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# ALVEOLAR RECRUITMENT MANEUVER FOR ROBOT-ASSISTED LAPAROSCOPIC SURGERY IN TRENDELENBURG POSITIONING

Atanas Zanev[1, 2] Mirela Neykova[1, 2]
*1)Department of Anesthesiology, Emergency and Intensive Care Medicine, Medical University, Varna, Bulgaria.*
*2)Clinic of Anesthesiology and Intensive Care, University Hospital "St. Marina" – Varna, Bulgaria.*

## ABSTRACT

**Purpose.** This study aims to evaluate the effect of the alveolar recruitment maneuver on intraoperative lung function in patients undergoing robot-assisted surgery in the Trendelenburg position.

**Materials and methods.** A prospective, single-center randomized study was conducted at University Hospital "St. Marina" – Varna from June 2023 to July 2024, after approval by the Ethic Committee (No. 128/02.03.2023). 131 patients undergoing robot-assisted surgery in the Trendelenburg position were included. All patients were ventilated with VC/AutoFlow, a tidal volume (Vt) of 6-8 ml/kg, and respiratory rate (RR) adjusted according to $ETCO_2$, targeting 28-42 mmHg. $FiO_2$ was reduced after anesthesia induction to maintain $SpO_2 > 95\%$. In the experimental group, an alveolar recruitment maneuver (RM) was performed twice: first after Trendelenburg positioning and before pneumoperitoneum, and second after pneumoperitoneum and leveling of the operating table. At the end of the recruitment, Vt was maintained at 6-8 ml/kg and PEEP at 5 $cmH_2O$. Surgeries were performed by a single surgical team using the da Vinci robotic system.

**Results.** The performance of the alveolar recruitment maneuver significantly increased dynamic lung compliance (Cdyn), particularly in obese patients. It also reduced peak inspiratory pressures (Ppeak) and allowed for a significant reduction in $FiO_2$.

**Conclusion.** The alveolar recruitment maneuver is a valuable part of modern protective ventilation strategies, especially for preventing intraoperative pulmonary atelectasis. It can be considered a safe and effective method, particularly for obese patients and those undergoing robotic surgery in the Trendelenburg position.

**Key words:** alveolar recruitment, Trendelenburg position, robot-assisted surgery, protective ventilation,

## INTRODUCTION

Modern surgery has seen a significant push towards the use of minimally invasive interventions. Robot-assisted operations, as a groundbreaking advancement in medical technology, have transformed the face of contemporary surgery. These procedures combine the surgeon's skills with robotic technology to enhance the quality and safety of surgical procedures. This evolution also poses challenges for the modern anesthesiologist to be "up to date" and to actively engage with the new realities in medicine.

The idea of developing robot-assisted surgery dates back to the 1980s, when it was initially designed for military medicine purposes. In the following decades, it progressed rapidly. A pivotal moment came in 1998 with the introduction of two revolutionary robotic systems: ZEUS (Computer Motion, Inc.) and da Vinci Surgical (Intuitive Surgical, Inc.). Currently, many manufacturers are providing robotic systems, but da Vinci remains the most widespread, with over 5,114 consoles installed and operational worldwide [1]. The advantages of robotic surgery are indisputable: it enables the performance of complex tasks with sub-millimeter precision, thanks to high-definition 3D imaging and the precise control of robotic instruments, which eliminate fine tremors and accidental movements of the operator [2]. Reduced tissue trauma can also significantly decrease blood loss during surgery [3]. Smaller incisions lead to less postoperative pain, smaller skin scars, and a lower risk of infections. All of this contributes to shorter hospital stays and faster recovery for patients [4].

Despite the numerous advantages of robotic surgery, there are certain limitations that must be taken into account during the workflow. The equipment, with each component being exceptionally bulky, requires substantial space in the operating room. Encroachment into the anesthesia workspace is almost inevitable, and anesthesiologists need to be aware that proper initial positioning of the patient on the operating table is critically important, as further adjustments are nearly impossible once the robot is docked for the procedure [5].

A significant portion of robotic surgery is performed in non-anatomical positions—such as steep Trendelenburg, gynecological positioning, or lateral positioning with the operating table bent at various angles. These positions can lead to injuries to the skin, bones, and nerves, as well as negatively affect respiratory, cardiovascular, and other systems [6].

The robot cannot replace the surgeon; it only enhances the precision of the surgeon's hands. The presence of a robotic system is not a guarantee of success without the requisite knowledge and skills of the team performing the procedure [7].

The major risks associated with robotic surgery are linked to the need for general anesthesia (GA), positioning of the operating table, pneumoperitoneum required for most general surgical, gynecological, and urological procedures, and the specific characteristics of each individual surgery. All these factors significantly impact the respiratory system. During the perioperative period, multiple factors can impair respiratory function. General anesthesia itself is a proven independent risk factor for gas exchange impairment [8].

Respiratory system changes begin with the positioning of the operating table. The standard position for most surgical interventions, and mandatory during the induction of GA, is the supine position. Transitioning from an upright to a supine position, even in healthy individuals, leads to a decrease in Functional Residual Capacity (FRC) by 0.8-1.0 L (15%), due to abdominal pressure and the cranial displacement of the diaphragm. Additionally, in healthy individuals with spontaneous breathing, compliance decreases from 200 to 160 mL/cm$H_2O$, and resistance increases from 1.78 to 2.50 cm$H_2O$/L/s when moving from a seated to a supine position [9]. The induction of GA further causes diaphragm relaxation and additional cranial displacement, reducing FRC by another 0.4-0.5 L. Many surgical procedures require specific body positioning, such as the Trendelenburg position—where the head is tilted below the level of the feet. Moreover, some procedures, like robot-assisted prostatectomy, hysterectomy, and others, necessitate an extreme Trendelenburg position with a 25-30° tilt of the operating table [10]. This positioning further reduces FRC and lung compliance [11]. Obesity is another factor affecting ventilation, particularly in patients with a BMI over 30 kg/m$^2$, in whom FRC can decrease by over 20% [12]. FRC also decreases in patients with elevated abdominal pressure, such as those requiring artificial pneumoperitoneum with $CO_2$. As a result, FRC becomes smaller than Closing capacity (CC) relatively early in the procedure, leading to the formation of atelectasis [12]. It is no surprise that numerous studies report the occurrence of atelectasis and impaired oxygenation in over 90% of patients undergoing general anesthesia [13, 14].

Oxygen, vital for sustaining life, can also have a detrimental impact on lung tissue. Oxygen-derived free radicals are the most likely cause of such effects. High levels of $FiO_2$, can damage the pulmonary epithelium, inactivate surfactant, and ultimately lead to pulmonary atelectasis [15]. Combined with higher Tidal Volume (Vt), these factors exacerbate oxidative stress and worsen lung tissue injury [16]. Additionally, mechanical ventilation with high VT and/or elevated Peak Inspiratory Pressure (PIP, Ppeak) can directly damage lung parenchyma by overdistending the alveoli, causing volutrauma or barotrauma, respectively. Both conditions disrupt pulmonary structure and impair gas exchange [17]. These processes are associated with the development of Ventilator-Induced Lung Injury (VILI) and Postoperative Pulmonary Complications (PPCs). Currently, it is recognized that even routine mechanical ventilation in healthy patients can lead to VILI in approximately 22-39% of cases, a rate that can increase to 83% in the presence of preexisting pulmonary pathology. Additional risk factors include laparoscopic interventions and prolonged surgical procedures [18].

## Ventilation strategies in general anesthesia (GA) and robotic-assisted surgery:

The use of general anesthesia is fundamental for performing the vast majority of surgical interventions and is indispensable in robotic and laparoscopic surgery. Ensuring safe mechanical ventilation is essential for this purpose. The selection of an appropriate ventilation mode is critical for the smooth progression of the intraoperative period and the prevention of intra- and postoperative pulmonary complications. The main factors in this regard are tidal volume, ventilation pressures, and the application of Positive End-Expiratory Pressure (PEEP) [19]. In recent decades, various ventilation strategies have been developed to minimize potential damage caused by mechanical ventilation, collectively referred to as "Protective Lung Ventilation." Understanding and correctly interpreting pulmonary physiology form the basis for clinical decision-making in this area. Nevertheless, optimal ventilation parameters remain a subject of extensive debate [10].

Modern recommendations advocate for ventilation with a low tidal volume of 6-8 mL/kg to reduce alveolar damage caused by overdistension [20]. However, ventilation with low tidal volume can potentially lead to atelectasis, particularly during artificial pneumoperitoneum and the Trendelenburg positioning. The additional application of PEEP effectively improves lung ventilation and oxygenation by preventing alveolar collapse and may shorten the time to postoperative extubation in patients undergoing prolonged laparoscopic surgery [18]. Although no definitive guidelines exist regarding safe PEEP levels, values around 10 cm$H_2O$ or lower have minimal effects on the circulatory system and are unlikely to impair cardiac function, even in patients with cardiac disease [21]. Other important components of protective ventilation include avoiding high $FiO_2$ levels and limiting peak airway pressures (Ppeak) to a maximum of 35 $cmH_2O$.

Alveolar recruitment

Preventing the formation of atelectasis is a critical step in modern ventilation strategies during anesthesia. However, as previously mentioned, atelectasis is unavoidable even in young patients undergoing GA. To manage this, the implementation of a Recruitment Maneuver (RM) is recommended. RM is a combination of techniques aimed at reopening collapsed alveoli to improve ventilation and to increase $PaO_2$. Different strategies can be employed to achieve the "opening" of the airways, some of which are listed in Table 1. These strategies can be either ventilatory or non-ventilatory. Ventilatory techniques typically require mechanical ventilation and, in many cases, deep sedation and muscle relaxation [13].

**Table 1.** Methods to achieve alveolar recruitment

| |
|---|
| Treatment of underlying disease process: removal of airway obstruction, diuresis, treatment of infection |
| Stepwise recruitment (incremental PEE) |
| Airway Pressure Release Ventilation (APRV) |
| High Frequency Oscillatory Ventilation (HFOV) |
| Prone positioning |

## MATERIALS AND METHODS

The study was conducted from June 2023 to July 2024 at the University Hospital "St. Marina" - Varna. It was approved by the Research Ethic Committee (protocol N128/02.03.2023) at the Medical University of Varna. We followed 131 patients undergoing robot-assisted surgery in the Trendelenburg position (23°–25° tilt). The patients were divided into two groups: an experimental group (n=64) in which the alveolar recruitment maneuver was performed, and a control group (n=67) without recruitment.

All patients underwent pneumoperitoneum with pressures between 10–20 mmHg. Combined and balanced general intubation anesthesia was administered to all patients using the Draeger Perseus anesthetic machine. For the induction of anesthesia, we administered intravenous anesthetics: 2–2.5 mg/kg Propofol, preceded by 1–2 mg Midazolam. To facilitate endotracheal intubation, we used muscle relaxants Atracurium 0.5 mg/kg or Succinylcholine 1 mg/kg, followed by a maintenance dose of Atracurium upon signs of intraoperative decurarization. For intraoperative analgesia, 1 mcg/kg Fentanyl was administered prior to intubation, followed by intermittent maintenance doses during the procedure. Anesthesia maintenance was achieved using the inhalational anesthetic Sevoflurane. Induction of anesthesia was preceded by preoxygenation with $FiO_2$ 1.0 via face mask for a period of 3–5 minutes. After induction, the patients were mechanically ventilated with a VC/AutoFlow mode, with tidal volumes (Vt) 6–8 ml/kg and respiratory rates adjusted according to $ETCO_2$ to maintain target levels of 28–42 mmHg. After intubation, $FiO_2$ was minimized to values which allow the maintenance of $SpO_2$ above 95%.

In the experimental group, an alveolar recruitment maneuver was performed twice: the first, after positioning in the Trendelenburg position and prior to the initiation of pneumoperitoneum, and the second after the cessation of surgical pneumoperitoneum and the return to a horizontal table position. The recruitment maneuver was conducted in a stepwise and automated manner, with maximum settings of Ppeak 32 $cmH_2O$ and PEEP 12 $cmH_2O$, lasting 90–120 seconds. At the end of the maneuver, Vt was reset to 6–8 ml/kg and PEEP to 5 $cmH_2O$.

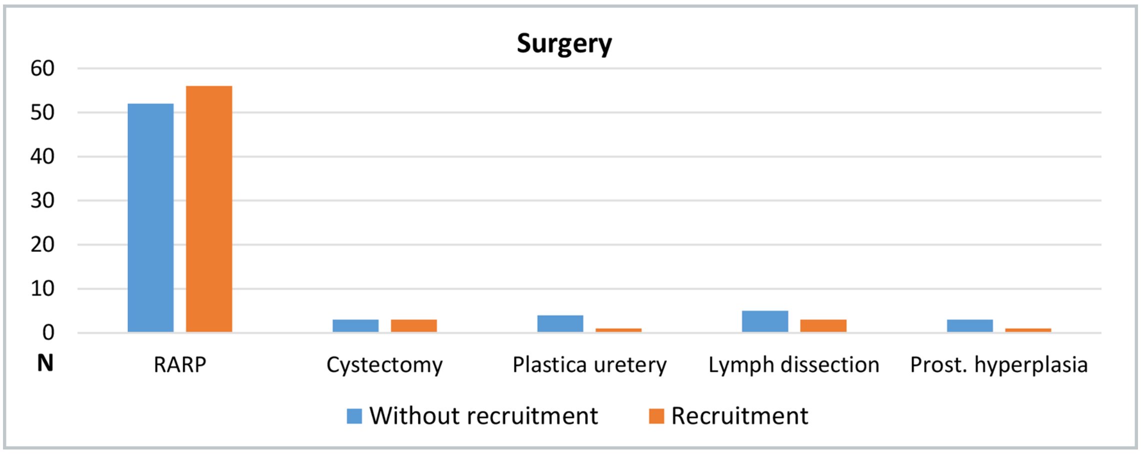
All surgical interventions were performed by a single surgical team using the da Vinci robotic system.

Intraoperative monitoring included parameters such as $SpO_2$ (via pulse oximetry), mean arterial pressure (MAP), heart rate (HR), Ppeak, dynamic compliance (Cdyn), $ETCO_2$, and others. The collected data were processed using SPSS, with graphical representations prepared in Excel.

## RESULTS

The types of robot-assisted surgeries involved in our study are shown in fig. 1.

**Fig. 1.** Types of surgical interventions



There is an evident predominance of surgeries performed for prostate carcinoma, which also explains the gender distribution—with a significantly higher percentage of men included in our study. In the experimental group, 96.9% (n=62) were men and 3.1% (n=2) were women, while in the control group, 94% (n=63) were men and 6% (n=4) were women. The average duration of the surgical procedures was 164 minutes (SD±24) for the experimental group and 169 minutes (SD±26) for the control group, with no statistically significant difference between the two groups (p=0.89). Preoperative patient assessment was performed according to the ASA classification, and the results are presented in Table 2.

**Table 2.** Distribution according to the ASA classification between the control and experimental groups

| | ASA II | ASA III | *p* |
|---|---|---|---|
| Without recruitment | 28 | 39 | *0,9* |
| Recruitment | 39 | 25 | |

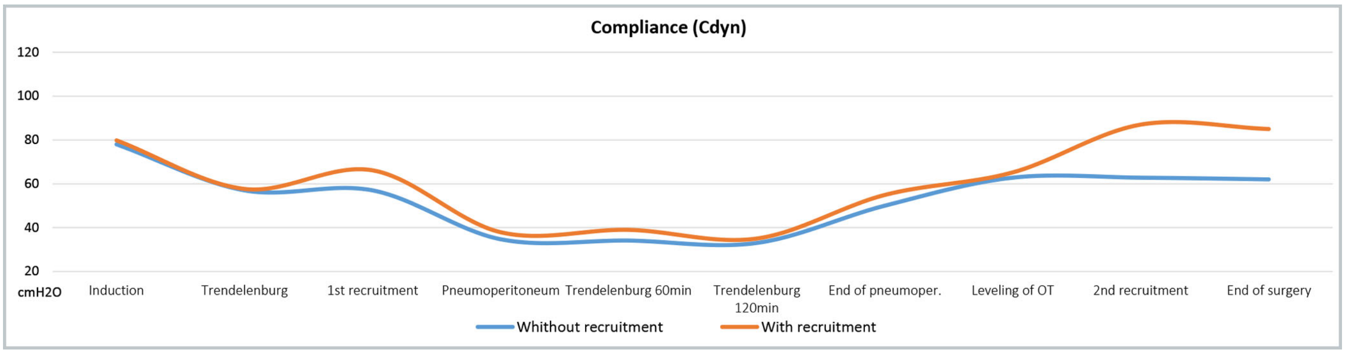
One of the primary parameters used to compare pulmonary status between the two groups, presented in this study, were Ppeak, Cdyn, and $FiO_2$ during the intraoperative period.

When comparing the dynamic lung compliance, the results demonstrated a statistically significant difference between the two groups. After the first recruitment, following the establishment of pneumoperitoneum and at the 60th minute of the intraoperative period, the pulmonary compliance in the experimental group was significantly higher compared to the control group. After the 120th minute, the values between the two groups converged, and although slightly higher in patients with recruitment, the differences were no longer statistically significant. Following the second recruitment, there was again a statistically significant improvement in pulmonary compliance, which was maintained until the end of the anesthesia. The results are illustrated in Table 3 and Fig. 2.

**Table 3.** Differences in Cdyn between the control and experimental groups at different stages of the surgical intervention

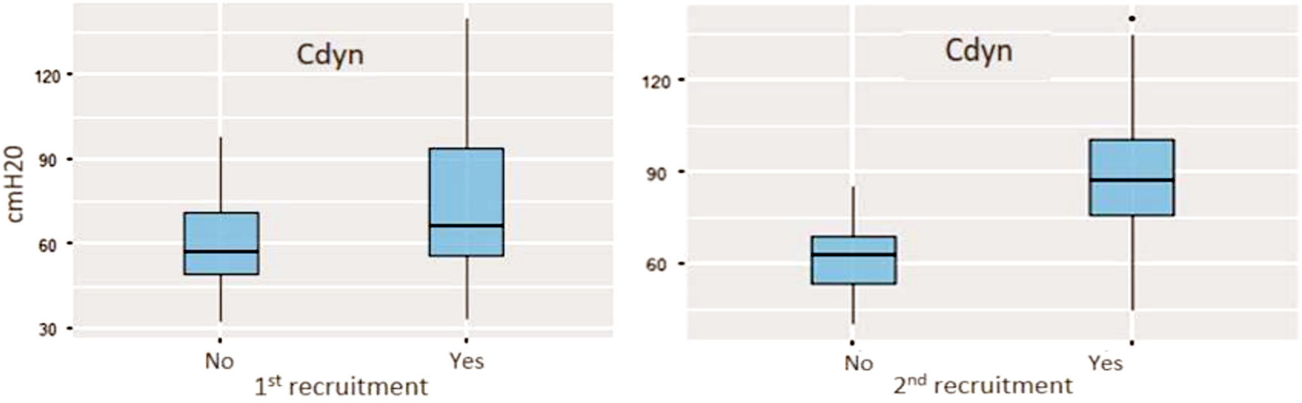
| **Compliance cmH20** | **Groups** | **Median** | **-Q1** | **Q3** | ***p* (Mann-Whitney)** |
|---|---|---|---|---|---|
| Induction | Contr. | 78 | 65,2 | 91 | 0,474 |
| | Exper. | 79,8 | 69,05 | 94,25 | |
| Trendelenburg | Contr. | 57 | 49 | 71,2 | 0,5 |
| | Exper. | 57,65 | 47,8 | 78,85 | |
| $1^{st}$ recruitment | Contr. | 57 | 49 | 71,2 | < .001 |
| | Exper. | 66,15 | 56 | 94 | |
| Pneumoperitoneum | Contr. | 34,7 | 30 | 38,2 | 0,001 |
| | Exper. | 37,9 | 34,08 | 43 | |
| Trendelenburg 60min | Contr. | 34,1 | 30,55 | 38,3 | 0,003 |
| | Exper. | 39 | 33 | 44 | |
| Trendelenburg 120min | Contr. | 33 | 32 | 37,8 | 0,328 |
| | Exper. | 35 | 32 | 43 | |
| End of pneumoperitoneum | Contr. | 50 | 44,25 | 59,55 | 0,252 |
| | Exper. | 54,9 | 44,95 | 65 | |
| Leveling of the operating table | Contr. | 62,8 | 53,7 | 68,75 | 0,092 |
| | Exper. | 65,2 | 55 | 75,05 | |
| $2^{nd}$ recruitment | Contr. | 62,8 | 53,7 | 68,75 | < .001 |
| | Exper. | 87 | 76 | 100,5 | |
| End of surgery | Contr. | 62 | 50,4 | 68,25 | < .001 |
| | Exper. | 85 | 77,75 | 93,25 | |

**Fig. 2.** Dynamics of Cdyn during the intraoperative period between the two patient groups.



The differences in Cdyn were even more significant when comparing only patients with obesity (those with BMI > 25), with a significant increase after the second recruitment maneuver, as shown in Fig. 3.

**Fig. 3.** Cdyn in obese patients.



Regarding another important parameter of pulmonary ventilation monitored in our study - Peak inspiratory pressure (Ppeak), we also observed a difference between the two groups. The results are shown in Table 4. As seen, after the first recruitment maneuver, the difference was statistically significant and was maintained during the pneumoperitoneum. In the following time intervals, despite the lower reported values of Ppeak, no statistically significant difference was found until the second recruitment maneuver was performed.

**Table 4.** Values of Ppeak in different intraoperative periods.

| **Ppeak mmHg** | **Groups** | **Median** | **Q1** | **Q3** | **p (Mann-Whitney)** |
|---|---|---|---|---|---|
| Induction | Contr. | 14 | 13 | 15 | 0,482 |
| | Exper. | 13,5 | 13 | 15 | |
| Trendelenburg | Contr. | 16 | 14 | 19 | 0,709 |
| | Exper. | 16,5 | 14 | 19,25 | |
| 1st recruitment | Contr. | 16 | 14 | 19 | 0,022 |
| | Exper. | 14 | 14 | 18 | |
| Pneumoperitoneum | Contr. | 22 | 20 | 24 | 0,03 |
| | Exper. | 21 | 19 | 24 | |

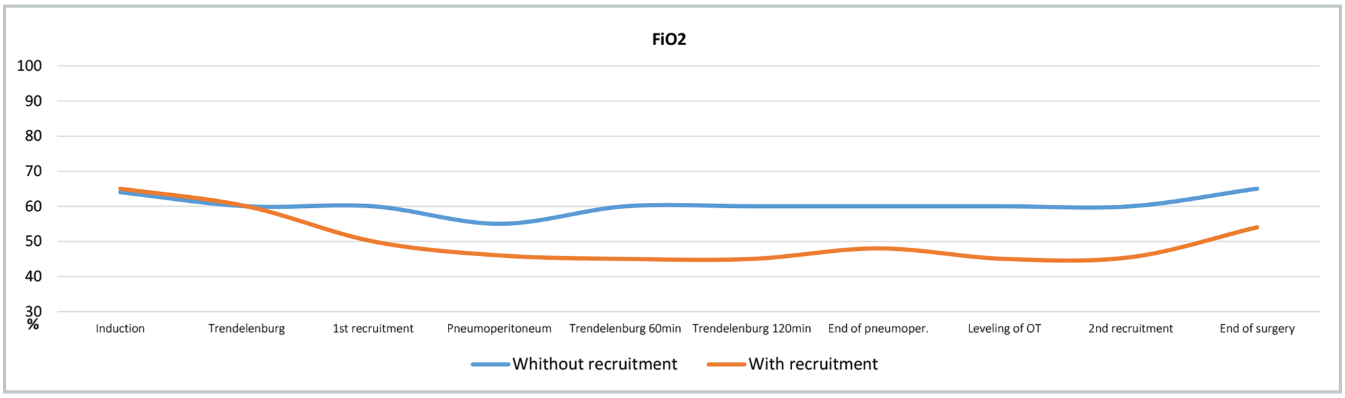
| | | | | | |
|---|---|---|---|---|---|
| Trendelenburg 60min | Contr. | 22 | 21 | 24 | 0,049 |
| | Exper. | 21 | 19 | 24 | |
| Trendelenburg 120min | Contr. | 22 | 22 | 26 | 0,073 |
| | Exper. | 22 | 20 | 24 | |
| End of pneumoperitoneum | Contr. | 18 | 16 | 20 | 0,819 |
| | Exper. | 17 | 16 | 20 | |
| Leveling of the operating table | Contr. | 16 | 15 | 17,5 | 0,219 |
| | Exper. | 16 | 15 | 17,25 | |
| 2nd recruitment | Contr. | 16 | 15 | 17,5 | 0,01 |
| | Exper. | 15 | 13 | 16 | |
| End of surgery | Contr. | 16 | 15 | 16 | < .001 |
| | Exper. | 14 | 13 | 16 | |

Regarding the use of $O_2$, statistically significant differences were again found between the two patient groups. In the group where recruitment was applied, we were able to reduce $FiO_2$ right after the first procedure, and it remained low throughout the anesthesia without causing any difference in $SpO_2$ between the two groups. These data are shown in Table 5 and Fig. 4.

**Table 5.** Values of FiO2 in patients with and without applied recruitment.

| **FiO2 %** | **Groups** | **Mean** | **Min** | **Max** | **p** |
|---|---|---|---|---|---|
| Induction | Contr. | 73,34 | 60 | 100 | 0,085 |
| | Exper. | 67,69 | 50 | 91 | |
| Trendelenburg | Contr. | 60,31 | 45 | 80 | 0,61 |
| | Exper. | 54,09 | 40 | 68 | |
| 1st recruitment | Contr. | 60,31 | 45 | 80 | < .001 |
| | Exper. | 49,55 | 35 | 61 | |
| Pneumoperitoneum | Contr. | 57,49 | 40 | 80 | < .001 |
| | Exper. | 46,53 | 35 | 56 | |
| Trendelenburg 60min | Contr. | 57,45 | 40 | 80 | < .001 |
| | Exper. | 46,08 | 30 | 63 | |
| Trendelenburg 120min | Contr. | 59,12 | 50 | 70 | < .001 |
| | Exper. | 45,04 | 30 | 65 | |
| End of pneumoperitoneum | Contr. | 57,7 | 40 | 80 | < .001 |
| | Exper. | 46,41 | 30 | 65 | |
| Leveling of the operating table | Contr. | 58,31 | 40 | 80 | < .001 |
| | Exper. | 46,2 | 30 | 65 | |
| 2nd recruitment | Contr. | 58,31 | 40 | 80 | < .001 |
| | Exper. | 46,84 | 35 | 65 | |
| End of surgery | Contr. | 71,63 | 40 | 100 | < .001 |
| | Exper. | 52,8 | 35 | 72 | |

**Fig. 4.** FiO2 in patients with and without recruitment



## DISCUSSION

Each year, over 313 million surgical procedures worldwide are performed under general anesthesia (GA), accompanied by associated risks for the development of postoperative pulmonary complications (PPCs) (19). Even minor improvements in perioperative management can significantly reduce morbidity and improve outcomes for a large patient population. Alveolar recruitment is unequivocally one of the potential techniques for achieving this. However, the question of its routine application in every case of GA remains open. We strongly recommend using recruitment maneuvers in laparoscopic surgery, anesthesia lasting more than 120 minutes, and particularly in patients with obesity.

Additional discussions and research are needed to establish protocols for the frequency of intraoperative recruitment maneuvers, the pressures and PEEP levels used during recruitment, and the appropriate values for maintenance PEEP.

Given that in our study, ventilation parameters between the two patient groups converged after 120 minutes, strategies involving more frequent recruitment maneuvers, especially during prolonged procedures, should be considered. Recruitment maneuvers are also recommended whenever ventilation status changes—such as patient circuit disconnection (accidental or during suctioning), increases in intra-abdominal pressure, elevated ventilation pressures, reduced lung compliance, or hypoxia (absent other clear causes, such as developing intraoperative atelectasis).

Modern anesthetic machines with capabilities for multistep automated recruitment are preferable to the classical method of delivering constant pressure of 40 $cmH_2O$ for 40 seconds. Additionally, we advocate for using higher PEEP values than the standard 5 $cmH_2O$, particularly during laparoscopic procedures in the Trendelenburg position.

Another important aspect of recruitment, requiring further discussion and in-depth research, is its impact on PPCs. In our study, we found no direct association between the application of recruitment techniques and postoperative pulmonary complications or differences in postoperative hospital stay duration.

## CONCLUSION

The alveolar recruitment maneuver, combined with low tidal volume ventilation and consistent PEEP, is a key component of modern protective ventilation strategies. Its application significantly improves lung compliance - a direct indicator of alveolar ventilation efficiency and corresponding blood oxygenation. By allowing a reduction in ventilation pressures, it can help protect lung tissue from barotrauma.

Alveolar recruitment reduces the formation of atelectasis and, unlike using PEEP alone, facilitates the reopening and ventilation of already collapsed alveoli. Enhanced respiratory mechanics enable the reduction of $FiO_2$, concentrations, with the lowest levels in our study reaching 0.3 in some patients from the experimental group without compromising oxygen saturation. This reduction minimizes oxygen's toxic effects on alveolocytes.

This approach is particularly beneficial for obese patients, who are highly prone to atelectasis formation and subsequent hypoxemia. The alveolar recruitment maneuver can also be considered a safe technique, as our study did not record severe hemodynamic disturbances or pneumothorax events that necessitated procedure termination. Furthermore, there was no statistical difference in the intraoperative use of catecholamines between the two groups, indicating that their administration is more influenced by the surgical phase and preoperative patient status than by the application of recruitment maneuvers.

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**Address for correspondence:**
Atanas Zanev, MD, PhD
Institution of the leading author for correspondence
1, Hr. Smirnenski Blvd., 9010, Varna, Bulgaria
E-mail: naskozanev@gmail.com,