($p \leq 0.001$) (Table 2). Consequently, it may be assumed that points 3 and 6 were crucial because they indicated the largest percentage of examined patients with abnormal results.

Table 2. Frequency of atelectasis depending on localization.

Assessment	Atelectasis (N) n (%)						Q(5)	p
	1	2	3	4	5	6		
preoperative	1%	3%	9%	1%	3%	9%	30.59	<0.001
10 min. after induction	1%	3%	20%	1%	5%	23%	85.17	<0.001
before recruitment	2%	10%	92%	2%	13%	92%	343.00	<0.001
recruitment	2%	2%	6%	2%	2%	7%	21.15	0.001
final PEEP settings	2%	2%	6%	2%	2%	7%	21.15	0.001
2 h after extubation	2%	2%	10%	2%	2%	13%	40.33	<0.001

Legend. 1—right side—upper field; 2—right side—middle field; 3—right side—lower field; 4—left side—upper field; 5—left side—middle field; 6—left side—lower field. Q—Cochran’s Q test value; p—test probability.

3.6. Analysis of Intraoperative Mechanical Ventilation Parameters

Next, mechanical ventilation parameters were analyzed. The following data were considered: peak pressure, PEEP, lung compliance, and, additionally, oxygen saturation. Detailed results are presented in Table 3.

Table 3. Basic statistics for peak pressure, PEEP, saturation and compliance at consecutive stages of the procedure.

Assessment	Me	IQR	Min.	Max.
preoperatively				
Saturation	96.00	2.00	88.00	99.00
10 min. after induction				
Saturation	99.00	1.00	92.00	100.00
Peak pressure	15.50	3.00	12.00	25.00
Compliance	42.00	11.00	20.00	70.00
PEEP	5.00	0.00	5.00	5.00
before recruitment				
Saturation	99.00	2.00	92.00	100.00
Peak pressure	18.00	3.00	12.00	26.00
Compliance	34.00	11.25	19.00	60.00
PEEP	5.00	0.00	5.00	5.00
recruitment				
Saturation	99.00	0.00	96.00	100.00
Peak pressure	29.00	4.00	19.00	34.00
PEEP	17.00	2.50	9.00	19.00
final ventilation settings				
Saturation	99.00	0.00	98.00	100.00
Peak pressure	18.00	4.00	13.00	26.00
Compliance	47.00	15.50	29.00	89.00
PEEP	9.00	2.00	5.00	11.00
2 h after extubation				
Saturation	99.00	0.00	97.00	100.00

Legend. Me—median; IQR—interquartile range; Min.—minimum value; Max.—maximum value.

Statistical analyses revealed that the mean PEEP at which atelectasis reversed in the ultrasound image was 17cmH₂O. In the case of one patient (1.1%), sufficient PEEP resulting in the reduction in atelectasis was 9cmH₂O, for three patients (3.4%) the PEEP value was 11cmH₂O, and for nine patients (10.4%) it was 13cmH₂O. The mean end-expiratory pressure preventing the alveoli collapse was 9cmH₂O (the minimal value: 5cmH₂O, the maximum value: 11cmH₂O). During the performed recruitment process, no patient achieved peak pressure higher than 34cmH₂O, and mean peak pressure was 28cmH₂O. The difference between peak pressure and the value of end-expiratory pressure remained low during the entire recruitment process, and in the final stage it was lower than at the beginning of anesthesia.

3.7. Analysis of Transcutaneous Oxygen Saturation in the Perioperative Period

The analysis revealed that the saturation level at the preoperative assessment was significantly lower than during other measurements ($p < 0.001$). In the 2 h postoperative period, saturation levels did not decrease, including those patients who had abnormal saturation before surgery. In the entire study group, SaO₂ ranged between 97 and 100%.

3.8. Analysis of Changes in Lung Compliance in the Perioperative Period

Repeated measures analysis of variance was performed to establish changes in compliance at consecutive stages of the procedure. Statistically significant differences were revealed between all taken measurements ($p < 0.001$). The lowest compliance level occurred before recruitment ($M = 35.81$; $SE = 0.94$), and the highest in the measurement taken after recruitment maneuvers ($M = 49.91$; $SE = 1.33$).

4. Discussion

Recruitment maneuvers are a routine intervention procedure in mechanically ventilated patients. Irrespective of whether they are administered for patients undergoing surgery or patients with acute respiratory distress syndrome (ARDS) treated at the ICU, they require monitoring to assess their effectiveness. Apart from clinical monitoring (e.g., assessment of lung compliance dynamics, assessment of arterial blood gas), it is also possible to assess the effectiveness of the performed maneuvers using ultrasound [23]. Numerous publications concerning the employment of computed tomography (CT) [24,25] and electrical impedance tomography [12,26,27] have been published. CT requires the patient to be transported to the radiology unit, which is not always possible due to the patient's status, and is actually impossible for patients for whom recruitment is performed intraoperatively. Despite common access to ultrasound devices in operating rooms and ICUs, the number of publications devoted to the use of ultrasonography in monitoring recruitment maneuvers is scarce and studies refer mostly to patients with ARDS [28–30]. In a healthy lung, in a dynamic ultrasound image, an aerated lung is characterized by the normal pleural line, mirror-image artifact and A-line artifacts with simultaneously preserved lung sliding [31]. Along with the reduction in aeration, single, and with the exacerbation of atelectasis, multiple overlapping B-lines appear. The next stage is the appearance of subpleural consolidations with a static air bronchogram or without bronchogram, with frequent B-lines coexisting marginally. When the aeration of pulmonary alveoli improves, the changes are observed in the reverse order: the initial subpleural consolidations will turn into B-line artifacts, and with further improvement—it is possible to obtain the normal lung image, i.e., A-line artifacts [31–35].

From the publications discussing this topic, Tusman's paper [22] merits attention as he proposes and justifies the use of ultrasound during recruitment. The algorithm suggested by him, after modification, was implemented in this study. The study published by Généreux [36] reported that areas of atelectasis were significantly less frequently visualized in ultrasound in patients who underwent recruitment maneuvers; however, this effect disappeared after extubation. In our study, the permanent effect of improved lung aeration was achieved, and the recruited status did not lessen after the discontinuation of mechanical ventilation. We associate this with retaining patient-specific PEEP after the completed recruitment maneuver. We believe that the continuation of ventilation with individually determined end-expiratory pressure level prevents the worsening of lung aeration and improves the final outcome of the procedure. The study published by Song [37] is interesting in this context as it discusses the employment of lung ultrasound in preventing anesthesia-induced atelectasis in infants. It reported that the PEEP level of 5cmH₂O did not prevent the development of atelectasis. We obtained similar results in our study—at the initial PEEP of 5cmH₂O, in 87% of patients we detected subpleural areas of atelectasis. The mean pressure that prevented disturbances in aeration was 9cmH₂O. Considering the specificity of mechanical ventilation in the pediatric population and significant differences in lung compliance in children, these results, we believe, are not directly comparable.

The main aim of this study was to determine whether the suggested recruitment method with a simultaneous ultrasound assessment may lead to the reduction in mechanical ventilation pressures owing to the patient-based adjustment of the therapy. We revealed that in 91.9% of patients it was possible to recruit atelectasis successfully with the

mean peak pressure of 29cmH₂O and the mean PEEP of 17cmH₂O. The achieved pressure values are significantly lower as compared to non-customized therapy, which reduces the risk of hyperinflation and other complications. In seven patients (8.1%) the reduction in atelectasis, as observed in the ultrasound image, was not successful. We suppose that this may be associated with additional overlapping pathologies in these patients, e.g., heart failure and pulmonary congestion. This issue requires further research—extending the assessment to include echocardiographic projections and, additionally, the assessment of the inferior vena cava [38–43].

An important issue observed in our study is that abnormalities in lung ultrasound images were found preoperatively in as many as 19 patients (19%); 5 of them underwent emergency surgery, and 14 had elective surgery. Patients who qualified for elective surgeries did not present with dyspnea and symptoms of decompensated heart failure. This observation confirms that lung ultrasound is a diagnostic tool that facilitates the detection of lung pathologies at an early stage, before overt clinical symptoms appear [31–33]. Abnormalities detected preoperatively impacted the activities undertaken intra- and post-operatively, mostly fluid therapy, decisions concerning the prolonged monitoring of the patient's status, and the employment of high-flow nasal cannula and respiratory rehabilitation. In our view, the suggested procedure reduces the risk of postoperative respiratory complications. However, it is most beneficial for patients with comorbidities. In the available literature, there are reports that do not confirm the effectiveness of recruitment maneuvers in the context of reducing the risk of postoperative complications [44–46]. Yet, these studies were not based on ultrasound monitoring.

Irrespective of the recruitment method, this procedure is associated with the risk of complications (e.g., barotrauma, volutrauma, hemodynamic destabilization). In our study, we did not find any significant clinical complications arising from alveolar recruitment. The proposed method assumes a gradual and slow increase in the PEEP level, facilitating the adaptation of the circulatory system to pressure changes in the chest. Moreover, maneuvers were performed in patients with stabilized intravascular volume, which significantly reduced the risk of hypotension. During classic intraoperative monitoring, including ultrasonography, we are not able to detect the risk of barotrauma and volutrauma. To this end, it is necessary to measure transpulmonary pressure [47,48].

In our study, we have revealed the positive impact of the employed method, but this method has, however, some limitations. The interpretation of the ultrasound image is largely dependent on the operator. Consequently, in order to increase the reliability of our results, all ultrasound examinations in our study were performed by one person, experienced in lung ultrasound assessment. It would be optimal if ultrasound images were assessed by two operators independently, taking into account the degree of agreement and consistency between the results. However, the limitations imposed by performing the examinations in the operating room make it impossible to implement such a solution. Another important limitation, in our view, is the fact that lung ultrasound does not detect hyperinflation that may occur during recruitment, definitely an unwanted phenomenon. Ultrasound images of normally aerated lungs and excessively aerated lungs will be identical. Considering that owing to the customization of the recruitment process, quite low peak pressures were obtained (on average 29cmH₂O), the risk of hyperinflation seems lower than in traditional recruitment maneuvers, where often pressures of approximately 40cmH₂O are used. B-lines in lung ultrasound image suggest pathologies involving the interstitium. This may indicate progressing atelectasis, but the appearance of B-lines artifacts may also result from intraoperative coexisting circulatory insufficiency or hypervolemia. It is not possible to differentiate the etiology of B-lines in ultrasound. The type of surgery, the position of the patient, and the type of surgical draping may make the ultrasound examination difficult to perform effectively for the operator. This study concerns, for the most part, patients who underwent elective surgeries and whose initial status was generally good. The results cannot be referred to patients with severe lung diseases, respiratory failure and ARDS.

5. Conclusions

Ultrasound-guided recruitment maneuvers facilitate the procedure customization, thus allowing for the reduction in ventilation pressures required to aerate the areas of intraoperative atelectasis, simultaneously reducing the risk of complications resulting from the procedure. The described method allows for the individual patient-based adjustment of the PEEP value that prevents atelectasis. The suggested protocol may be particularly beneficial for patients with a high risk of postoperative respiratory complications.

Author Contributions: conceptualization, J.C. and N.B.; methodology J.C. and N.B.; investigation J.C., data curation J.C. writing—original draft preparation, J.C. and N.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by Ethics Committee of the Regional Medical Chamber in Warsaw (no KB/1154/19, approval date 19 September 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Brismar, B.; Hedenstierna, G.; Lundquist, H.; Strandberg, Å.; Svensson, L.; Tokics, L. Pulmonary Densities during Anesthesia with Muscular Relaxation—A Proposal of Atelectasis. *Anesthesiology* **1985**, *62*, 422–428, doi:10.1097/0000542-198504000-00009.
2. Ladha, K.; Vidal Melo, M.F.; McLean, D.J.; Wanderer, J.P.; Grabitz, S.D.; Kurth, T.; Eikermann, M. Intraoperative protective mechanical ventilation and risk of postoperative respiratory complications: Hospital-based registry study. *BMJ* **2015**, *351*, h3646, doi:10.1136/bmj.h3646.
3. Güldner, A.; Kiss, T.; Serpa Neto, A.; Hemmes, S.N.; Canet, J.; Spieth, P.M.; Rocco, P.R.; Schultz, M.J.; Pelosi, P.; Gama de Abreu, M. In-traoperative protective mechanical ventilation for prevention of postoperative pulmonary complications: A comprehensive review of the role of tidal volume, positive end-expiratory pressure, and lung recruitment maneuvers. *Anesthesiology* **2015**, *123*, 692–713.
4. Hemmes, S.N.; Serpa Neto, A.; Schultz, M.J. Intraoperative ventilatory strategies to prevent postoperative pulmonary complications: A meta-analysis. *Curr. Opin. Anaesthesiol.* **2013**, *26*, 126–133.
5. Tusman, G.; Böhm, S.H. Prevention and reversal of lung collapse during the intra-operative period. *Best Pr. Res. Clin. Anaesthesiol.* **2010**, *24*, 183–197, doi:10.1016/j.bpa.2010.02.006.
6. Tusman, G.; Böhm, S.H.; Warner, D.O.; Sprung, J. Atelectasis and perioperative pulmonary complications in high-risk patients. *Curr. Opin. Anaesthesiol.* **2012**, *25*, 1–10, doi:10.1097/aco.0b013e32834dd1eb.
7. Steinberg, J.M.; Schiller, H.J.; Halter, J.M.; Gatto, L.A.; Lee, H.M.; Pavone, L.A.; Nieman, G.F. Alveolar instability causes early ventilator-induced lung injury independent of neutrophils. *Am. J. Respir. Crit. Care Med.* **2004**, *169*, 57–63.
8. Tremblay, L.N.; Slutsky, A.S. Ventilator-induced injury: From barotrauma to biotrauma. *Proc. Assoc. Am. Physicians* **1998**, *110*, 482–488.
9. Halbertsma, F.J.J.; Vaneker, M.; Scheffer, G.J.; Van Der Hoeven, J.G. Cytokines and biotrauma in ventilator-induced lung injury: A critical review of the literature. *Neth. J. Med.* **2005**, *63*, 382–392.
10. Hartland, B.L.; Newell, T.J.; Damico, N. Alveolar Recruitment Maneuvers Under General Anesthesia: A Systematic Review of the Literature. *Respir. Care* **2014**, *60*, 609–620, doi:10.4187/respcare.03488.
11. Martin, J.B.; Garbee, D.; Bonanno, L. Effectiveness of positive end-expiratory pressure, decreased fraction of inspired oxygen and vital capacity recruitment maneuver in the prevention of pulmonary atelectasis in patients undergoing general anesthesia: A systematic review. *JBI Database Syst. Rev. Implement. Rep.* **2015**, *13*, 211–249.
12. He, H.; Yuan, S.; Yi, C.; Long, Y.; Zhang, R.; Zhao, Z. Titration of extra-PEEP against intrinsic-PEEP in severe asthma by electrical impedance tomography: A case report and literature review. *Medicine* **2020**, *99*, e20891.
13. Suzumura, E.A.; Amato, M.B.P.; Cavalcanti, A.B. Understanding recruitment maneuvers. *Intensiv. Care Med.* **2016**, *42*, 908–911, doi:10.1007/s00134-015-4025-5.
14. Santos, R.S.; Silva, P.L.; Pelosi, P.; Rocco, P.R. Recruitment maneuvers in acute respiratory distress syndrome: The safe way is the best way. *World J. Crit. Care Med.* **2015**, *4*, 278–286, doi:10.5492/wjccm.v4.i4.278.
15. Yu, X.; Zhai, Z.; Zhao, Y.; Zhu, Z.; Tong, J.; Yan, J.; Ouyang, W. Performance of Lung Ultrasound in Detecting Peri-Operative Atelectasis after General Anesthesia. *Ultrasound Med. Biol.* **2016**, *42*, 2775–2784.
16. Monastesse, A.; Girard, F.; Massicotte, N.; Chartrand-Lefebvre, C.; Girard, M. Lung Ultrasonography for the Assessment of Peri-operative Atelectasis: A Pilot Feasibility Study. *Anesth. Analg.* **2017**, *124*, 494–504.

17. Wang, J.; Zhou, H.Y.; Du, Y.; Cao, F.F.; Zhang, Y.H.; Zhang, H.T. Diagnosis and treatment value of bedside pulmonary ultrasound for atelectasis in patients after cardiac surgery. *Zhonghua Yi Xue Za Zhi* **2020**, *100*, 220–224.
18. Volpicelli, G.; Elbarbary, M.; Blaivas, M.; Lichtenstein, D.A.; Mathis, G.; Kirkpatrick, A.W.; Melniker, L.; Gargani, L.; Noble, V.E.; Via, G.; et al. International Liaison Committee on Lung Ultrasound (ILC-LUS) for International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensiv. Care Med.* **2012**, *38*, 577–591.
19. Bouhemad, B.; Mongodi, S.; Via, G.; Rouquette, I. Ultrasound for “lung monitoring” of ventilated patients. *Anesthesiology* **2015**, *122*, 437–447.
20. Myatra, S.N. Hemodynamic effects of alveolar recruitment maneuvers in the operating room: Proceed with caution. *J. Anaesthesiol. Clin. Pharmacol.* **2019**, *35*, 431–433, doi:10.4103/joacp.joacp_223_19.
21. Hanouz, J.L.; Coquerel, A.; Persyn, C.; Radenac, D.; Gérard, J.L.; Fischer, M.O. Changes in stroke volume during an alveolar recruitment maneuvers through a stepwise increase in positive end expiratory pressure and transient continuous positive airway pressure in anesthetized patients. A prospective observational pilot study. *J. Anaesthesiol. Clin. Pharmacol.* **2019**, *35*, 453–459.
22. Tusman, G.; Acosta, C.M.; Costantini, M. Ultrasonography for the assessment of lung recruitment maneuvers. *Crit. Ultrasound J.* **2016**, *8*, 1–4, doi:10.1186/s13089-016-0045-9.
23. Bello, G.; Blanco, P. Lung Ultrasonography for Assessing Lung Aeration in Acute Respiratory Distress Syndrome: A Narrative Review. *J. Ultrasound Med.* **2019**, *38*, 27–37.
24. Malbouisson, L.M.; Muller, J.C.; Constantin, J.M.; Lu, Q.; Puybasset, L.; Rouby, J.J.; CT Scan ARDS Study Group. Computed tomography assessment of positive end-expiratory pressure-induced alveolar recruitment in patients with acute respiratory distress syndrome. *Am. J. Respir. Crit. Care Med.* **2001**, *163*, 1444–1450.
25. Caironi, P.; Gattinoni, L. How to monitor lung recruitment in patients with acute lung injury. *Curr. Opin. Crit. Care* **2007**, *13*, 338–343, doi:10.1097/mcc.0b013e32814db80c.
26. Wrigge, H.; Zinserling, J.; Muders, T.; Varelmann, D.; Günther, U.; von der Groeben, C.; Magnusson, A.; Hedenstierna, G.; Putensen, C. Electrical impedance tomography compared with thoracic computed tomography during a slow inflation maneuver in experimental models of lung injury. *Crit Care Med.* **2008**, *36*, 903–909.
27. Spadaro, S.; Mauri, T.; Böhm, S.H.; Scaramuzzo, G.; Turrini, C.; Waldmann, A.D.; Ragazzi, R.; Pesenti, A.; Volta, C.A. Variation of poorly ventilated lung units (silent spaces) measured by electrical impedance tomography to dynamically assess recruitment. *Crit. Care* **2018**, *22*, 26.
28. Bouhemad, B.; Brisson, H.; Le-Guen, M.; Arbelot, C.; Lu, Q.; Rouby, J.-J. Bedside Ultrasound Assessment of Positive End-Expiratory Pressure-Induced Lung Recruitment. *Am. J. Respir. Crit. Care Med.* **2011**, *183*, 341–347, doi:10.1164/rccm.201003-0369oc.
29. Rode B, Vučić M, Siranović M, Horvat A, Krolo H, Kelečić M, Gopčević A. Positive end-expiratory pressure lung recruitment: comparison between lower inflection point and ultrasound assessment. *Wien. Klin. Wochenschr.* **2012**, *124*, 842–847.
30. Chaari A, Bousselmi K, Assar W, Kumar V, Khalil E, Kauts V, Abdelhakim K. Usefulness of ultrasound in the management of acute respiratory distress syndrome. *Int. J. Crit. Illn. Inj. Sci.* **2019**, *9*, 11–15.
31. Lichtenstein, D.A. *Lung Ultrasound in the Critically Ill*; Springer: Berlin, Germany, 2016; Volume 20, pp. 315–22, doi:10.1007/978-3-319-15371-1.
32. Volpicelli, G.; Melniker, L.A.; Cardinale, L.; Lamorte, A.; Frascisco, M.F. Lung ultrasound in diagnosing and monitoring pulmonary interstitial fluid. *Radiol. Med.* **2012**, *118*, 196–205, doi:10.1007/s11547-012-0852-4.
33. Mojoli, F.; Bouhemad, B.; Mongodi, S.; Lichtenstein, D. Lung Ultrasound for Critically Ill Patients. *Am. J. Respir. Crit. Care Med.* **2019**, *199*, 701–714, doi:10.1164/rccm.201802-0236ci.
34. Buda, N.; Kosiak, W.; Wełnicki, M.; Skoczylas, A.; Olszewski, R.; Piotrkowski, J.; Skoczyński, S.; Radzikowska, E.; Jassem, E.; Grabczak, E.M.; et al. Recommendations for Lung Ultrasound in Internal Medicine. *Diagnostics* **2020**, *10*, 597, doi:10.3390/diagnostics10080597.
35. Volpicelli, G.; Silva, F.; Radeos, M. Real-time lung ultrasound for the diagnosis of alveolar consolidation and interstitial syndrome in the emergency department. *Eur. J. Emerg. Med.* **2010**, *17*, 63–72.
36. Génèreux, V.; Chassé, M.; Girard, F.; Massicotte, N.; Chartrand-Lefebvre, C.; Girard, M. Effects of positive end-expiratory pressure/recruitment manoeuvres compared with zero end-expiratory pressure on atelectasis during open gynaecological surgery as assessed by ultrasonography: A randomised controlled trial. *Br. J. Anaesth.* **2020**, *124*, 101–109.
37. Song, I.-K.; Kim, E.-H.; Lee, J.-H.; Ro, S.; Kim, H.-S.; Kim, J.-T. Effects of an alveolar recruitment manoeuvre guided by lung ultrasound on anaesthesia-induced atelectasis in infants: A randomised, controlled trial. *Anaesthesia* **2017**, *72*, 214–222, doi:10.1111/anae.13713.
38. Lichtenstein, D. Fluid administration limited by lung sonography: The place of lung ultrasound in assessment of acute circulatory failure (the FALLS-protocol). *Expert Rev. Respir. Med.* **2012**, *6*, 155–162.
39. Ricci F, Aquilani R, Radico F, Bianco F, Dipace GG, Miniero E, De Caterina R, Gallina S. Role and importance of ultrasound lung comets in acute cardiac care. *Eur. Heart J. Acute Cardiovasc Care* **2015**, *4*, 103–112, doi: 10.1177/2048872614553166.
40. Bedetti, G.; Gargani, L.; Corbisiero, A.; Frassi, F.; Poggianti, E.; Mottola, G. Evaluation of ultrasound lung comets by hand-held echocardiography. *Cardiovasc. Ultrasound* **2006**, *4*, 34, doi:10.1186/1476-7120-4-34.
41. Frassi, F.; Gargani, L.; Gligorova, S.; Ciampi, Q.; Mottola, G.; Picano, E. Clinical and echocardiographic determinants of ultrasound lung comets☆. *Eur. J. Echocardiogr.* **2007**, *8*, 474–479, doi:10.1016/j.euje.2006.09.004.

42. Zawadka, M.; Marchel, M.; Andruszkiewicz, P. Diastolic dysfunction of the left ventricle—A practical approach for an anaesthetist. *Anaesthesiol. Intensiv. Ther.* **2020**, *52*, 237–244.
43. Piotrkowski, J.; Buda, N.; Januszko-Giergielewicz, B.; Kosiak, W. Use of bedside ultrasound to assess fluid status: A literature re-view. *Pol. Arch. Intern Med.* **2019**, *129*, 692–699.
44. Barbosa, F.T.; Castro, A.A.; De Sousa-Rodrigues, C.F. Positive end-expiratory pressure (PEEP) during anaesthesia for prevention of mortality and postoperative pulmonary complications. *Cochrane Database Syst. Rev.* **2014**, doi:10.1002/14651858.cd007922.pub3.
45. Bluth, T.; Serpa Neto, A.; Schultz, M.J.; Pelosi, P.; Gama de Abreu, M.; PROBESE Collaborative Group; Bluth, T.; Bobek, I.; Canet, J.C.; Cinnella, G.; et al. Effect of Intraoperative High Positive End-Expiratory Pressure (PEEP) With Recruitment Maneuvers vs. Low PEEP on Postoperative Pulmonary Complications in Obese Patients: A Randomized Clinical Trial. *JAMA* **2019**, *321*, 2292–2305.
46. Suzumura, E.A.; Figueiró, M.; Normilio-Silva, K.; Laranjeira, L.; Oliveira, C.; Buehler, A.M.; Bugano, D.; Amato, M.B.P.; Carvalho, C.R.R.; Berwanger, O.; et al. Effects of alveolar recruitment maneuvers on clinical outcomes in patients with acute respiratory distress syndrome: A systematic review and meta-analysis. *Intensiv. Care Med.* **2014**, *40*, 1227–1240, doi:10.1007/s00134-014-3413-6.
47. Mauri, T.; Yoshida, T.; Bellani, G.; Goligher, E.; Carteaux, G.; Rittayamai, N.; Mojoli, F.; Chiumello, D.; Piquilloud, L.; Grasso, S.; et al. Esophageal and transpulmonary pressure in the clinical setting: Meaning, usefulness and perspectives. *Int. Care Med.* **2016**, *42*, 1360–1373.
48. Dreyfuss, D.; Soler, P.; Basset, G.; Saumon, G. High Inflation Pressure Pulmonary Edema: Respective Effects of High Airway Pressure, High Tidal Volume, and Positive End-expiratory Pressure. *Am. Rev. Respir. Dis.* **1988**, *137*, 1159–1164, doi:10.1164/ajrccm/137.5.1159.

Submitted:
19.09.2021
Accepted:
17.11.2021
Published:
08.02.2022

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

Jolanta Cylwik¹, Natalia Buda²

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

DOI: 10.15557/JoU.2022.0002

Keywords

general anesthesia;
atelectasis;
recruitment
maneuvers;
chest
ultrasonography;
postoperative
pulmonary
complications

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 <i>M (SD)</i>	63.90 (11.34)	64.17 (14.03)	<i>p</i> = 0.881
BMI <i>M (SD)</i>	28.31 (5.08)	29.61 (5.75)	<i>p</i> = 0.173
Gender n (%)			
Females	66 (66.0)	50 (50.0)	<i>p</i> = 0.022
Males	34 (34.0)	50 (50.0)	
ASA Score n (%)			
1	1 (1.0)	4 (4.0)	<i>p</i> = 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)	<i>p</i> = 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)	<i>p</i> = 0.112
Ischemic heart disease	13 (13.0)	17 (17.0)	<i>p</i> = 0.428
COPD	1 (1.0)	3 (3.0)	<i>p</i> = 0.621
Asthma	6 (6.0)	2 (2.0)	<i>p</i> = 0.279
Diabetes	24 (24.0)	18 (18.0)	<i>p</i> = 0.298
Atherosclerosis	12 (12.0)	15 (15.0)	<i>p</i> = 0.535
Number of comorbidities n (%)			
0	26 (26.0)	24 (24.0)	<i>p</i> = 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)	<i>p</i> = 0.506
Emergency	10 (10.0)	13 (13.0)	
Surgery duration n (%)			
<2 h	45 (45.0)	43 (43.0)	<i>p</i> = 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, volutrauma, 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 (FiO₂) 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 CO₂ (EtCO₂) 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 H₂O.

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 H₂O. 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 (SaO₂) 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 $\alpha = 0.05$. 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 frequently

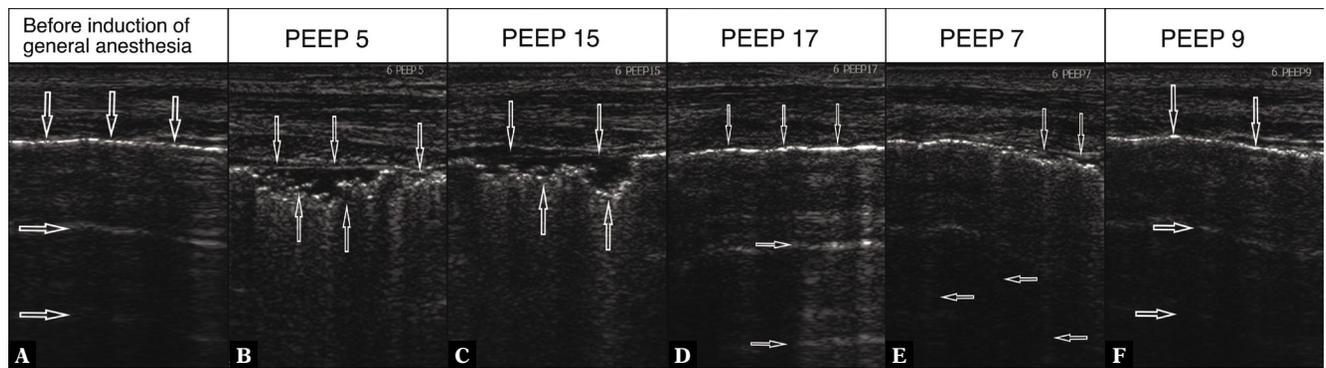


Fig. 1. Sample of the recruitment process with a good ultrasound effect: **A.** LUS image before anesthesia – normal, continuous, hyperechoic pleural line (↓) and A-line artifact (→), normal image; **B.** control assessment during anesthesia, at PEEP 5 cm H₂O – blurred, fragmented pleural line (↓), with small, irregular hypoechoic subpleural consolidations (↑), image typical of atelectasis; **C.** when increasing PEEP to 11 cm H₂O – persistent ultrasound features of atelectasis with a visible gradual reduction of subpleural consolidations (↑); **D.** when achieving PEEP value of 13 cm H₂O – normal, continuous, hyperechoic pleural line visible again (↓); **E.** when reducing pressures, PEEP 7 cm H₂O – segmental disturbances in the pleural line continuity (↓) visible again – initial image of atelectasis; **F.** after increasing end-expiratory pressure by 2 cm H₂O, disturbances in lung aeration reversed and normal pleural line and A-line artifacts were visualized

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,

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 <i>et al.</i> (2021)	adults	20/20	convex	yes	100%	ND
Elshalzy <i>et al.</i> (2020)	adults	20/20	convex	yes	ND	ND
Song <i>et al.</i> (2018)	pediatric	61/61	linear	yes	21%	13%
Song <i>et al.</i> (2016)	pediatric	20/20	linear	yes	50%	30%

RM – recruitment maneuvers; ND – no data

and 3 papers only evaluated PEEP. Finally, only 5 publications were identified that directly related to the discussed topic (Tab. 3).

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 definitively 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 anaesthesia.

Conclusion

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

References

1. Miskovic A, Lumb AB: Postoperative pulmonary complications. *Br J Anaesth* 2017; 118: 317–334.
2. Smetana GW, Lawrence VA, Cornell JE, American College of Physicians: Preoperative pulmonary risk stratification for noncardiothoracic surgery: systematic review for the American College of Physicians. *Ann Intern Med* 2006; 144: 581–595.
3. Güldner A, Kiss T, Serpa Neto A, Hemmes SN, Canet J, Spieth PM *et al.*: Intraoperative protective mechanical ventilation for prevention of postoperative pulmonary complications: a comprehensive review of the role of tidal volume, positive end-expiratory pressure, and lung recruitment maneuvers. *Anesthesiology* 2015; 123: 692–713.
4. Hemmes SN, Serpa Neto A, Schultz MJ: Intraoperative ventilatory strategies to prevent postoperative pulmonary complications: a meta-analysis. *Curr Opin Anaesthesiol* 2013; 26: 126–133.
5. Tusman G, Böhm SH: Prevention and reversal of lung collapse during the intra-operative period. *Best Pract Res Clin Anaesthesiol* 2010; 24: 183–197.
6. Brismar B, Hedenstierna G, Lundquist H, Strandberg A, Svensson L, Tokics L: Pulmonary densities during anaesthesia with muscular relaxation – a proposal of atelectasis. *Anesthesiology* 1985; 62: 422–428.
7. Ladha K, Vidal Melo MF, McLean DJ, Wanderer JP, Grabitz SD, Kurth T *et al.*: Intraoperative protective mechanical ventilation and risk of postoperative respiratory complications: hospital based registry study. *BMJ* 2015; 351: h3646.
8. Hartland BL, Newell TJ, Damico N: Alveolar recruitment maneuvers under general anaesthesia: a systematic review of the literature. *Respir Care* 2015; 60: 609–620.
9. Martin JB, Garbee D, Bonanno L: Effectiveness of positive end-expiratory pressure, decreased fraction of inspired oxygen and vital capacity recruitment maneuver in the prevention of pulmonary atelectasis in patients undergoing general anaesthesia: a systematic review. *JBIM Database System Rev Implement Rep* 2015; 13: 211–249.
10. He H, Yuan S, Yi C, Long Y, Zhang R, Zhao Z: Titration of extra-PEEP against intrinsic-PEEP in severe asthma by electrical impedance tomography: a case report and literature review. *Medicine (Baltimore)* 2020; 99: e20891.
11. Suzumura EA, Amato MBP, Cavalcanti AB: Understanding recruitment maneuvers. *Intensive Care Med* 2016; 42: 908–911.
12. Santos RS, Silva PL, Pelosi P, Rocco PR: Recruitment maneuvers in acute respiratory distress syndrome: the safe way is the best way. *World J Crit Care Med* 2015; 4: 278–286.
13. Cui Y, Cao R, Li G, Gong T, Ou Y, Huang J: The effect of lung recruitment maneuvers on post-operative pulmonary complications for patients undergoing general anaesthesia: a meta-analysis. *PLoS One* 2019; 14: e0217405.
14. Tusman G, Acosta CM, Costantini M: Ultrasonography for the assessment of lung recruitment maneuvers. *Crit Ultrasound J* 2016; 8: 8.
15. Cylwik J, Buda N: Lung ultrasonography in the monitoring of intraoperative recruitment maneuvers. *Diagnostics (Basel)* 2021; 11: 276.
16. Park SK, Yang H, Yoo S, Kim WH, Lim YJ, Bahk JH *et al.*: Ultrasound-guided versus conventional lung recruitment manoeuvres in laparoscopic gynaecological surgery: a randomised controlled trial. *Eur J Anaesthesiol* 2021; 38: 275–284.
17. Futier E, Constantin JM, Paugam-Burtz C, Pascal J, Eurin M, Neuschwander A *et al.*: A trial of intraoperative low-tidal-volume ventilation in abdominal surgery. *N Engl J Med* 2013; 369: 428–437.
18. Song I-K, Kim E-H, Lee J-H, Ro S, Kim H-S, Kim J-T: Effects of an alveolar recruitment manoeuvre guided by lung ultrasound on anaesthesia-induced atelectasis in infants: a randomised, controlled trial. *Anaesthesia* 2017; 72: 214–222.
19. Deng QW, Tan WC, Zhao BC, Wen SH, Shen JT, Xu M: Intraoperative ventilation strategies to prevent postoperative pulmonary complications: a network meta-analysis of randomised controlled trials. *Br J Anaesth* 2020; 124: 324–335.
20. Malbouisson LM, Muller JC, Constantin JM, Lu Q, Puybasset L, Rouby JJ *et al.*: Computed tomography assessment of positive end-expiratory pressure-induced alveolar recruitment in patients with acute respiratory distress syndrome. *Am J Respir Crit Care Med* 2001; 163: 1444–1450.
21. Caironi P, Gattinoni L: How to monitor lung recruitment in patients with acute lung injury. *Curr Opin Crit Care* 2007; 13: 338–343.
22. Wrigge H, Zinserling J, Muders T, Varelmann D, Günther U, von der Groeben C *et al.*: Electrical impedance tomography compared with thoracic computed tomography during a slow inflation maneuver in experimental models of lung injury. *Crit Care Med* 2008; 36: 903–909.
23. Spadaro S, Mauri T, Böhm SH, Scaramuzza G, Turrini C, Waldmann AD *et al.*: Variation of poorly ventilated lung units (silent spaces) measured by electrical impedance tomography to dynamically assess recruitment. *Crit Care* 2018; 22: 26.
24. Elshazly M, Khair T, Bassem M, Mansour M: The use of intraoperative bedside lung ultrasound in optimizing positive end expiratory pressure in obese patients undergoing laparoscopic bariatric surgeries. *Surg Obes Relat Dis* 2021; 17: 372–378.
25. Song IK, Kim EH, Lee JH, Kang P, Kim HS, Kim JT: Utility of perioperative lung ultrasound in pediatric cardiac surgery: a randomized controlled trial. *Anesthesiology* 2018; 128: 718–727.
26. Lichtenstein D: Lung ultrasound in the critically ill. *Curr Opin Crit Care* 2014; 20: 315–322.
27. Volpicelli G, Melniker LA, Cardinale L, Lamorte A, Frascisco MF: Lung ultrasound in diagnosing and monitoring pulmonary interstitial fluid. *Radiol Med* 2013; 118: 196–205.
28. Mojoli F, Bouhemad B, Mongodi S, Lichtenstein D: Lung ultrasound for critically ill patients. *Am J Respir Crit Care Med* 2019; 199: 701–714. Erratum in: *Am J Respir Crit Care Med* 2020; 201: 1015. Erratum in: *Am J Respir Crit Care Med* 2020; 201: 1454.
29. Lichtenstein D: Fluid administration limited by lung sonography: the place of lung ultrasound in assessment of acute circulatory failure (the FALLS-protocol). *Expert Rev Respir Med* 2012; 6: 155–162.
30. Volpicelli G, Silva F, Radeos M: Real-time lung ultrasound for the diagnosis of alveolar consolidation and interstitial syndrome in the emergency department. *Eur J Emerg Med* 2010; 17: 63–72.
31. Bedetti G, Gargani L, Corbisiero A, Frassi F, Poggianti E, Mottola G: Evaluation of ultrasound lung comets by hand-held echocardiography. *Cardiovasc Ultrasound* 2006; 4: 34.
32. Frassi F, Gargani L, Gligorova S, Ciampi Q, Mottola G, Picano E: Clinical and echocardiographic determinants of ultrasound lung comets. *Eur J Echocardiogr* 2007; 8: 474–479.
33. Zawadka M, Marchel M, Andruszkiewicz P: Diastolic dysfunction of the left ventricle – a practical approach for an anaesthetist. *Anaesthesiol Intensive Ther* 2020; 52: 237–244.
34. Piotrkowski J, Buda N, Januszko-Giergielewicz B, Kosiak W: Use of bedside ultrasound to assess fluid status: a literature review. *Pol Arch Intern Med* 2019; 129: 692–699.

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.

WYKAZ CYTOWANEGO PIŚMIENNICTWA

REFERENCES

1. Brismar: B.; Hedenstierna, G.; Lundquist, H.; Strandberg, Å.; Svensson, L.; Tokics, L. Pulmonary Densities during Anesthesia with Muscular Relaxation—A Proposal of Atelectasis. *Anesthesiology* **1985**, *62*, 422–428, doi:10.1097/00000542-198504000-00009.
2. Ladha, K.; Vidal Melo, M.F.; McLean, D.J.; Wanderer, J.P.; Grabitz, S.D.; Kurth, T.; Eikermann, M. Intraoperative protective mechanical ventilation and risk of postoperative respiratory complications: Hospital-based registry study. *BMJ* **2015**, *351*, h3646, doi:10.1136/bmj.h3646.
3. Güldner, A.; Kiss, T.; Serpa Neto, A.; Hemmes, S.N.; Canet, J.; Spieth, P.M.; Rocco, P.R.; Schultz, M.J.; Pelosi, P.; Gama de Abreu. In-traoperative protective mechanical ventilation for prevention of postoperative pulmonary complications: A comprehensive review of the role of tidal volume, positive end-expiratory pressure, and lung recruitment maneuvers. *Anesthesiology* **2015**, *123*, 692–713.
4. Hemmes, S.N.; Serpa Neto, A.; Schultz, M.J. Intraoperative ventilatory strategies to prevent postoperative pulmonary complications: A meta-analysis. *Curr. Opin. Anaesthesiol.* **2013**, *26*, 126–133.
5. Tusman, G.; Böhm, S.H. Prevention and reversal of lung collapse during the intra-operative period. *Best Pr. Res. Clin. Anaesthesiol.* **2010**, *24*, 183–197, doi:10.1016/j.bpa.2010.02.006.

6. Tusman, G.; Böhm, S.H.; Warner, D.O.; Sprung, J. Atelectasis and perioperative pulmonary complications in high-risk patients. *Curr. Opin. Anaesthesiol.* **2012**, *25*, 1–10, doi:10.1097/aco.0b013e32834dd1eb.
7. Steinberg, J.M.; Schiller, H.J.; Halter, J.M.; Gatto, L.A.; Lee, H.M.; Pavone, L.A.; Nieman, G.F. Alveolar instability causes early ventilator-induced lung injury independent of neutrophils. *Am. J. Respir. Crit. Care Med.* **2004**, *169*, 57–63.
8. Tremblay, L.N.; Slutsky, A.S. Ventilator-induced injury: From barotrauma to biotrauma. *Proc. Assoc. Am. Physicians* **1998**, *110*, 482–488.
9. Halbertsma, F.J.J.; Vaneker, M.; Scheffer, G.J.; Van Der Hoeven, J.G. Cytokines and biotrauma in ventilator-induced lung injury: A critical review of the literature. *Neth. J. Med.* **2005**, *63*, 382–392.
10. Hartland, B.L.; Newell, T.J.; Damico, N. Alveolar Recruitment Maneuvers Under General Anesthesia: A Systematic Review of the Literature. *Respir. Care* **2014**, *60*, 609–620, doi:10.4187/respcare.03488.
11. Martin, J.B.; Garbee, D.; Bonanno, L. Effectiveness of positive end-expiratory pressure, decreased fraction of inspired oxygen and vital capacity recruitment maneuver in the prevention of pulmonary atelectasis in patients undergoing general anesthesia: A systematic review. *JBI Database Syst. Rev. Implement. Rep.* **2015**, *13*, 211–249.

12. He, H.; Yuan, S.; Yi, C.; Long, Y.; Zhang, R.; Zhao, Z. Titration of extra-PEEP against intrinsic-PEEP in severe asthma by electrical impedance tomography: A case report and literature review. *Medicine* **2020**, *99*, e20891.
13. Suzumura, E.A.; Amato, M.B.P.; Cavalcanti, A.B. Understanding recruitment maneuvers. *Intensiv. Care Med.* **2016**, *42*, 908–911, doi:10.1007/s00134-015-4025-5.
14. Santos, R.S.; Silva, P.L.; Pelosi, P.; Rocco, P.R. Recruitment maneuvers in acute respiratory distress syndrome: The safe way is the best way. *World J. Crit. Care Med.* **2015**, *4*, 278–286, doi:10.5492/wjccm.v4.i4.278.
15. Yu, X.; Zhai, Z.; Zhao, Y.; Zhu, Z.; Tong, J.; Yan, J.; Ouyang, W. Performance of Lung Ultrasound in Detecting Peri-Operative Atelectasis after General Anesthesia. *Ultrasound Med. Biol.* **2016**, *42*, 2775–2784.
16. Monastesse, A.; Girard, F.; Massicotte, N.; Chartrand-Lefebvre, C.; Girard, M. Lung Ultrasonography for the Assessment of Peri-operative Atelectasis: A Pilot Feasibility Study. *Anesth. Analg.* **2017**, *124*, 494–504. *Diagnostics* **2021**, *11*, 276 12 of 13
17. Wang, J.; Zhou, H.Y.; Du, Y.; Cao, F.F.; Zhang, Y.H.; Zhang, H.T. Diagnosis and treatment value of bedside pulmonary ultrasound for atelectasis in patients after cardiac surgery. *Zhonghua Yi Xue Za Zhi* **2020**, *100*, 220–224.

18. Volpicelli, G.; Elbarbary, M.; Blaivas, M.; Lichtenstein, D.A.; Mathis, G.; Kirkpatrick, A.W.; Melniker, L.; Gargani, L.; Noble, V.E.; Via, G.; et al. International Liaison Committee on Lung Ultrasound (ILC-LUS) for International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensiv. Care Med.* **2012**, *38*, 577–591.
19. Bouhemad, B.; Mongodi, S.; Via, G.; Rouquette, I. Ultrasound for “lung monitoring” of ventilated patients. *Anesthesiology* **2015**, *122*, 437–447.
20. Myatra, S.N. Hemodynamic effects of alveolar recruitment maneuvers in the operating room: Proceed with caution. *J. Anaesthesiol. Clin. Pharmacol.* **2019**, *35*, 431–433, doi:10.4103/joacp.joacp_223_19.
21. Hanouz, J.L.; Coquerel, A.; Persyn, C.; Radenac, D.; Gérard, J.L.; Fischer, M.O. Changes in stroke volume during an alveolar recruitment maneuvers through a stepwise increase in positive end expiratory pressure and transient continuous positive airway pressure in anesthetized patients. A prospective observational pilot study. *J. Anaesthesiol. Clin. Pharmacol.* **2019**, *35*, 453–459.
22. Tusman, G.; Acosta, C.M.; Costantini, M. Ultrasonography for the assessment of lung recruitment maneuvers. *Crit. Ultrasound J.* **2016**, *8*, 1–4, doi:10.1186/s13089-016-0045-9.

23. Bello, G.; Blanco, P. Lung Ultrasonography for Assessing Lung Aeration in Acute Respiratory Distress Syndrome: A Narrative Review. *J. Ultrasound Med.* **2019**, *38*, 27–37.
24. Malbouisson, L.M.; Muller, J.C.; Constantin, J.M.; Lu, Q.; Puybasset, L.; Rouby, J.J.; CT Scan ARDS Study Group. Computed tomography assessment of positive end-expiratory pressure-induced alveolar recruitment in patients with acute respiratory distress syndrome. *Am. J. Respir. Crit. Care Med.* **2001**, *163*, 1444–1450.
25. Caironi, P.; Gattinoni, L. How to monitor lung recruitment in patients with acute lung injury. *Curr. Opin. Crit. Care* **2007**, *13*, 338–343, doi:10.1097/mcc.0b013e32814db80c.
26. Wrigge, H.; Zinserling, J.; Muders, T.; Varelmann, D.; Günther, U.; von der Groeben, C.; Magnusson, A.; Hedenstierna, G.; Putensen, C. Electrical impedance tomography compared with thoracic computed tomography during a slow inflation maneuver in experimental models of lung injury. *Crit Care Med.* **2008**, *36*, 903–909.
27. Spadaro, S.; Mauri, T.; Böhm, S.H.; Scaramuzzo, G.; Turrini, C.; Waldmann, A.D.; Ragazzi, R.; Pesenti, A.; Volta, C.A. Variation of poorly ventilated lung units (silent spaces) measured by electrical impedance tomography to dynamically assess recruitment. *Crit. Care* **2018**, *22*, 26.

28. Bouhemad, B.; Brisson, H.; Le-Guen, M.; Arbelot, C.; Lu, Q.; Rouby, J.-J. Bedside Ultrasound Assessment of Positive End-Expiratory Pressure–induced Lung Recruitment. *Am. J. Respir. Crit. Care Med.* **2011**, *183*, 341–347, doi:10.1164/rccm.201003-0369oc.
29. Rode B, Vučić M, Siranović M, Horvat A, Krolo H, Kelečić M, Gopčević A. Positive end-expiratory pressure lung recruitment: comparison between lower inflection point and ultrasound assessment. *Wien. Klin. Wochenschr.* **2012**, *124*, 842–847.
30. Chaari A, Bousselmi K, Assar W, Kumar V, Khalil E, Kauts V, Abdelhakim K. Usefulness of ultrasound in the management of acute respiratory distress syndrome. *Int. J. Crit. Illn. Inj. Sci.* **2019**, *9*, 11–15.
31. Lichtenstein, D.A. *Lung Ultrasound in the Critically Ill*; Springer: Berlin, Germany, 2016; Volume 20, pp. 315–22, doi:10.1007/978-3-319-15371-1.
32. Volpicelli, G.; Melniker, L.A.; Cardinale, L.; Lamorte, A.; Frascisco, M.F. Lung ultrasound in diagnosing and monitoring pulmonary interstitial fluid. *Radiol. Med.* **2012**, *118*, 196–205, doi:10.1007/s11547-012-0852-4.
33. Mojoli, F.; Bouhemad, B.; Mongodi, S.; Lichtenstein, D. Lung Ultrasound for Critically Ill Patients. *Am. J. Respir. Crit. Care Med.* **2019**, *199*, 701–714, doi:10.1164/rccm.201802-0236ci.

34. Buda, N.; Kosiak, W.; Welnicki, M.; Skoczylas, A.; Olszewski, R.; Piotrkowski, J.; Skoczyński, S.; Radzikowska, E.; Jassem, E.; Grabczak, E.M.; et al. Recommendations for Lung Ultrasound in Internal Medicine. *Diagnostics* **2020**, *10*, 597, doi:10.3390/diagnostics10080597.
35. Volpicelli, G.; Silva, F.; Radeos, M. Real-time lung ultrasound for the diagnosis of alveolar consolidation and interstitial syndrome in the emergency department. *Eur. J. Emerg. Med.* **2010**, *17*, 63–72.
36. Génèreux, V.; Chassé, M.; Girard, F.; Massicotte, N.; Chartrand-Lefebvre, C.; Girard, M. Effects of positive end-expiratory pressure/recruitment manoeuvres compared with zero end-expiratory pressure on atelectasis during open gynaecological surgery as assessed by ultrasonography: A randomised controlled trial. *Br. J. Anaesth.* **2020**, *124*, 101–109.
37. Song, I.-K.; Kim, E.-H.; Lee, J.-H.; Ro, S.; Kim, H.-S.; Kim, J.-T. Effects of an alveolar recruitment manoeuvre guided by lung ultrasound on anaesthesia-induced atelectasis in infants: A randomised, controlled trial. *Anaesthesia* **2017**, *72*, 214–222, doi:10.1111/anae.13713.
38. Lichtenstein, D. Fluid administration limited by lung sonography: The place of lung ultrasound in assessment of acute circulatory failure (the FALLS-protocol). *Expert Rev. Respir. Med.* **2012**, *6*, 155–162.

39. Ricci F, Aquilani R, Radico F, Bianco F, Dipace GG, Miniero E, De Caterina R, Gallina S. Role and importance of ultrasound lung comets in acute cardiac care. *Eur. Heart J. Acute Cardiovasc Care* **2015**, *4*, 103–112, doi:10.1177/2048872614553166.
40. Bedetti, G.; Gargani, L.; Corbisiero, A.; Frassi, F.; Poggianti, E.; Mottola, G. Evaluation of ultrasound lung comets by hand-held echocardiography. *Cardiovasc. Ultrasound* **2006**, *4*, 34, doi:10.1186/1476-7120-4-34.
41. Frassi, F.; Gargani, L.; Gligorova, S.; Ciampi, Q.; Mottola, G.; Picano, E. Clinical and echocardiographic determinants of ultrasound lung comets☆. *Eur. J. Echocardiogr.* **2007**, *8*, 474–479, doi:10.1016/j.euje.2006.09.004.
42. Zawadka, M.; Marchel, M.; Andruszkiewicz, P. Diastolic dysfunction of the left ventricle—A practical approach for an anaesthetist. *Anaesthesiol. Intensiv. Ther.* **2020**, *52*, 237–244.
43. Piotrkowski, J.; Buda, N.; Januszko-Giergielewicz, B.; Kosiak, W. Use of bedside ultrasound to assess fluid status: A literature review. *Pol. Arch. Intern Med.* **2019**, *129*, 692–699.
44. Barbosa, F.T.; Castro, A.A.; De Sousa-Rodrigues, C.F. Positive end-expiratory pressure (PEEP) during anaesthesia for prevention of mortality and postoperative pulmonary complications. *Cochrane Database Syst. Rev.* **2014**, doi:10.1002/14651858.cd007922.pub3.

45. Bluth, T.; Serpa Neto, A.; Schultz, M.J.; Pelosi, P.; Gama de Abreu, M.; PROBESE Collaborative Group; Bluth, T.; Bobek, I.; Canet, J.C.; Cinnella, G.; et al. Effect of Intraoperative High Positive End-Expiratory Pressure (PEEP) With Recruitment Maneuvers vs. Low PEEP on Postoperative Pulmonary Complications in Obese Patients: A Randomized Clinical Trial. *JAMA* **2019**, *321*, 2292–2305.

46. Suzumura, E.A.; Figueiró, M.; Normilio-Silva, K.; Laranjeira, L.; Oliveira, C.; Buehler, A.M.; Bugano, D.; Amato, M.B.P.; Carvalho, C.R.R.; Berwanger, O.; et al. Effects of alveolar recruitment maneuvers on clinical outcomes in patients with acute respiratory distress syndrome: A systematic review and meta-analysis. *Intensiv. Care Med.* **2014**, *40*, 1227–1240, doi:10.1007/s00134-014-3413-6.

47. Mauri, T.; Yoshida, T.; Bellani, G.; Goligher, E.; Carteaux, G.; Rittayamai, N.; Mojoli, F.; Chiumello, D.; Piquilloud, L.; Grasso, S.; et al. Esophageal and transpulmonary pressure in the clinical setting: Meaning, usefulness and perspectives. *Int. Care Med.* **2016**, *42*, 1360–1373.

48. Dreyfuss, D.; Soler, P.; Basset, G.; Saumon, G. High Inflation Pressure Pulmonary Edema: Respective Effects of High Airway Pressure, High Tidal Volume, and Positive End-expiratory Pressure. *Am. Rev. Respir. Dis.* **1988**, *137*, 1159–1164, doi:10.1164/ajrccm/137.5.1159

ZGODA KOMISJI BIOETYCZNEJ /
CONSENT OF THE BIOETHICS COMMITTEE

Uchwała Nr 48/19

Komisji Bioetycznej
przy Okręgowej Izbie Lekarskiej w Warszawie
z dnia 19 września 2019 r.

w sprawie wydania opinii o eksperymencie medycznym o nr rejestracji KB/1154/19

Na podstawie art. 29 ust.1 Ustawy z dnia 5 grudnia 1996 r. o zawodzie lekarza i lekarza dentystry (Dz. U. z 2008 r., Nr 136, poz. 857 z późni. zm.), §6 Rozporządzenia Ministra Zdrowia i Opieki Społecznej z dnia 11 maja 1999 roku w sprawie szczegółowych zasad powoływania i finansowania oraz trybu działania komisji bioetycznych (Dz. U. Nr 47, poz. 480) oraz ustawy z dnia 6 września 2004 – Prawo Farmaceutyczne (Dz. U. z 2008 r. nr 45, poz. 271 z późni. zm.) uchwała się co następuje:

§ 1

Komisja Bioetyczna przy Okręgowej Izbie Lekarskiej w Warszawie w składzie :

1. z-ca – mgr farm. Elżbieta Przymus - Góralczyk
2. prof. nadzw. dr hab. n. med. Stanisław Ancyparowicz
3. dr n. med. Andrzej Dąbrowski
4. lek. stom. Ewa Miękus-Pączek
5. dr hab. n. med. Stanisław Niemczyk
6. mgr Renata Piasecka - Krawczyk
7. ks.dr hab. Dariusz Pater
8. dr n. med. Joanna Romejko - Jarosińska
9. dr n. med. Michał Stępka
10. dr n. med. Marek Stopiński
11. dr n. praw. Radosław Tymiński

na posiedzeniu w dniu 19.09.2019 r. wydała *pozytywną* opinię o następującym eksperymencie medycznym:

Tytuł badania: *Przydatność ultrasonografii płuc w optymalizacji procesu rekrutacji.*

Główny badacz lek. Jolanta Cylwik

Badanie będzie prowadzone w: Mazowiecki Szpital Wojewódzki w Siedlcach Sp. z o. o.,
ul. Poniatowskiego 26, 08-110 Siedlce

Zastrzeżenie:

Badanie może zostać rozpoczęte pod warunkiem:

- dostarczenia uzasadnienia merytorycznego (bibliografii) zastosowania USG do badania płuc;
- dostarczenia opisu technicznego i metodologii badania USG płuc;
- dostarczenia informacji o własnych doświadczeniach w badaniach USG płuc;
- dostarczenia informacji udziale w badaniu współbadacza dr Budy.

§2

Komisja Bioetyczna stwierdza, że złożony wniosek zawiera kompletną dokumentację, w tym w szczególności:

1. Wniosek z dnia 22.08.2019
2. Podpisany życiorys głównego badacza w języku polskim z dnia 20.08.2019r.
3. Życiorys drugiego badacza w języku polskim z dnia 20.08.2019
4. Informacja dla Pacjenta
5. Formularz Świadomej Zgody razem ze zgodą Pacjenta na przetwarzanie danych osobowych
6. Streszczenie Protokołu Badania
7. Protokół Badania z dołączoną kartą badania
8. Zgoda jednostki na przeprowadzenie badania
9. Informacja o ośrodku, w którym ma być przeprowadzona badanie
10. Oświadczenie że projekt jest eksperymentem niesponsorowanym

(W/w dokumenty zostały wyszczególnione według informacji zawartych we wniosku złożonym przez głównego badacza)

§ 3

Skład i działanie Komisji Bioetycznej jest zgodne z Wskazówkami i Zaleceniami dla Europejskich Komisji Etycznych opracowanymi przez EFGCP, Zasadami Prawidłowego Prowadzenia Badań Klinicznych (GCP) oraz wymogami lokalnymi.

§ 4

Uchwała wchodzi w życie z dniem podjęcia *i obowiązuje w okresie trwania ważności polisy ubezpieczeniowej dołączonej do wniosku*

§ 5

Komisja Bioetyczna zobowiązuje głównego badacza do :

1. zgłoszenia wszelkich zmian i odchyłeń w protokole eksperymentu medycznego,
2. zgłoszenia wszelkich nowych informacji wiążących się z niekorzystnym wpływem na bezpieczeństwo osób biorących udział w eksperymencie oraz na jego przebieg,
3. zgłoszenia wszelkich ciężkich lub nieoczekiwanych niepożądanych działań leków (ADR) a także ciężkich zdarzeń niepożądanych (SAE)
4. informowania o decyzjach innych komisji bioetycznych,
5. sporządzania rocznych raportów z przebiegu eksperymentu (nie później niż do końca grudnia każdego roku)
6. informowania o zakończeniu eksperymentu i jego wynikach, w tym wymóg dostarczenia kopii ostatecznej wersji raportu z eksperymentu po jego zakończeniu.

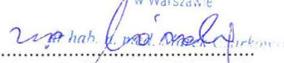
Wszelka korespondencja musi być przekazywana na piśmie listem poleconym bądź za potwierdzeniem odbioru.

§ 6

Tekst uchwały został sporządzony w 2 jednobrzmiących egz. po jednym dla wnioskodawcy i Komisji Bioetycznej.

§ 7

Od niniejszej uchwały wnioskodawcy przysługuje odwołanie do Odwoławczej Komisji Bioetycznej przy Ministerstwie Zdrowia, za pośrednictwem Komisji Bioetycznej Okręgowej Izby Lekarskiej w Warszawie, wniesione w terminie 14 dni od jej otrzymania.

Przewodniczący Komisji Bioetycznej
przy Okręgowej Izbie Lekarskiej
w Warszawie

Podpis Przewodniczącego

Podpisy członków Komisji Bioetycznej głoszących projekt KB/1253/19
w dniu 19 września 2019 r.

Główny badacz: lek. Jolanta Cylwik

Przewodniczący

dr hab. n. med. Marek Czarkowski
(internista, endokrynolog, kardiolog)

Członkowie:

mgr farm. Elżbieta Przymus - Góralczyk
(vice-Przewodnicząca, farmaceuta)

prof. nadzw. dr hab. Stanisław Ancyparowicz
(chirurg)

dr n. med. Andrzej Dąbrowski
(internista, pulmonolog, alergolog)

dr n. med. Rafał Machowicz
(internista)

prof. dr n. med. Magdalena Marczyńska
(pediatra)

lek. dent. Ewa Miękus-Pączek
(stomatolog)

prof. Stanisław Niemczyk
(nefrológ, endokrynolog, transplantolog kliniczny)

mgr Renata Piasecka -Krawczyk
(pielęgniarka)

ks.dr hab. Dariusz Pater
(duchowny, etyk)

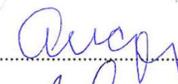
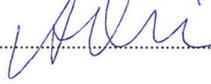
dr n. med. Bożena Pietrzykowska
(psychiatra)

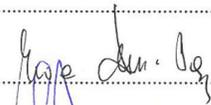
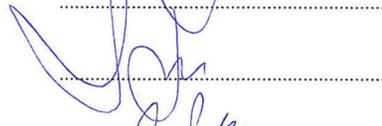
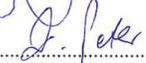
dr n. med. Joanna Romejko - Jarosińska
(internista, onkolog kliniczny)

Dr n. med. Michał Stępa
(internista, gastroenterolog, diabetolog)

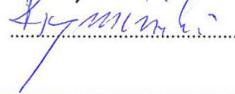
dr n. med. Marek Stopiński
(internista, nefrológ)

dr n. praw. Radosław Tymiński
(radca prawny)



Z/20018/1254/19

Warszawa, dnia 24 października 2019

Lek. Jolanta Cylwik
Mazowiecki Szpital Wojewódzki w Siedlcach Sp. z o. o.
ul. Poniatowskiego 26,
08-110 Siedlce

Dotyczy badania: KB/1254/19

Tytuł badania: Przydatność ultrasonografii płuc w optymalizacji procesu rekrutacji.

Komisja Bioetyczna Okręgowej Izby Lekarskiej w Warszawie na posiedzeniu w dniu 24.10.2019 zapoznała się i wydała pozytywną opinię dotyczącą:

- uzasadnienia merytorycznego (z bibliografią zastosowania usg do badania płuc);
- uzupełnienia opisu technologicznego i metodologii badania - Protokół badania wersja 2 z dnia 30.09.2019
- Informacji o własnych doświadczeniach w badaniu USG płuc - życiorys głównego badacza Jolanty Cylwik wersja 2 z dnia 30.09.2019
- Informacji o udziale w badaniu współbadacza dr Natalii Budy - Protokół Badania wersja 2 z dnia 30.09.2019.

Przewodniczący Komisji Bioetycznej
Okręgowej Izby Lekarskiej
w Warszawie

dr hab. n. med. Marek Czarkowski

(podpis przewodniczącego)

Komisja Bioetyczna Okręgowej Izby Lekarskiej w Warszawie

Lista obecności członków Komisji Bioetycznej na posiedzeniu w dniu 24 października 2019 r.

L.p.	Nazwisko i imię	Zawód, kwalifikacje	Miejsce pracy	Podpis
1.	prof. nadzw. dr hab. Ancyparowicz Stanisław	chirurg	Centralna Wojskowa Przychodnia Lekarska SPZOZ „CePeLek”	
2.	dr hab. n. med. Czarkowski Marek	internista, kardiolog, endokrynolog	Prywatna Praktyka Lekarska	
3.	dr n. med. Dąbrowski Andrzej	internista pulmonolog, alergolog	CSK WUM w Warszawie	
4.	prof. dr hab. n. med. Marczyńska Magdalena	pediatra	Warszawski Uniwersytety Medyczny	
5.	lek. dent. Miękus-Pączek Ewa	stomatolog	Szpital Psychiatryczny w Radomiu	
6.	dr n. med. Rafał Machowicz	internista	Warszawski Uniwersytety Medyczny	
7.	prof. dr hab. n. med. Niemczyk Stanisław	nefrolog, endokrynolog, transplantolog kliniczny, geriatra	Wojskowy Instytut Medyczny W Warszawie	
8.	mgr Renata Piasecka Krawczyk	pielęgniarka	Prywatna Praktyka	
9.	ks. dr hab. Dariusz Pater	duchowny, etyk	Uniwersytet Kardynała Stefana Wyszyńskiego w Warszawie	
10.	dr n. med. Pietrzykowska Bożena	psychiatria	Prywatna Praktyka Lekarska	
11.	mgr farm. Przymus-Góralezyk Elżbieta	farmaceuta	Apteka w W-wie	
12.	dr n. med. Romejko- Jarosińska Joanna	internista, onkolog kliniczny	Centrum Onkologii Instytut im. Marii Skłodowskiej - Curie	
13.	dr n. med. Michał Stępka	internista, gastroenterolog, diabetolog	Wojewódzki Szpital Chirurgii Udarowej św. Anny	
14.	dr n. med. Stopiński Marek	nefrolog	Szpital w Grodzisku Mazowieckim	
15.	dr n. praw. Radosław Tymiński	prawnik	Radosław Tymiński Kancelaria Prawna	

OŚWIADCZENIA WSPÓŁAUTORÓW /
STATEMENTS OF THE CO-AUTHORS

Gdańsk, dnia...06.12.2021

Dr. n. med. Natalia Buda

.....
(tytuł zawodowy, imię i nazwisko)

OŚWIADCZENIE

Jako współautor pracy pt. „Lung Ultrasonography in the Monitoring of Intraoperative Recruitment Maneuvers”, autorstwa: Cyłwik J, Buda N., wydanej w Diagnostics, 2021;11,276, oświadczam, iż mój własny wkład merytoryczny w przygotowanie, przeprowadzenie i opracowanie badań oraz przedstawienie pracy w formie publikacji to: opracowanie koncepcji, metodologii i pisanie manuskryptu.

Jednocześnie wyrażam zgodę na przedłożenie w/w pracy przez lek. Jolantę Cyłwik jako część rozprawy doktorskiej w formie spójnego tematycznie zbioru artykułów opublikowanych w czasopismach naukowych.

Oświadczam, iż samodzielna i możliwa do wyodrębnienia część ww. pracy wykazuje indywidualny wkład lek. Jolanty Cyłwik przy opracowywaniu koncepcji, metodologii, wykonywaniu części eksperymentalnej, opracowaniu i interpretacji wyników tej pracy, pisaniu manuskryptu.

Buda Natalia
.....

(podpis współautora)

Gdańsk, dnia 06.12.2021

Dr. n. med. Natalia Buda

.....
(tytuł zawodowy, imię i nazwisko)

OŚWIADCZENIE

Jako współautor pracy pt. „The impact of ultrasound-guided recruitment maneuvers on the risk of postoperative pulmonary complications in patients undergoing general anesthesia” autorstwa: Cylwik J, Buda N., wydanej w Journal of Ultrasonography, oświadczam, iż mój własny wkład merytoryczny w przygotowanie, przeprowadzenie i opracowanie badań oraz przedstawienie pracy w formie publikacji to: opracowanie koncepcji, metodologii i pisanie manuskryptu.

Jednocześnie wyrażam zgodę na przedłożenie w/w pracy przez lek. Jolantę Cylwik jako część rozprawy doktorskiej w formie spójnego tematycznie zbioru artykułów opublikowanych w czasopismach naukowych.

Oświadczam, iż samodzielna i możliwa do wyodrębnienia część ww. pracy wykazuje indywidualny wkład lek. Jolanty Cylwik przy opracowywaniu koncepcji, metodologii, wykonywaniu części eksperymentalnej, opracowaniu i interpretacji wyników tej pracy, pisaniu manuskryptu.

Buda Natalie B

.....
(podpis współautora)