"COMPARISON OF LUNG RECRUITMENT MANOEUVRE WITH PEEP (POSITIVE END- EXPIRATORY PRESSURE) AND ONLY PEEP (POSITIVE END -EXPIRATORY PRESSURE) ON DEVELOPMENT OF ATELECTASIS IN PATIENTS UNDERGOING LAPAROSCOPIC SURGERY - A RANDOMIZED CONTROL TRIAL"

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Sub: Institutional Ethical Clearance for the study.

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LIST OF ABBREVIATIONS

PEEP	Positive End-Expiratory Pressure
LUS	Lung Ultrasound
RM	Recruitment Manoeuvre
LRM	Lung Recruitment Manoeuvre
FRC	Functional Residual Capacity
PPCs	Postoperative Pulmonary Complications
ASA	American Society of Anesthesiologists
IAP	Intra-Abdominal Pressure
PACU	Post-Anaesthesia Care Unit
T1	Preoperative Baseline Time Point
T2	15 Minutes After Arrival in PACU
T3	3 Hours Postoperatively
PCV	Pressure-Controlled Ventilation
VCV	Volume-Controlled Ventilation
$ETCO_2$	End-Tidal Carbon Dioxide
ABG	Arterial Blood Gas
SpO_2	Peripheral Oxygen Saturation
MAP	Mean Arterial Pressure
SD	Standard Deviation
IQR	Interquartile Range
RCT	Randomized Controlled Trial
BMI	Body Mass Index
ARDS	Acute Respiratory Distress Syndrome
COPD	Chronic Obstructive Pulmonary Disease
ICU	Intensive Care Unit

VT	Tidal Volume
OLS	Open Lung Strategy
HR	Heart Rate
BP	Blood Pressure
SVR	Systemic Vascular Resistance
PVR	Pulmonary Vascular Resistance
CBF	Cerebral Blood Flow
ICP	Intracranial Pressure
IOP	Intraocular Pressure
USG	Ultrasonography
POCUS	Point-of-Care Ultrasound

ABSTRACT

Title of the article: Comparison of Lung Recruitment Manoeuvre with PEEP (Positive End-Expiratory Pressure) and Only PEEP on Development of Atelectasis in Patients Undergoing Laparoscopic Surgery – A Randomized Control Trial

Context: Pulmonary atelectasis is a common consequence of general anaesthesia, particularly in elective laparoscopic surgery due to pneumoperitoneum and Trendelenburg positioning. Atelectasis can impair oxygenation, reduce lung compliance, and contribute to postoperative pulmonary complications. Lung-protective ventilation strategies incorporating positive end-expiratory pressure (PEEP) and lung recruitment manoeuvres (LRMs) have been proposed to mitigate these effects. However, the optimal intraoperative strategy remains a subject of debate.

Aims: This study aims to compare the incidence of atelectasis in patients undergoing elective laparoscopic surgery under general anaesthesia, receiving either lung recruitment manoeuvre with PEEP (RM Group) or PEEP alone (Control Group). The study further evaluates changes in lung ultrasound scores (LUS) and the impact on perioperative lung function.

Settings and Design: This study is a randomized controlled trial (RCT) conducted at a tertiary care centre, involving patients undergoing elective laparoscopic surgery under general anaesthesia.

Methods and Material: A total of 68 patients (ASA I & II, aged 18–60 years) were randomly assigned into two groups. The RM Group received 6 cm H_2O PEEP with lung recruitment manoeuvre using the sustained inflation technique (30 cm H_2O for 30 seconds), while the Control Group received 6 cm H_2O PEEP alone without recruitment manoeuvres. Lung ultrasound was performed at three time points: preoperative baseline

(T1), 15 minutes post-extubation upon arrival in the post-anaesthesia care unit (T2), and three hours postoperatively (T3). Atelectasis was assessed based on LUS scores, with higher scores indicating greater loss of lung aeration.

Statistical analysis used: Descriptive statistics were reported as mean ± standard deviation (SD) and median (IQR). Chi-square tests were used for categorical variables, while Mann-Whitney U tests were employed for continuous variables. A p-value <0.05 was considered statistically significant.

Results: At baseline (T1), no patient exhibited atelectasis. At T2, all patients developed atelectasis (100% incidence in both groups), confirming the impact of pneumoperitoneum and anaesthesia. At T3, the incidence of atelectasis was significantly lower in the RM Group (47.06%) compared to the Control Group (100%) ($p < 0.001$). The mean total LUS score was also significantly lower in the RM Group (8 ± 2.1) than in the Control Group (17.76 ± 3.64) ($p < 0.001$), indicating improved lung aeration.

Conclusions: Lung recruitment manoeuvres, when combined with PEEP, significantly reduce the incidence and severity of postoperative atelectasis compared to PEEP alone. This strategy improves lung aeration, as reflected by lower LUS scores, without causing significant hemodynamic instability. The findings support the integration of LRMs as a standard intraoperative ventilation strategy in elective laparoscopic surgery to optimize perioperative lung function and reduce postoperative pulmonary complications.

Keywords: Atelectasis, lung recruitment manoeuvre, positive end-expiratory pressure, laparoscopic surgery, general anaesthesia, lung ultrasound, postoperative pulmonary complications

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INTRODUCTION

Pulmonary atelectasis is a well-recognized complication of general anaesthesia, occurring in nearly 90% of mechanically ventilated patients, particularly those undergoing laparoscopic surgery.[1] The induction of pneumoperitoneum, along with the Trendelenburg position, significantly increases intrathoracic pressure, leading to diaphragmatic cephalad displacement, reduced functional residual capacity (FRC), and alveolar collapse.[2,3] These physiological changes impair gas exchange, reduce oxygenation, and contribute to postoperative pulmonary complications (PPCs), including hypoxemia and pneumonia.[4,5,6] Given the high incidence and associated morbidity of PPCs, optimizing intraoperative ventilation strategies is crucial.[7]

To mitigate atelectasis, lung-protective ventilation (LPV) strategies incorporating positive end-expiratory pressure (PEEP) and lung recruitment maneuvers (LRMs) have been widely investigated. PEEP prevents alveolar collapse by maintaining airway pressure above the closing threshold, while LRMs transiently increase airway pressure to re-expand collapsed alveoli.[8] However, the optimal PEEP level remains controversial, as excessive PEEP can lead to lung overdistension and hemodynamic instability, whereas inadequate PEEP may fail to prevent atelectasis.[9, 10]

Lung recruitment maneuvers have demonstrated efficacy in improving oxygenation and lung compliance, but their effectiveness depends on the method of application, frequency, and combination with PEEP.[11]

Given the existing evidence supporting the role of LRMs and PEEP in lung-protective ventilation, this study aims to compare the efficacy of lung recruitment manoeuvre with PEEP versus PEEP alone in preventing atelectasis in patients undergoing elective laparoscopic surgery. By employing a randomized controlled trial design, this study will evaluate the impact of these ventilation strategies on perioperative oxygenation, lung compliance, and postoperative pulmonary complications, thereby contributing to the ongoing optimization of intraoperative ventilation management.

OBJECTIVE

The objective for my study is to compare the prevalence of atelectasis in those receiving elective laparoscopic surgery under general anaesthesia receiving Lung Recruitment Manoeuvre with PEEP (Recruitment Manoeuvre Group /RM Group) and PEEP alone (Control Group/ C Group).

REVIEW OF LITERATURE

Atelectasis is a well-recognized complication in patients undergoing elective laparoscopic surgery due to the effects of pneumoperitoneum and patient positioning. Lung compliance significantly decreases during laparoscopic gynaecological procedures, and even after desufflation, compliance remains 23.8% lower than its initial value. Recruitment manoeuvres (RMs) have been shown to restore compliance, with a 17.5% increase post-recruitment, particularly in patients with higher BMI and lower initial compliance as demonstrated by Griva et al. in 2024.[12] Furthermore, individualized stepwise lung RM has been found to significantly reduce postoperative pulmonary complications (POPCs) when combined with protective lung ventilation in upper abdominal surgeries under general anaesthesia as reported by Salama et al in 2023.[13]

Lung recruitment manoeuvres (LRMs) have been widely studied for their role in preventing atelectasis and improving postoperative pulmonary function. A compliance-based intraoperative PEEP titration approach has been found to reduce postoperative lung atelectasis as assessed by lung ultrasound in major laparoscopic gynaecological surgeries, leading to improved oxygenation and decreased need for postoperative supplemental oxygen as found in the study by L D, Kumar R, et al. in 2023.[14] Similarly, driving pressure-guided dynamic, individualized PEEP lowers pulmonary atelectasis in the early postoperative period and improves respiratory mechanics compared to standard PEEP strategies in laparoscopic surgery as investigated by Xu Q et al. in 2022 and concluded that choice of PEEP strategy significantly impacts perioperative lung protection. They also showed that standard PEEP strategies are not superior to conventional ventilation in preventing atelectasis, whereas driving pressure-guided dynamic, individualized PEEP yields better postoperative respiratory outcomes.[15] A combination of RM with a stepwise increase in PEEP has been shown to significantly increase tidal volume (VT) without inducing respiratory or hemodynamic complications, making it a safe and effective approach to improving lung function in paediatric patients as observed by Tsukamoto et al. in 2023.[16]

Lung ultrasound (LUS) has emerged as a valuable tool for assessing lung aeration during recruitment manoeuvres. Bedside lung ultrasound assessments have demonstrated that RMs significantly improve lung aeration, particularly in posterior lung regions, compared to prone positioning according to Cammarota et al. in 2023.[17] Additionally, LUS was extensively used during the COVID-19 pandemic for pneumonia diagnosis and monitoring, proving its role in predicting disease severity and guiding pulmonary management as reviewed by Lê MP et al. in 2022.[18] Several novel lung recruitment approaches have been explored in recent studies. Sequential lateral positioning has been identified as an effective lung recruitment manoeuvre, improving respiratory mechanics and oxygenation without increasing airway pressure or causing negative hemodynamic consequences as explored by Roldán R et al. in 2022.[19] Similarly, recruitment manoeuvres performed in a semi-lateral position have been found to maintain hemodynamic stability while increasing regional lung ventilation, making them a promising alternative to traditional RM techniques as examined by Eun Jung Oh et al in 2003.[20]

Despite their benefits, RMs can have significant physiological effects. RMs performed as sustained inflations in ventilated paediatric ICU patients have been associated with improved oxygenation lasting up to six hours without notable adverse effects, but further research is required to establish optimal timing and methods as noted by Duff J et al. in 2007.[21] However, RMs performed in patients who are haemodynamically stable, following cardiac surgery have been shown to markedly reduce cardiac output and left ventricular end-diastolic volume as reported by Nielsen J et al. in 2005.[22] Additionally, a study comparing pulmonary expansion manoeuvres to usual care found no significant differences in ventilatory mechanics, atelectasis incidence, or ICU stay duration as found by da Silva K et al. in 2023,[23] highlighting the need for further research to determine their efficacy across different patient populations.

The existing literature underscores the importance of individualized lung recruitment manoeuvres and PEEP strategies in preventing postoperative atelectasis and optimizing perioperative respiratory function. While RMs have demonstrated efficacy in improving lung compliance, oxygenation, and reducing atelectasis, their hemodynamic effects and optimal application require further investigation. Lung ultrasound continues to be a valuable tool in monitoring lung recruitment effectiveness. Future studies should explore long-term effects, individualized approaches, and alternative recruitment strategies to optimize patient outcomes in laparoscopic and other surgical settings

BASIC SCIENCES

LAPAROSCOPIC SURGERY

The laparoscopic approach has become a standard of care for many abdominal surgical procedures. Compared with laparotomy, laparoscopy allows smaller incisions, reduces the perioperative stress response, reduces postoperative pain, and results in shorter recovery time.

Anaesthetic concerns in patients undergoing laparoscopic and robotic surgery differ from those in patients undergoing open abdominal surgery.

Laparoscopy requires creation of a pneumoperitoneum by insufflation of gas, usually carbon dioxide (CO_2), to open up the space in abdomen for visualization and surgical manipulation. CO_2 insufflation can be performed blindly using a Veress needle or by placement of a port under direct vision through a small subumbilical incision. The gas source is connected to the needle or port; intraabdominal pressure (IAP) is monitored as gas is insufflated, aiming for a pressure $\leq$15 mmHg to minimize physiologic effects.

Physiologic effects of the pneumoperitoneum, absorption of CO_2, and positioning required for surgery can influence intraoperative care and outcomes. In addition, some laparoscopic procedures take longer than the open alternative.

PHYSIOLOGICAL EFFECTS OF LAPAROSCOPY

Pulmonary changes —

Pneumoperitoneum with CO_2 and surgical positioning are associated with changes in pulmonary function and gas exchange:

Table 1: Pulmonary changes during laparoscopic surgery [24]

Parameter	Change	Causes
Lung volume (ie, functional residual capacity)	Decrease	• Elevation of diaphragm • Increased intraabdominal pressure • Positioning
Lung compliance	Decreased Increased pleural pressure Increased airway pressure	• Elevation of diaphragm • Increased intraabdominal pressure
PCO_2	Increased, depending on ventilation	CO_2 absorption
PO_2	Variable	Interaction among: • Atelectasis • Hypoxic pulmonary vasoconstriction • Preoperative pulmonary status
Tracheal position	Cephalad displacement, possible mainstem intubation	• Increased intraabdominal pressure • Trendelenburg position

These changes can result from increased IAP with pneumoperitoneum and from absorption of CO_2.

During laparoscopy, minute ventilation must be increased to compensate for absorption of CO_2. Hyperventilation may be difficult for patients with COPD, asthma, and/or severe obesity, especially in Trendelenburg position. In patients with COPD and in older patients, end-tidal CO_2 ($ETCO_2$) may not accurately reflect arterial partial pressure of CO_2; in such patients, arterial blood gases may be required to monitor ventilation.

The absorption and elimination of CO_2 in patients with severe obesity appears to be similar to patients without obesity [25]. Arterial oxygenation decreases and alveolar–arterial oxygen gradient increases in anesthetized patients with obesity when placed in Trendelenburg position, though CO_2 insufflation tends to slightly reverse these effects [26].

- **Changes in pulmonary mechanics** – Pneumoperitoneum causes cephalad displacement of the diaphragm and mediastinal structures, which reduces functional residual capacity (FRC) and pulmonary compliance, resulting in atelectasis and increased peak airway pressures. These effects are exacerbated with steep Trendelenburg positioning (eg, during pelvic surgery) and are reduced with reverse Trendelenburg positioning (eg, during cholecystectomy and gastric surgery). The changes in pulmonary compliance may be less with retroperitoneal insufflation (eg, during renal or adrenal procedures) compared with intraperitoneal insufflation

- **Ventilation/perfusion matching** – The reduction in FRC and atelectasis associated with laparoscopy may theoretically lead to shunting and ventilation/perfusion mismatch; however, in healthy patients, these effects are minimal and well tolerated, even with steep Trendelenburg positioning [27,28,29].

Endotracheal tube position – Pneumoperitoneum and Trendelenburg positioning may cause cephalad movement of the carina, which can result in mainstem endobronchial migration of the endotracheal tube, hypoxia, and high inspiratory pressure [30,31]. In addition, endotracheal tube cuff pressure increases in some patients during laparoscopy.[32]

Cardiovascular changes —

Cardiovascular changes during laparoscopy relate to the increase in intraabdominal pressure (IAP) associated with carbon dioxide (CO_2) insufflation, effects of positioning, and of absorption of CO_2, as follows:

- **Effects of pneumoperitoneum:** Pneumoperitoneum and the associated increase in IAP result in neuroendocrine and mechanical effects on cardiovascular physiology.
    - Neuroendocrine effects – Increase in IAP results in catecholamine release and activation of the renin–angiotensin system with vasopressin release. This increases MAP in most patients and may contribute to increases in SVR and pulmonary vascular resistance (PVR).

      Vagal stimulation, from insertion of the Veress needle or peritoneal stretch with gas insufflation, can result in bradyarrhythmias. Bradycardia is common in this setting, while atrioventricular dissociation, nodal rhythm, and asystole have been reported [33].

    - Mechanical effects – Mechanical aspects of laparoscopy are dynamic; the resulting cardiovascular effects depend on the patient's preexisting volume status, insufflation pressure, and position. Compression of arterial vasculature with pneumoperitoneum increases SVR and PVR, with variable effects on CO and blood pressure (BP) [34,35,36].

      Hypercarbia caused by CO_2 absorption may also increase SVR and PVR; in most cases, minute ventilation is increased to prevent hypercarbia, but the increase in intrathoracic pressure that accompanies ventilator adjustments may further increase SVR and PVR.

Cardiovascular effects tend to resolve quickly as pneumoperitoneum is maintained.

- **Effects of hypercarbia:** Absorption of CO_2 during laparoscopy can have direct and indirect cardiovascular effects. The direct effects of hypercarbia and associated acidosis include decreased cardiac contractility, sensitization to arrhythmias, and systemic vasodilation. Indirect effects are the result of sympathetic stimulation, and include tachycardia and vasoconstriction, which may counteract vasodilation.

Regional circulatory changes –

- **Splanchnic blood flow** – The mechanical and neuroendocrine effects of pneumoperitoneum can decrease splanchnic circulation. However, hypercapnia can cause direct splanchnic vasodilatation. Thus, the overall effects on splanchnic circulation are not clinically significant [37,38].

- **Renal blood flow** – The creation of a pneumoperitoneum results in reduction in renal perfusion and urine output associated with renal parenchymal compression, reduced renal vein flow, and increased levels of vasopressin. When IAP is kept under 15 mmHg, renal function and urine output generally normalize soon after pneumoperitoneum deflation, without histologic evidence of pathologic changes.
- **Cerebral blood flow** – Increased intraabdominal and intrathoracic pressures, hypercarbia, and Trendelenburg positioning can all increase cerebral blood flow (CBF) and intracranial pressures (ICP). In healthy patients undergoing

prolonged pneumoperitoneum and steep Trendelenburg position, cerebral oxygenation and cerebral perfusion remain within safe limits [39].

- **Intraocular pressure** – Intraocular pressure (IOP) increases with pneumoperitoneum and increases further when the patient is positioned in Trendelenburg.

LUNG RECRUITMENT MANOEUVRE

Recruitment manoeuvres (RMs) are ventilatory strategies designed to reopen collapsed alveoli and improve lung compliance, particularly in conditions such as Acute Respiratory Distress Syndrome (ARDS), intraoperative atelectasis, and post-operative pulmonary complications.[40]

Alveolar collapse can occur due to factors like low tidal volume ventilation, decreased of functional residual capacity (FRC) during anaesthesia, and increased airway resistance.[41]

The principle of recruitment manoeuvres is based on increasing transpulmonary pressure to counteract alveolar derecruitment. This is typically achieved by applying a brief, sustained increase in airway pressure or a stepwise titration of positive end-expiratory pressure (PEEP) to optimize alveolar opening while minimizing ventilator-induced lung injury (VILI).[42]

Recruitment manoeuvres are commonly utilized to maintain lung aeration and prevent postoperative pulmonary complications. However, their application requires careful monitoring, as excessive pressures may lead to hemodynamic instability, barotrauma, or transient oxygen desaturation.[42]

TYPES OF RECRUITMENT MANOEUVRES

[1] Sustained Inflation (SI):

The most commonly used manoeuvre in clinical settings is the sustained inflation manoeuvre, which involves the application of a constant airway pressure of 30 to 40 cm H_2O for 30 to 40 seconds. [42]

[2] Incremental PEEP Titration:

Another commonly used method is the stepwise increase of PEEP in increments of 2 to 5 cm H_2O, typically every 3 to 5 minutes, while monitoring lung compliance and oxygenation. [42]

[3] Vital Capacity (VC) Manoeuvre:

A vital capacity manoeuvre, in which a peak airway pressure of 40 cm H_2O is applied for 7–8 seconds, has been shown to recruit nearly all collapsed lung regions and improve oxygenation. [41]

[4] Open Lung Strategy (OLS):

An open lung strategy incorporates a combination of low tidal volume ventilation, adequate levels of PEEP, and recruitment manoeuvres to minimize lung stress and prevent repeated alveolar collapse. [42]

CLINICAL APPLICATIONS

1. **ARDS Management:**

Recruitment manoeuvres are often used in patients with acute respiratory distress syndrome (ARDS) to improve oxygenation by reopening collapsed alveoli, although evidence on their effect on mortality remains mixed. [42]

2. **One-Lung Ventilation (OLV):**

During one-lung ventilation, recruitment manoeuvres are employed to prevent atelectasis and improve oxygenation following lung collapse and re-expansion.[40]

3. **Postoperative Atelectasis:**

   Recruitment manoeuvres can be used in the postoperative setting to prevent or reverse atelectasis, particularly following major thoracic or abdominal surgery.[41]

POTENTIAL RISKS AND LIMITATIONS: [42]

1. **Hemodynamic Instability:**

   The transient increase in intrathoracic pressure during a recruitment manoeuvre can reduce venous return, leading to hypotension and decreased cardiac output.

2. **Ventilator-Induced Lung Injury (VILI):**

   Excessive airway pressures used in recruitment manoeuvres may cause alveolar overdistension, increasing the risk of barotrauma and volutrauma.

3. **Transient Oxygen Desaturation:**

   Some patients may experience a temporary decline in oxygen saturation during the application of a recruitment manoeuvre, particularly in cases of severe hypoxemia.

LUNG ULTRASOUND [43]

Introduction

Point-of-care ultrasound (POCUS) is routinely used for pulmonary and critical care procedures and diagnostic applications in pulmonary and critical care medicine.

POCUS differs from comprehensive ultrasound examinations performed by technicians and interpreted by radiologists or cardiologists in at least two important ways. First, POCUS is often used to answer urgent clinical questions when comprehensive imaging may not be available, practical, or necessary. Second, POCUS is best targeted to specific questions for which a dedicated examination of a single or limited number of structures might be obtained to provide a dichotomous 'yes or no' answer. An adept clinician will use POCUS in these settings, understanding that appropriate follow-up may require a traditional comprehensive diagnostic ultrasound study to address nuanced or complex questions.

Physics of Ultrasound

Humans hear sounds in the frequency range of 20 to 20,000 Hz. Ultrasound imaging uses sound pressure waves generated in a handheld transducer with frequencies of 2 to 15 MHz. In conventional ultrasound transducers, sound waves are generated by the application of an electrical current across a crystal lattice, which induces vibration and sound wave formation, a phenomenon known as the reverse piezoelectric effect.

The transducer is placed on a patient's skin with a layer of conductive gel to facilitate transmission of sound waves into the body. Waves then travel through the tissues and are reflected back to the transducer by the underlying structures. Reflected sound waves are translated by the transducer crystals into electrical signals (i.e., the piezoelectric effect), which then generate images on the ultrasound screen. The depth of structures in the body is computed using the time required for waves (“echoes”) to return to the skin surface from these structures.

Table 2: Ultrasound physics

Term	Definition	Clinical application
Echogenicity	Interpretation of returning sound wave energy by the ultrasound machine that results from differences in tissue impedance, attenuation, reflection, and scatter of sound waves	Tissues are described as isoechoic when similar in intensity or brightness, hyperechoic when brighter than reference, hypoechoic when dimmer, and anechoic when black
Frequency	The physical property of sound waves indicating the time elapsed between wave peaks passing a specific point	Higher frequency, shorter wavelength waves attenuate more quickly in body tissues, so are best for imaging structures close to the skin surface
Focal zone	A property of the beam emitted from the transducer where it is most narrow	Lateral resolution, or the ability to distinguish objects side by side, is best for any transducer within its focal zone
Acoustic impedance	Property of a tissue that influences sound wave propagation, including transmission, reflection of waves, and energy loss over distance	Physical basis for visualizing distinct tissues with ultrasound
Acoustic enhancement	Region of increased echogenicity immediately distal to a tissue with low acoustic impedance relative to surrounding tissues, such as a cyst or blood vessel	May facilitate identification of vessels and cysts compared to soft-tissue masses or nodules, such as lymph nodes

Acoustic shadowing	Region of hypoechoic or anechoic signal immediately distal to a tissue with very high impedance relative to surrounding tissues, such as a bone	Allows identification of bones, calcifications, and certain stones

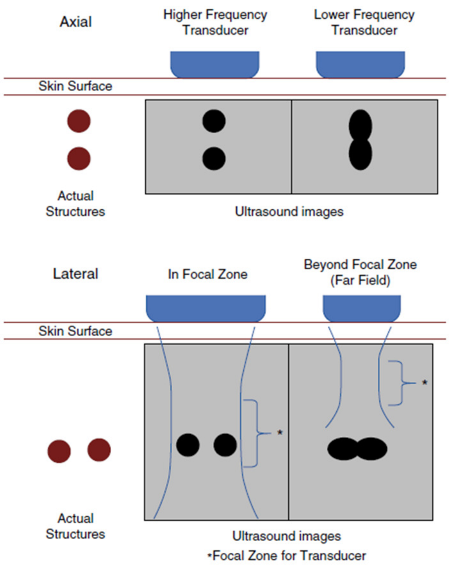


Figure 1: Axial & lateral resolution in ultrasound

Axial resolution is the ability to distinguish two structures in a line parallel to the course of the ultrasound beam (e.g., a superficial structure overlying a deeper one). Axial resolution is generally greater at higher sound frequencies.

Lateral resolution is the ability to distinguish two structures aligned perpendicular to the ultrasound beam (side by side). Lateral resolution is generally better with wider ultrasound transducers. For any frequency or transducer size, lateral resolution is greatest within the focal zone.

In combination, these principles result in a tradeoff for imaging characteristics inherent to ultrasound at higher versus lower frequencies. As a rule, higher frequency, shorter wavelength transducers provide superior imaging of superficial structures, whereas lower frequency, longer wavelength transducers provide better imaging of deeper structures.

Table 3: Ultrasound modes

Term	Definition	Clinical application
B-mode or two-dimensional	"Brightness" mode, or two-dimensional imaging, wherein pixel intensity corresponds to the strength of the returning sound wave energy	The most commonly used modality in point-of-care ultrasound
M-mode	"Motion" mode of imaging, wherein a signal intensity along a single line within the transducer beam is evaluated over time	Often used to detect and measure movement of structures, such as the pleura, diaphragm, vessel walls, or heart structures

Table 4: Knobology

Term	Defintion	Clinical application
Depth	Distance from the transducer; shallow structures appear at the top of the ultrasound screen; deeper structures appear lower	Depth is often adjusted so that the region of interest is in the middle of the screen; in procedural ultrasound, depth may be set to maximize the operative field of view for needle passage
Far field/near field	Region distal (far) or proximal (near) to the focal zone within the	Lateral resolution, or the ability to distinguish objects

	ultrasound beam, a property of the transducer	side by side, is poorer for any transducer outside its focal zone
Gain	Factor by which all signals received from the transducer are multiplied as to make an image appear brighter or darker	Makes the image brighter or darker
Time gain compensation	Application of increasing gain inversely proportional to the timing of signal return to the transducer so as to compensate for sound wave attenuation due to distance traveled through the tissues	Used to make a tissue appear homogeneous through the depth of the image, whereas would otherwise appear darker at increasing depth due to ultrasound attenuation

Imaging Techniques and Planes in Lung USG

POCUS terminology includes the conventional terms for sagittal, coronal, and transverse body planes, as well as terms for planes specific to the structure being imaged. The longitudinal axis refers to imaging with the ultrasound beam parallel to the long axis of the structure. Cross-sectional or short-axis images refer to imaging with the beam perpendicular to the long axis of the structure.

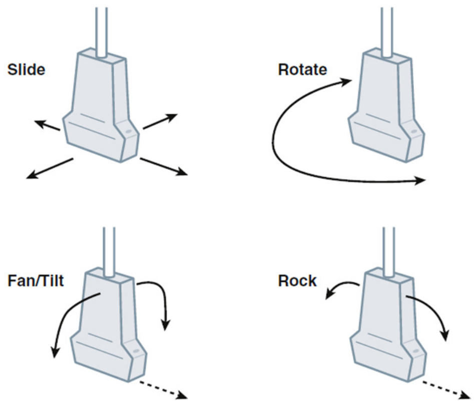


Figure 2: Conventional terms for movement within planes of examination in point-of- focus ultrasound.

Types of Ultrasound Probes and Their Significance

Transducers differ primarily in frequency and mode of crystal excitation. The optimal frequency choice for a given examination is the highest available that also provides the appropriate tissue penetration for the structure of interest.

Table 5: Details about linear transducer

Term	Definition	Clinical Application
Linear transducer	Transducer in which crystals are activated in a sequential, linear fashion along the length of the array. Narrow rectangular footprint	Best for examining static structures throughout the field, or motion within a single vertical line from the transducer

Figure 3: Linear Transducer

Thoracic imaging

A phased array (1–5 MHz) transducer is used to examine the heart and great vessels. In pulmonary imaging, sliding of the parietal and visceral pleura can be evaluated with either a phased array or high-frequency linear transducer, but for deeper evaluation of pleural effusion or lung parenchyma, a low-frequency transducer, either curvilinear or phased array, is preferred.

Thoracic Ultrasound

Normal pleura & lung:

By using 2D imaging with the ultrasound transducer oriented cephalad-caudad, the pleura is visualized as a hyperechoic line in the intercostal space just deep to the ribs. When the two pleural layers are normally apposed, the movement of visceral pleura against the relatively stationary parietal pleura creates a shimmering effect on the ultrasound screen. This is the pleural "sliding" or "gliding" sign (also called lung sliding).

Below the pleural line, normal lung is not visible, because it is fully aerated. Instead, an A-line reverberation pattern is seen on the ultrasound screen.

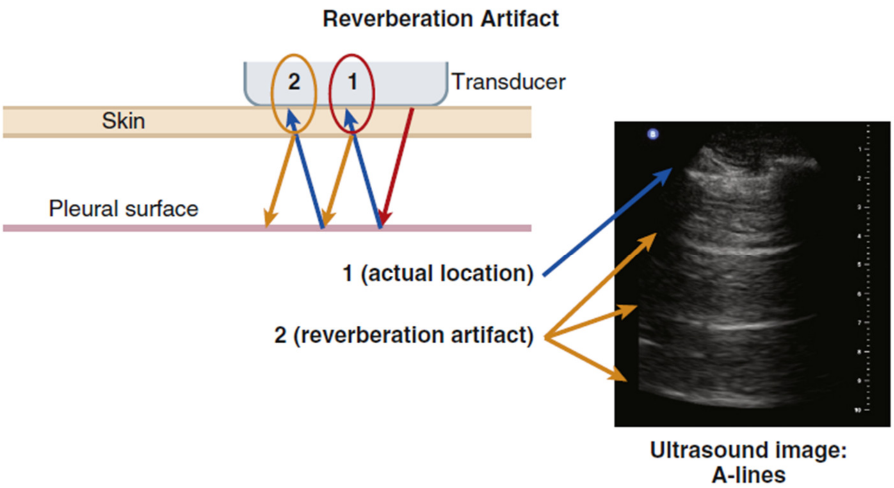


Figure 4: Reverberation artifact: A-lines.

An ultrasound beam (red arrow) leaves the transducer and reaches the pleural surface. The beam is reflected back to the transducer (blue arrows) and is interpreted as a bright line corresponding to the depth of the pleura relative to the skin surface (point 1; blue arrow on ultrasound image). Some of this reflected energy is, in turn, reflected off the inner surface of the skin (orange arrows) and back toward the pleural line. It takes twice as long as the first signal to return to the transducer, so it is interpreted as a second hyperechoic structure exactly twice the depth of the pleural line (point 2). This is the first A-line. This pattern repeats with each signal reflecting, generating multiple A-lines at equidistant depths on the ultrasound screen (orange arrows on ultrasound image).

In M-mode imaging of normal lung, the linear pattern seen with stationary subcutaneous tissues is interrupted at the pleural level due to pleural sliding, creating an appearance likened to lines of waves at the top of the screen meeting a sandy beach below the pleural line (the "seashore" sign)

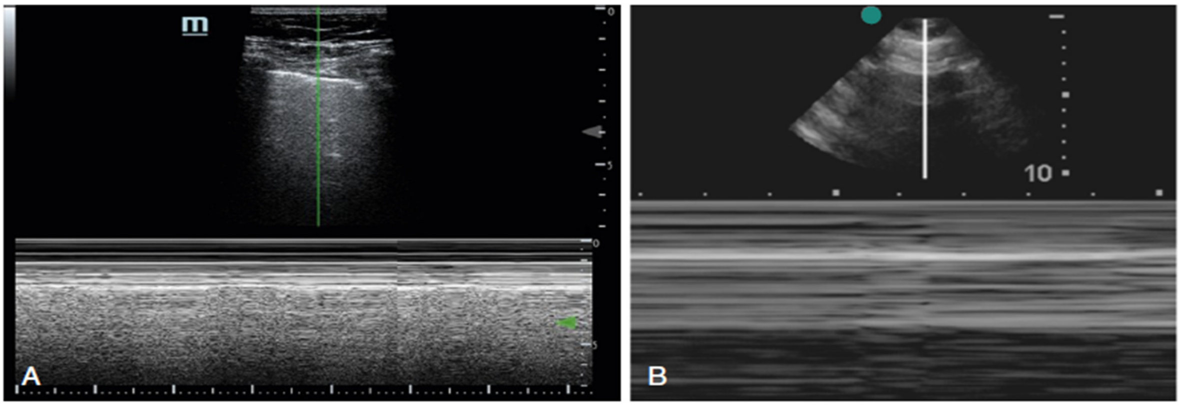


Figure 5: M-mode appearances of pleural sliding: normal and absent.

(A) Normal pleural sliding in M-mode: "seashore" sign. Immobile soft-tissue structures of the chest wall appear as horizontal lines at the top of the image, whereas sliding at the pleural surface creates a white noise pattern lower down, in the far field. (B) Absent pleural sliding: "stratosphere sign." In comparison, when the visceral parietal pleura layers are not in apposition (as in a pneumothorax) or are affixed together (as after a pleurodesis), the M-mode panel will demonstrate a lack of movement at all depths, appearing as fixed lines in a "bar code" or "stratosphere" sign

Table 6: Common ultrasound findings in thoracic imaging

Term	Definition	Clinical interpretation
PLEURA		
Pleural sliding (i.e., lung sliding)	Appearance of movement in the horizontal direction along the pleural line in thoracic ultrasound.	Results from the movement of visceral pleura against the relatively stationary parietal pleura. Indicates that the two pleural layers are opposed (i.e., pneumothorax is not present).
Seashore sign	M-mode finding of normal lung and pleura in thoracic ultrasound.	M-mode correlate of pleural sliding. Indicates normal apposed pleura.
Stratosphere sign	M-mode finding in pneumothorax with exclusively horizontal lines through the field of view.	M-mode correlate of absent pleural sliding and A-line reverberation pattern. Consistent with, although not diagnostic of, pneumothorax.
Lung point	A transition involving the appearance of sliding in	Represents the point at which inflated lung

	part of the field of view and absence of sliding in an adjacent area.	contacts the visceral pleura at the edge of a pneumothorax. Has high specificity for pneumothorax
LINE ARTIFACTS		
A-lines	Reverberation artifact in which ultrasound beams "bounce" between two strong reflectors. Repeated signal return is interpreted by the machine as multiple equidistant structures deep to the reflector	Seen at the interface of tissues with markedly different impedance, in thoracic ultrasound this refers to signal reverberation between the skin surface and pleura, resulting in a pattern of repeating horizontal A-lines deep to the pleural line. Present in normal lung and with pneumothorax.
B-lines	Continuous, long vertical lines that appear to move with the pleura that result primarily from reverberation artifacts near the lung surface	Indicates lung tissue is present beyond the pleura, and is not fully aerated. B-lines increase in number and width with increased septal thickness or alveolar filling as in interstitial lung diseases, early pneumonia, pulmonary edema, and other conditions
OTHER ARTIFACTS		
Mirroring	Interpretation by the ultrasound machine of returning sound wave signals as two images instead of one due to alternate paths of sound wave reflections returning to the transducer	Commonly seen with the liver and spleen adjacent to the diaphragm, wherein these organs may appear both above and below the diaphragm due to its reflective properties and

		the limited returning signal from the lung
Shred or fractal sign	An irregular linear interface between collapsed or consolidated lung and aerated lung within a lobe	Diagnostic of partially collapsed or consolidated lung

Pathophysiology of Atelectasis – USG Findings

When air spaces become completely fluid-filled (consolidated) or degassed (atelectasis), the lung is easily penetrable to ultrasound and appears as a solid organ with a similar echogenic texture as the liver. It is therefore described as 'hepatized' on ultrasound.

At the interface between aerated lung and an area of dense consolidation or atelectasis, a 'fractal' or 'shred' sign may be observed: an irregular hyperechoic border with B-lines emanating from it.

Clinical Applications of Lung USG

- **Pneumothorax Detection:** Absence of pleural sliding, presence of A-lines only, and lung point sign.
- **Pulmonary Edema:** Diffuse B-lines and reduced lung sliding.
- **Pneumonia:** Localized B-lines with consolidation and air bronchograms.
- **Pleural Effusion:** Anechoic area between pleura with sinusoid sign.
- **ARDS (Acute Respiratory Distress Syndrome):** Heterogeneous B-lines in dependent regions.

MATERIALS AND METHODS

“Source of Data: Patients between the age group of 18-60 years, of either gender, belonging to “American Society of Anaesthesiologists (ASA) grade I” & “II”, undergoing elective laparoscopic surgeries under General anaesthesia, at “KLES Prabhakar Kore Hospital & Medical Research Centre, Nehru Nagar, Belagavi”.

“Study Design: Randomised control trial”

“Study Period: One year”

“Sample Size: The minimum sample size formula based on two proportions is

$$n = \frac{(Z\alpha + Z\beta)^2 (P_1Q_1 + P_2Q_2)}{(P_1 - P_2)^2}$$

P_1= Incidence in RM group (39%)

P_2=incidence in C group (71%)

Q1= 100-P_1

Q2=100-P_2

z_α is linked with the level of significance and z_β is linked with the power of the test. For 5% level of the significance $z_\alpha = 1.96$ and $z_\beta = 0.85$ for 79% power of the test.

Ref: In the literature Yi Liu, Jingyu Wang , Yuan Geng ,Yiran Zhang,Hang Su and Yujiao Yang A total of 41 patients were investigated. The incidence of atelectasis was lower in RM group (31%) than in C group (79%) 15 min after arrival in the post-anesthesia care unit (PACU). Meanwhile, lung ultrasound scores groups were mainly due to the difference in lung ultrasound scores in the posterior regions.(1)

The parameter considered in the calculation is the rate of incidence of atelectasis, 15 minute safer arrival in the post-anaesthesia unit.

By taking proportion of, P_1= 79% and P_2 = 31% the sample size obtained is 34.

There would be two groups with size of 34 each.

So total sample size is 68

Sampling technique: Computerised randomisation software states that patients will be randomised to either the Recruiting Manoeuvres (RM) or Control (C) groups. The sealed envelopes containing these tasks will be unsealed after patient will have had general anaesthesia from an anaesthesiologist. Ultrasound scoring, and anaesthesia management will all be handled by an anaesthesiologist. The patient won't be aware of the grouping details; only the anaesthesiologist doing the lung ultrasonography and the anaesthesia induction will.

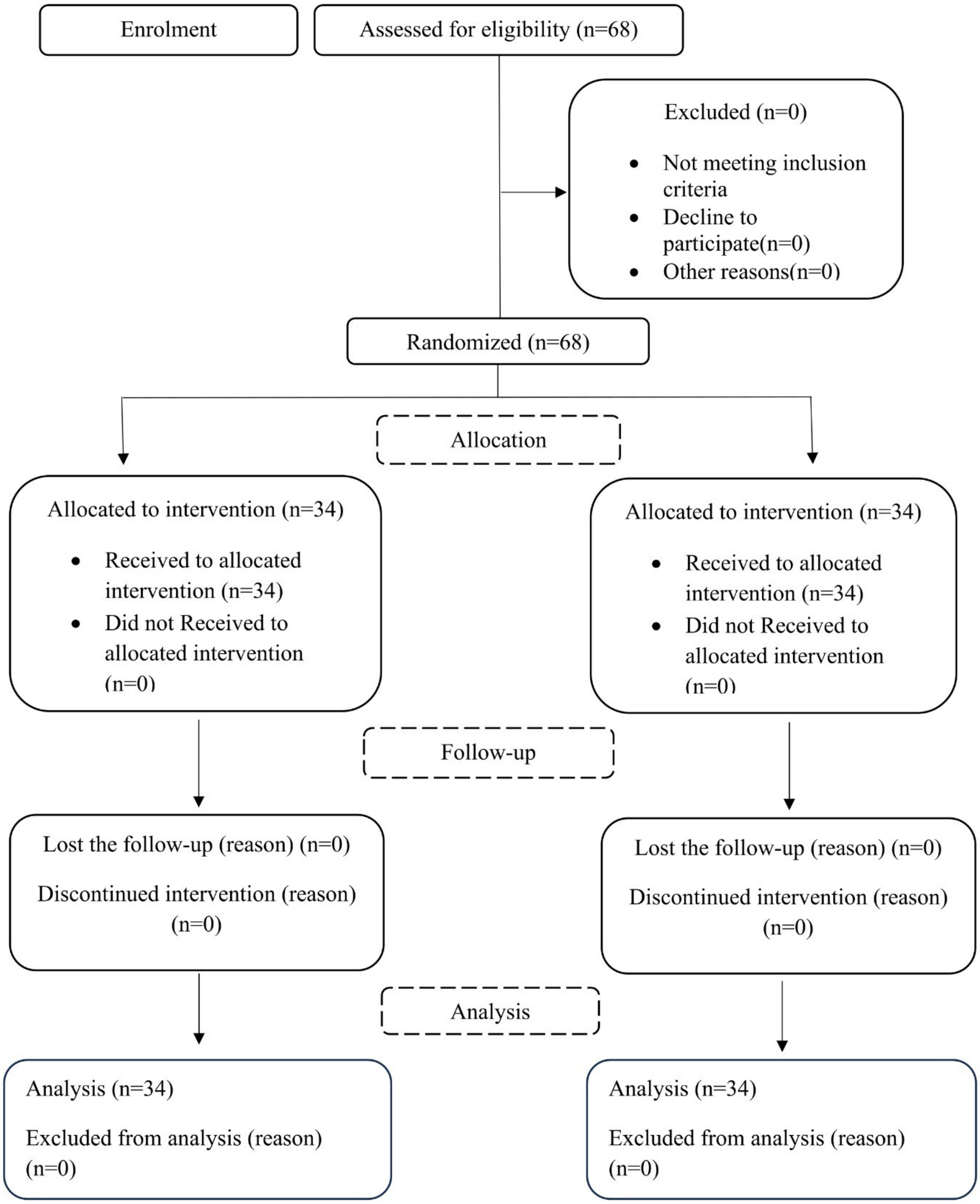
Inclusion Criteria:

- Patients with healthy lung, no respiratory symptoms, no pre-existing lung pathologies (Negative CXR)
- Age: between Eighteen-Sixty years old,
- Body mass index (BMI) <35 kg/m2
- ASA I & II
- Elective laparoscopic surgeries

Exclusion Criteria:

- Patients suffering from cardiac, pulmonary and neuromuscular disorders.
- Respiratory tract infections and corresponding surgery histories were not included.
- Those undergoing conversion from laparoscopic to open surgery
- Those who are suffering from significant postoperative complications like pneumothorax and severe subcutaneous emphysema.

Study Protocol: Consort flow chart for RCTs



After Obtaining the approval of ethical committee, patients receiving general anaesthesia for elective laparoscopic surgery meeting inclusion criteria, informed consent will be obtained, the day before the procedure, a comprehensive pre-anesthesia examination will be conducted, and eight hours of nil per mouth are recommended.

On the day of the procedure, the intravenous cannula will be fastened to the forearm and the nil per mouth status will be verified. The premedication for anti-aspiration prophylaxis will consist of intravenous (IV) Pantoprazole 40 mg and Ondansetron 8 mg. Prior to surgery, the baseline blood pressure and heart rate are recorded.

Continuous recording of the ECG, saturation level, ETCO2 level, and noninvasive blood pressure will be used for standard monitoring. All patients received intravenous Glycopyrrolate (0.005 mg kg-1), Midazolam (0.05 mg kg-1), and Fentanyl (2μg kg-1). Propofol (2 mg kg-1) and Succinylcholine (2 mg/kg) were used to induce General Anaesthesia, and all patients were kept on oxygen, N2O, Isoflurane (0.6%-1.0%), and Atracurium (0.5 mg kg-1) with continuous mandatory ventilation.

A 1:2 inspiratory:expiratory ratio and a starting respiratory rate of 12 breaths per minute will be used. The end-tidal carbon dioxide pressure will be maintained between 35 and 45 mmHg by the ventilator.

Patients will be divided into two groups:-

Recruitment Manoeuvre group- 6cm H2O PEEP and all chosen patients will get volume-controlled ventilation, "with a tidal volume of 6–8 ml/kg of ideal body weight".

Lung Recruitment Manoeuvre will be given 5mins after intubation and in an interval of 45mins till the end of surgery.

In this study we are doing sustained Inflation Lung Recruitment manoeuvre which includes changing the ventilator setting from Volume control to Pressure Control and giving a Pressure of 30 cm of H2O for 30 seconds and then again changing it back to Volume control.

Heart rate and mean arterial pressure may fluctuate by less than 15%. EPHEDRINE 6MG or MEPHENTERMINE 6MG will be given right away if the blood pressure drops by more than 20% from the baseline or if the SBP drops to 80 mmHg. 0.3–0.5 mg of atropine will be given when the heart beats less than 50 beats per minute.

Control group- 6cm H2O PEEP and all chosen patients will get volume-controlled ventilation, "with a tidal volume of 6–8 ml/kg of ideal body weight". When the patient will receive only PEEP.

Lung ultrasound time point:

T1 – IN THE PRE-OPERATIVE ROOM BEFORE SHIFTING TO OPERATION THEATRE.

T2- 15 MINUTES AFTER ARRIVAL IN THE PACU

T3 – 3 HOURS AFTER SURGERY

Lung Ultrasound Score:

"SCORE 1 – more than or equal to 3 B lines or one or more small subpleural consolidation separated by a normal pleural line".

"SCORE 2 – multiple coalescent B lines or multiple small subpleural consolidations separated by thickened or irregular pleural line".

"SCORE 3 – consolidation or small subpleural consolidation of > 1×2 cm in diameter"

If LUS is more than or equal to 2 in any location, atelectasis will be regarded significant.

The scores of the 12 distinct quadrants will be added together to determine LUS; values ranging from 0 to 36 points suggest a more serious aeration loss.

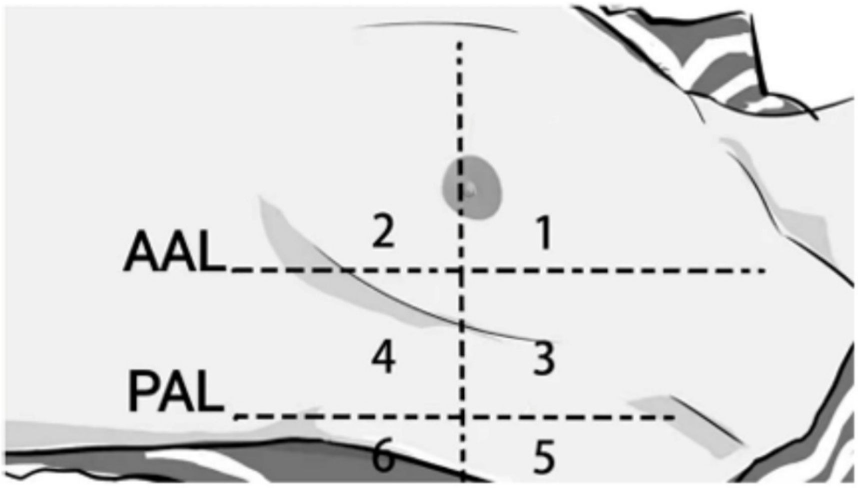


Figure 6: Hemithorax separated into 6 quadrants

Anterior, lateral and posterior zones separated by the anterior and posterior axillary lines as anatomical landmarks, and each area was further divided into superior and inferior portions. AAL - anterior axillary line; PAL - posterior axillary line

Data collection procedure:

The incidence of atelectasis will be assessed using lung ultrasound at three predefined time points—T1, T2, and T3. Corresponding lung ultrasound scores will be recorded at each time point. Additionally, data will be collected and analysed for intergroup comparisons, including demographic characteristics, BMI, ASA grade, incidence of atelectasis, individual lung ultrasound scores, and total lung ultrasound scores.

Data processing and analysis/statistical analysis:

"Microsoft Excel and the statistical program R version 4.4.2 are used to examine the data. Frequency charts representing categorical variables. Mean ± SD / Median (Min, Max) is the format used for continuous variables. The connection between categorical variables is examined using the chi square test. The QQ plot and Shapiro-Wilk test are used to verify if the variable is normal. In the event that the data is normally distributed, parametric testing will be employed. Non-parametric tests will be employed in the absence of this. Mann Whitney U test to compare the distribution of variables across groups is utilised. A P-value of 0.05 or less denotes statistical significance."

RESULTS

A total of sixty eight patients were comprehended in our study titled "Comparison of Lung Recruitment Manoeuvre with PEEP (Positive End-Expiratory Pressure) and Only PEEP on Development of Atelectasis in Patients Undergoing Laparoscopic Surgery – A Randomized Control Trial", where the following information was gathered after the patients were split up into two groups, Group C and Group RM, each consisting of 34 individuals.

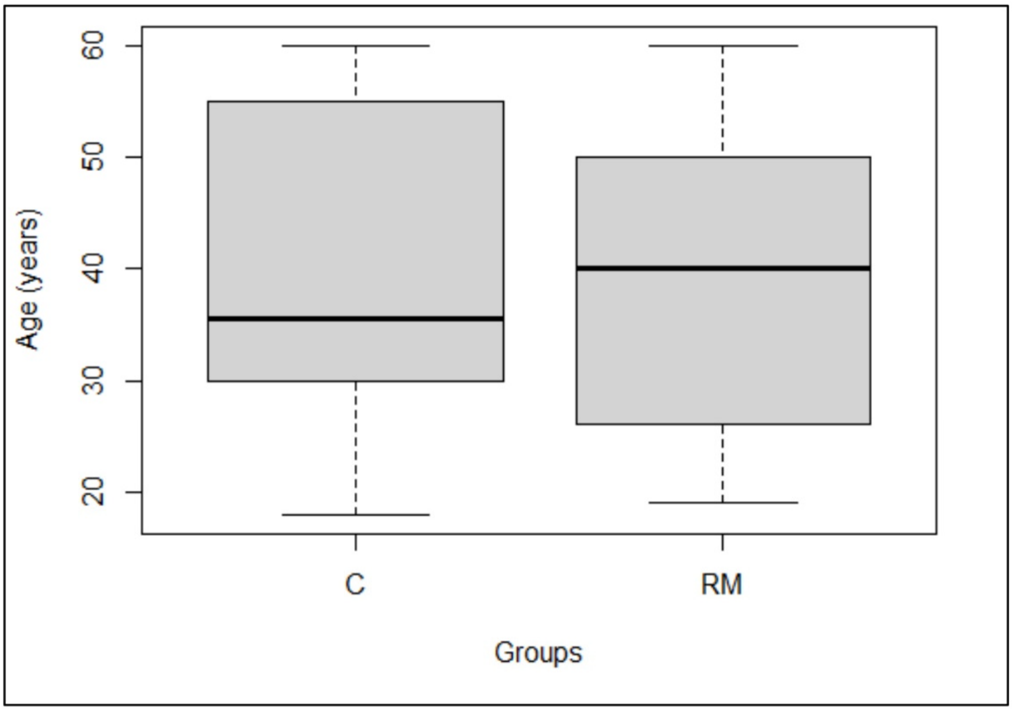
The table below gives the comparison of demographic details over groups.

Table 7: Comparison of demographic details over groups.

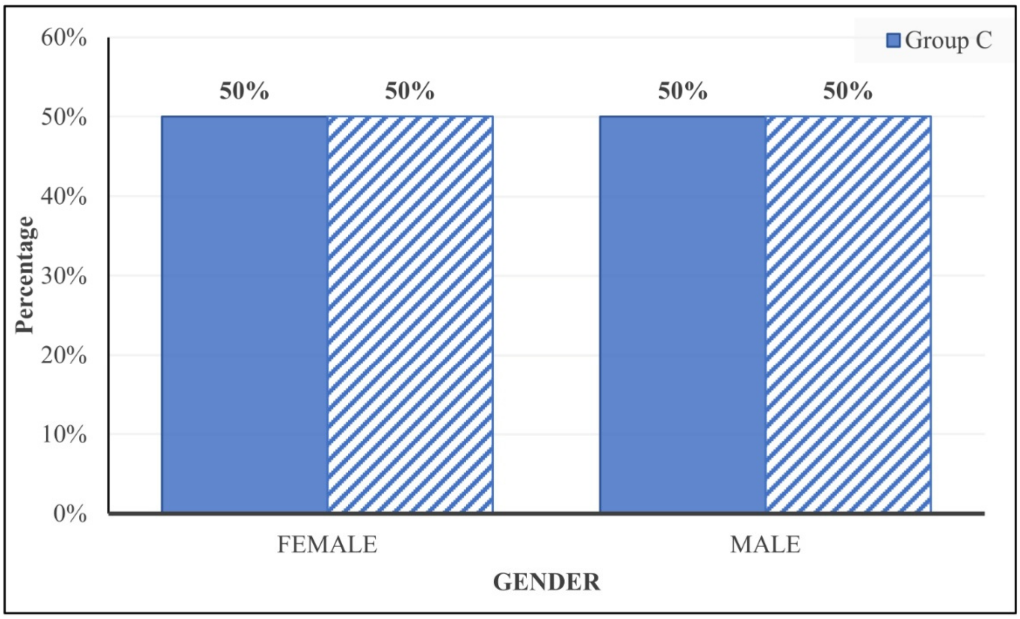
Variables	Sub Category	Group		Total	p-value
		C	RM		
Age (years)	Mean ± SD	40.29 ± 14.25	39.15 ± 13.42	39.72 ± 13.75	0.6854^{MW}
	Median (Min, Max)	35.5 (18, 60)	40 (19, 60)	38 (18, 60)	
Gender	Female	17 (50%)	17 (50%)	34 (50%)	1^{C}
	Male	17 (50%)	17 (50%)	34 (50%)	

Abbreviation: MW – Mann Whitney U test, C – Chi square test.

The mean age in Group C was 40.29 ± 14.25 years, while in Group RM, it was 39.15 ± 13.42 years. The median age was 35.5 years (range: 18–60) in Group C and 40 years (range: 19–60) in Group RM. The difference between groups was not statistically significant (p-value = 0.6854). Regarding gender distribution, both groups had an equal proportion of males and females, with 17 (50%) females and 17 (50%) males in each group (p-value = 1).



Graph 1: Box plot of age over groups.



Graph 2: Distribution of gender over groups.

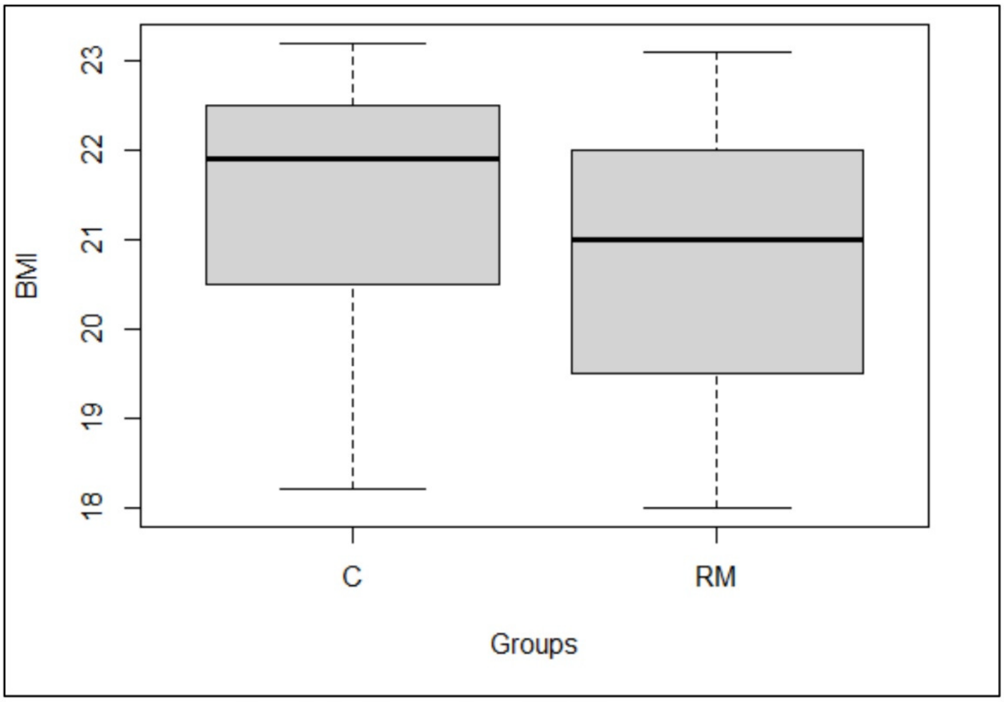
The following table gives the comparison of BMI over groups.

Table 8: Comparison of BMI over groups.

Variables	Sub Category	Group		Total	p-value
		C	RM		
BMI	Mean ± SD	21.44 ± 1.37	20.79 ± 1.52	21.11 ± 1.47	0.0813^{MW}
	Median (Min, Max)	21.9 (18.2, 23.2)	21 (18, 23.1)	21.4 (18, 23.2)	

Abbreviation: MW – Mann Whitney U test.

The mean BMI in Group C was 21.44 ± 1.37, while in Group RM, it was 20.79 ± 1.52. The median BMI was 21.9 (range: 18.2–23.2) in Group C and 21 (range: 18–23.1) in Group RM. The difference between the groups was not statistically significant (p-value = 0.0813) indicating that BMI distribution was comparable across the groups.



Graph 3: Mean plot of BMI over groups.

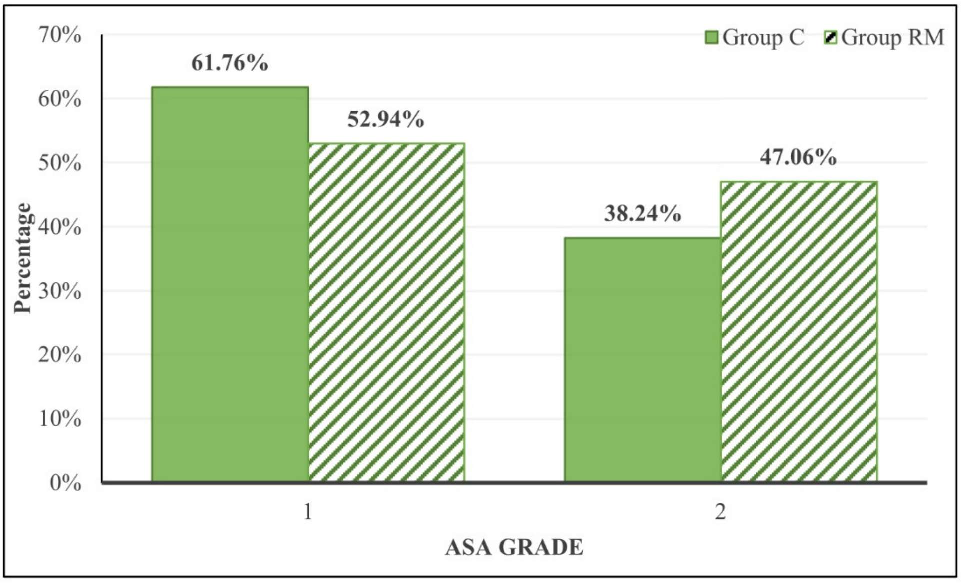
The following table gives the comparison of ASA grade over groups.

Table 9: Comparison of ASA grade over groups.

ASA grade	Group			p-value
	C	RM	Total	
1	21 (61.76%)	18 (52.94%)	39 (57.35%)	0.4620^{C}
2	13 (38.24%)	16 (47.06%)	29 (42.65%)	

Abbreviation: C – Chi square test.

In Group C, 21 (61.8%) participants were classified as ASA Grade 1, while 13 (38.2%) were ASA Grade 2. In Group RM, 18 (52.9%) participants were ASA Grade 1, and 16 (47.1%) were ASA Grade 2. The difference between the groups was not statistically significant (p-value = 0.4620), indicating that the ASA grade distribution was comparable across both groups.



Graph 4: Distribution of ASA grade over groups.

The following table gives the comparison of incidence of atelectasis over groups.

Table 10: Comparison of incidence of atelectasis over groups.

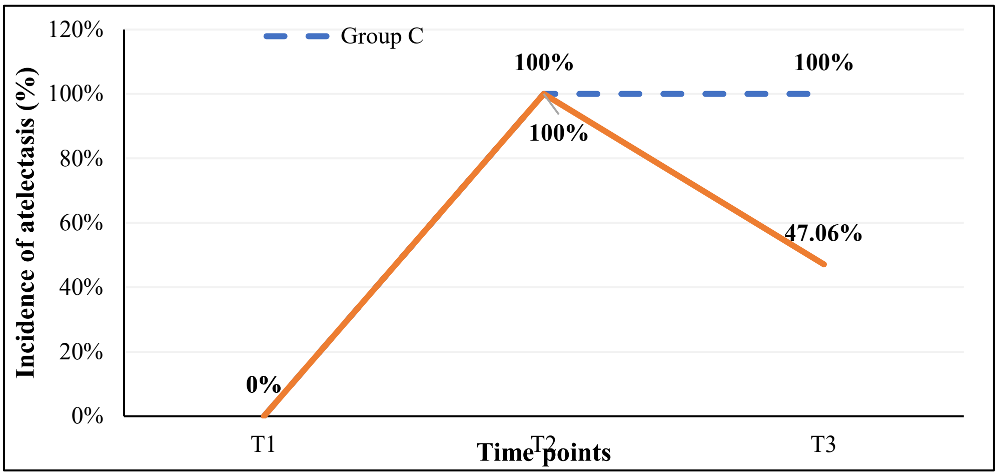
Time points	**Atelectasis**	**Group**		**Total**	**p-value**
		C	**RM**		
T1 (in pre-operative room)	No	34 (100%)	34 (100%)	68 (100%)	-
T2 (15 min after arrival in PACU)	Yes	34 (100%)	34 (100%)	68 (100%)	-
T3 (3 hrs after surgery)	No	0	18 (52.94%)	18 (26.47%)	**< 0.001^{C*}**
	Yes	34 (100%)	16 (47.06%)	50 (73.53%)	

*Abbreviation: C – Chi square test, * indicates statistical significance.*

At T1, no participants in either group exhibited atelectasis, with all 68 (100%) participants showing no signs of the condition.

At T2, all participants in both groups developed atelectasis, resulting in a 100% incidence across all 68 participants.

At T3, In Group C, all 34 (100%) participants continued to have atelectasis. In contrast, in Group RM, 16 (47.06%) participants had atelectasis, while 18 (52.94%) participants showed no signs of the condition. This difference between the groups at T3 was statistically significant (p-value < 0.001), indicating a higher resolution of atelectasis in Group RM compared to Group C.



Graph 5: Distribution of incidence of atelectasis over groups at different time points.

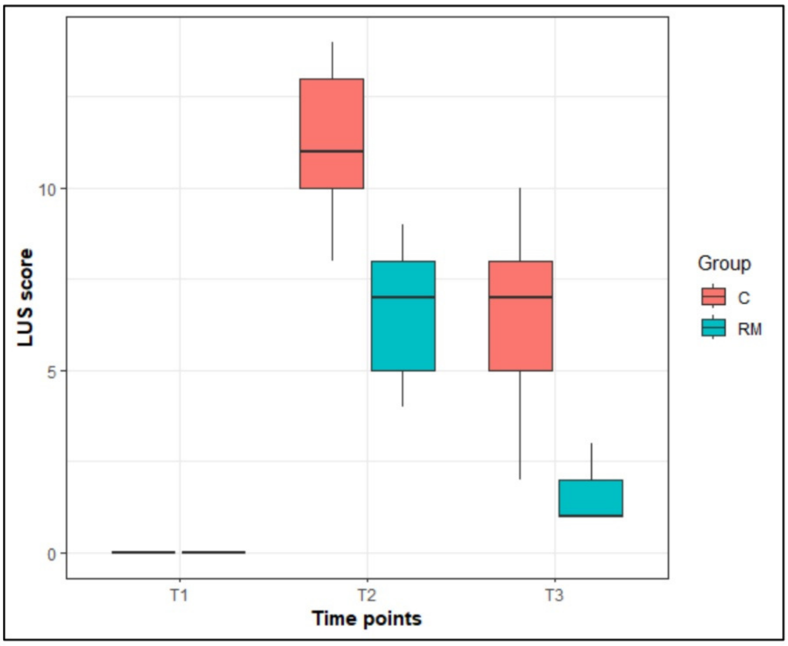
The following table gives the comparison of LUS score over groups.

Table 11: Comparison of LUS score over groups.

Time points	**Group**		**Total**	**p-value**
	C	**RM**		
T1 (in pre-operative room)	0 ± 0 0 (0, 0)	0 ± 0 0 (0, 0)	0 ± 0 0 (0, 0)	-
T2 (15 min after arrival in PACU)	11.03 ± 1.85 11 (8, 14)	6.47 ± 1.62 7 (4, 9)	8.75 ± 2.87 8.5 (4, 14)	**< 0.001**^{MW*}
T3 (3 hrs after surgery)	6.74 ± 1.93 7 (2, 10)	1.53 ± 0.61 1 (1, 3)	4.13 ± 2.98 3 (1, 10)	**< 0.001**^{MW*}

*Abbreviation: MW – Mann Whitney U test, * indicates statistical significance.*

The comparison of Lung Ultrasound (LUS) scores between the groups shows no abnormalities at T1, with both groups having a mean score of 0 ± 0. At T2, Group C had a significantly higher mean LUS score of 11.03 ± 1.85 (median: 11, range: 8–14) compared to Group RM, which had a mean score of 6.47 ± 1.62 (median: 7, range: 4–9), with the difference being statistically significant (p-value < 0.001). By T3, the LUS score in Group C remained higher (mean: 6.74 ± 1.93, median: 7, range: 2–10), while Group RM showed a much lower score (mean: 1.53 ± 0.61, median: 1, range: 1–3), again with a statistically significant difference (p -value < 0.001).



Graph 6: LUS score over time and groups.

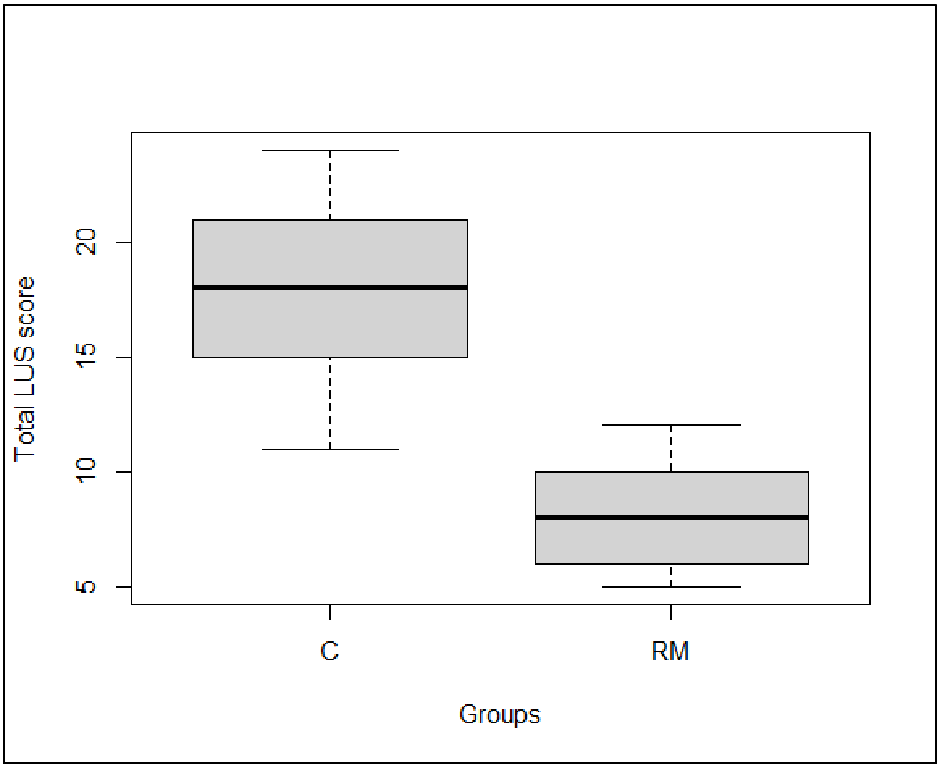
The following table gives the comparison of total LUS score over groups.

Table 12: Comparison of total LUS score over groups.

Variable	**Group**		**Total**	**p-value**
	C	**RM**		
Total LUS Score	17.76 ± 3.64 18 (11, 24)	8 ± 2.1 8 (5, 12)	12.88 ± 5.73 11.5 (5, 24)	**< 0.001^{MW*}**

*Abbreviation: MW – Mann Whitney U test, * indicates statistical significance.*

The comparison of total Lung Ultrasound (LUS) scores between the groups shows that Group C had a significantly higher mean total LUS score of 17.76 ± 3.64, with a median of 18 (range: 11–24), compared to Group RM, which had a mean score of 8 ± 2.1, with a median of 8 (range: 5–12). The difference between the groups was statistically significant (p-value < 0.001), indicating that Group RM had significantly lower LUS scores.



Graph 7: Box plot of total LUS score over groups.

DISCUSSION

“Comparison of Lung Recruitment Manoeuvre with PEEP (Positive End- Expiratory Pressure) and only PEEP (Positive End -Expiratory Pressure) on development of atelectasis in patients undergoing elective laparoscopic surgery” “The study included a sample size of 68 patients, aged 18 to 60 years, all classified as ASA I or II. Our findings revealed significant differences in outcomes between the two groups, offering valuable insights into the efficacy in maintaining lung aeration and optimizing perioperative oxygenation.”

The current study sought to determine how the development of atelectasis in patients having Elective Laparoscopic Surgery was affected by Lung Recruitment Manoeuvres (LRM) along with Positive End-Expiratory Pressure (PEEP) as opposed to PEEP alone. In comparison to PEEP alone, our results show that LRM plus PEEP considerably lower the incidence and severity of Postoperative atelectasis. This aligns with previous studies that have demonstrated the effectiveness of recruitment manoeuvres in improving pulmonary compliance, oxygenation, and lung aeration following laparoscopic procedures. [44-51]

Several studies support the observation that laparoscopic surgery-induced atelectasis can be mitigated through intraoperative lung recruitment strategies. A study by Cinnella et al. published in 2013, which involved 29 patients undergoing elective gynaecologic laparoscopic surgery, reported that pneumoperitoneum and Trendelenburg positioning result in a significant decrease in pulmonary compliance. The study also found that recruitment manoeuvres performed after desufflation significantly improve compliance and gas exchange.[45] Similarly, in 2022, Pei et al. conducted a meta-analysis that concluded RMs effectively reduce postoperative pulmonary complications (PPCs) and improve respiratory mechanics without major hemodynamic disturbances.[50] Our findings reinforce this conclusion by demonstrating a statistically significant reduction in lung ultrasound scores (LUS) among patients receiving combined LRM and PEEP interventions.

Ultrasound-guided LRM has emerged as an effective technique in monitoring atelectasis resolution. Wu et al. in a double-blinded study involving women undergoing laparoscopic gynaecological surgery, published in 2022, found that LUS significantly decreased in patients receiving ultrasound-guided LRM compared to those receiving only PEEP, corroborating our study's observation that atelectasis is more effectively reduced with LRM. They also highlighted that ultrasound-guided recruitment leads to better lung aeration, further supporting the role of real-time imaging in optimizing lung ventilation strategies. [52] A recent meta-analysis by Xu et al. confirmed that ultrasound-guided RM significantly reduces postoperative atelectasis and improves oxygenation indices.[53] Wu et al. further emphasized that ultrasound-guided RM outperforms sustained inflation RM in maintaining lung aeration postoperatively.[52]

The broader systematic review by Xu et al. also highlighted that ultrasound-guided recruitment significantly decreased postoperative hypoxemia and improved oxygenation indices across multiple RCTs.[53] These findings align with our study, which demonstrated significant improvements in lung aeration and gas exchange following LRM application.

Overall, our research adds to the increasing data that supports the use of Lung Recruitment techniques during Elective Laparoscopic Surgery. The combination of LRM and PEEP was associated with reduced atelectasis incidence, improved LUS scores, and better overall pulmonary compliance compared to PEEP alone. The use of ultrasound-guided techniques enhances the effectiveness of these interventions. Meta-analyses confirm the potential of LRM in reducing postoperative pulmonary complications and improving oxygenation.

<u>Strengths of the study:</u>

- Randomized Controlled Design – This study follows a randomized controlled trial (RCT) design, which minimizes selection bias and ensures the reliability of results.
- Use of Lung Ultrasound (LUS) for Atelectasis Detection – Unlike traditional methods such as chest X-rays, which may underestimate minor atelectatic changes, lung ultrasound provides a highly sensitive and real-time assessment of lung aeration, making the study's findings more precise.
- Clinical Relevance in Laparoscopic Surgery – The study directly addresses a common intraoperative complication—atelectasis—associated with laparoscopic surgery, thereby offering evidence-based insights into optimizing ventilation strategies.
- Comparison of Standard and Modified Ventilation Strategies – By comparing PEEP alone with Lung Recruitment Manoeuvres (LRM) + PEEP, this study provides clear, quantifiable differences in atelectasis resolution, which could guide future anaesthetic management.

- Statistical Robustness – The study employs appropriate statistical methods to ensure the validity of comparisons between groups, enhancing the credibility of results.

Limitations:

There are some issues with the current study. First, the results may not be as broadly applicable as they may be because of the very small sample size. Second, since the study was only conducted in one location, multicenter studies would be useful to confirm these findings. Thirdly, longer-term outcomes were not assessed, and there was a 12-hour postoperative follow-up interval. Additionally, differences in the patient's weight and age could have affected the results.

Future Scope:

The findings of this study pave the way for further research in several key areas. One important next step is to validate the results across multiple centres with diverse patient populations to confirm their generalizability. Furthermore, to evaluate the effects of Lung Recruitment Manoeuvres on postoperative respiratory function, pulmonary problems, and hospital stay duration beyond the immediate perioperative period, long-term follow-up studies are required.

Another promising area for future research is the use of individualized PEEP titration strategies. Instead of a fixed PEEP level, patient-specific PEEP adjustments based on driving pressure, lung compliance, or ultrasound-guided assessments could lead to better lung protection and improved clinical outcomes. Similarly, comparative studies evaluating different recruitment manoeuvre techniques, such as stepwise PEEP increments or vital capacity manoeuvres, could help determine the most effective and safest method for reducing atelectasis.

Moreover, further research should explore the hemodynamic effects of lung recruitment manoeuvres in greater detail, particularly in cardiac and critically ill patients, where changes in intrathoracic pressure may significantly affect cardiac output and cerebral perfusion. Expanding future trials to higher-risk populations, including obese patients, elderly individuals, and people with long-term lung conditions, might offer a more thorough comprehension of LRM's function in a wider therapeutic context.

In summary, while this study provides strong evidence supporting the use of lung recruitment manoeuvres in laparoscopic surgery, further research is needed to optimize ventilation strategies, assess long-term benefits, and refine patient selection criteria for maximum clinical benefit.

CONCLUSION

This study demonstrates that Lung Recruitment Manoeuvres (LRM) combined with PEEP significantly reduce atelectasis compared to PEEP alone in patients undergoing elective laparoscopic surgery under general anaesthesia. The lower incidence of atelectasis and improved LUS scores in the LRM group highlight its efficacy in maintaining lung aeration and optimizing perioperative oxygenation.

While PEEP alone provides some protective effects, it may not be sufficient to counteract the atelectatic changes induced by pneumoperitoneum and Trendelenburg positioning. The findings support the integration of recruitment manoeuvres as a routine intraoperative ventilation strategy to enhance lung compliance and reduce postoperative pulmonary complications. Further research is warranted to refine individualized ventilation approaches and assess their long-term impact on respiratory outcomes.

SUMMARY

Pulmonary atelectasis is a frequent complication in patients undergoing elective laparoscopic surgery under general anaesthesia, leading to impaired gas exchange and increased postoperative pulmonary complications. Positive end-expiratory pressure (PEEP) and lung recruitment manoeuvres (LRMs) have been explored to mitigate atelectasis, but the most effective strategy remains debated. This study compares the efficacy of lung recruitment manoeuvre with PEEP versus PEEP alone in preventing atelectasis in elective laparoscopic surgery.

A total of 68 patients (ASA I & II, aged 18–60 years) undergoing elective laparoscopic surgery were randomized into two groups. One group received 6 cm H_2O PEEP with lung recruitment manoeuvre using the sustained inflation technique (30 cm H_2O for 30 seconds at intervals), while the control group received 6 cm H_2O PEEP alone without recruitment manoeuvres. Lung ultrasound was performed at three time points: preoperative baseline, 15 minutes after arrival in the PACU, and three hours postoperatively. The incidence of atelectasis and lung ultrasound scores (LUS) were compared between the groups.

At baseline, none of the patients had atelectasis. By 15 minutes postoperatively, all patients in both groups developed atelectasis, emphasizing the impact of pneumoperitoneum and anaesthesia on lung function. At three hours postoperatively, the incidence of atelectasis was significantly lower in the recruitment manoeuvre group (47.06%) compared to the control group (100%), indicating the effectiveness of LRMs in reducing postoperative atelectasis. The mean total LUS score was also significantly lower in the recruitment manoeuvre group (8 ± 2.1) compared to the control group (17.76 ± 3.64), demonstrating improved lung aeration.

The findings suggest that lung recruitment manoeuvres, when combined with PEEP, effectively reduce postoperative atelectasis compared to PEEP alone. This strategy enhances lung aeration, as reflected by lower LUS scores, without significant hemodynamic instability. Incorporating LRMs as a routine intraoperative ventilation strategy may optimize respiratory function in elective laparoscopic surgery.

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ANNEXURE I – INFORMED CONSENT FORM

"COMPARISON BETWEEN LOW-DOSE KETAMINE & DEXMEDETOMIDINE ON INTRAOPERATIVE OPIOID REQUIREMENT IN PATIENTS UNDERGOING LAPAROSCOPIC SURGERIES – A RANDOMISED CONTROL TRIAL"

Objective:

To compare the incidence of atelectasis in patients undergoing Laparoscopic Surgery under General anaesthesia receiving Lung Recruitment Manoeuvre with PEEP (Recruitment Manoeuvre Group /RM Group) and PEEP alone (Control Group/ C Group)

Introduction: Mr./Mrs. ______________________________, we are requesting you to enrol yourself in the study titled "COMPARISON OF LUNG RECRUITMENT MANOEUVRE WITH PEEP (POSITIVE END- EXPIRATORY PRESSURE) AND ONLY PEEP (POSITIVE END -EXPIRATORY PRESSURE) ON DEVELOPMENT OF ATELECTASIS IN PATIENTS UNDERGOING LAPAROSCOPIC SURGERY - A RANDOMIZED CONTROL TRIAL", conducted by Jawaharlal Nehru Medical College, Belagavi, under KLE University, Belagavi.

Explanation of procedure: If you agree to enrol in my study, I will ask you the present & past medical history and family history. You will be examined clinically, in detail. When a person is under anaesthesia, their lungs may not work as fully as usual. We already use safe and common ways to help with this, and we want to compare two of these methods to see which one works better. We will also check your lungs with a quick and painless scan. Your treatment will not change whether you join or not, and your information will stay private

Withdrawal from participation in the study: Participation in this study is voluntary. You will be free to decide whether to participate in this study or continue participation once enrolled. In case you decide to withdraw your participation, you are free to do so. However, please convey the decision to the principal investigator.

Possible benefits from participating in the study: You will not have nor get any benefits by participating in this study. The data gathered will help the population at large.

Possible risks from participating in the study: There are no risks involved in participating in this study.

Privacy and confidentiality: The information collected from you will be coded, to prevent any person from identifying you. Your identity will never be revealed. The data collected from you will be kept confidential and only processed or aggregated data will be used for publication.

Financial incentives: You will not receive any payment for participating in this study.

Authorization for publication of aggregated data: Results obtained after processing of the aggregated data will be published for scientific purposes and or presented to scientific groups. However, your identity will never be revealed.

Questions: In case of any questions with regard to this study, you may contact Dr Harsha Hegde, Chairperson, Ethical committee of JNMC, 0831-2473777 Extension 4052.

Legal rights: By signing this consent form, we are not waving any of your legal rights.

CONSENT STATEMENT

I am making a voluntary decision to participate in the study **"COMPARISON OF LUNG RECRUITMENT MANOEUVRE WITH PEEP (POSITIVE END-EXPIRATORY PRESSURE) AND ONLY PEEP (POSITIVE END - EXPIRATORY PRESSURE) ON DEVELOPMENT OF ATELECTASIS IN PATIENTS UNDERGOING LAPAROSCOPIC SURGERY - A RANDOMIZED CONTROL TRIAL".** My signature below indicates that I have decided to participate and I have read the information provided above or the information provided above has been read to me in the language that I understand best. I was given the opportunity to ask questions and that they have been answered to my satisfaction.

Name of the participant:

Signature or left thumb impression of the participant:

Name of the witness:

Signature or left thumb impression of the witness:

Name of the investigator:

Signature of the investigator:

ANNEXURE II – PROFORMA

"Comparison of Lung Recruitment Manoeuvre with PEEP and only PEEP on atelectasis in patients undergoing Laproscopic Surgery- A Randomized Control Trail"

Patient's Name : I.P No. :

Age : Date of Examination :

Gender : Anaesthesiologist :

Address :

Pre-anesthetic evaluation:

Chief complaints:

Past History:

- H/o co-morbidities and drug intake :
- H/o previous surgery/(s) where difficult airway was encountered :
- Previous anaesthetic experience :

General physical examination:

Height (cm) : Weight (Kg): BMI :

Pallor : Icterus :

Cyanosis : Clubbing : BP :

PR : RR : SpO2:

Systemic examination:

RS: **CVS:**

CNS: **GIT:**

Airway Assessment:

Teeth: Jaw movements:

Investigations:

Hb (gm/dl): TLC: Platelet count:

Serum Creatinine**:** FBS: Chest x-ray: ECG:

Preoperative physical status: ASA Grade I II

Diagnosis:

Proposed surgery:

QUADRANTS	T1 (LUS Score 1-3)	T2 (LUS Score 1-3)	T3 (LUS Score 1-3)
LEFT ANTERIOR SUPERIOR			
LEFT ANTERIOR INFERIOR			
LEFT LATERAL SUPERIOR			
LEFT LATERAL INFERIOR			
LEFT POSTERIOR SUPERIOR			
LEFT POSTERIOR INFERIOR			
RIGHT ANTERIOR SUPERIOR			
RIGHT ANTERIOR INFERIOR			
RIGHT LATERAL SUPERIOR			
RIGHT LATERAL INFERIOR			
RIGHT POSTERIOR SUPERIOR			
RIGHT POSTERIOR INFERIOR			
TOTAL			

SIGNATURE OF THE ANAESTHESIOLOGIST: ___________________

SIGNATURE OF THE PRINCIPAL INVESTIGATOR: ________________

ANNEXURE III – PHOTOGRAPHS

Photograph 1: Ultrasound machine with linear transducer

Photograph 2: Lung ultrasonography

Photograph 3: A-lines

ANNEXURE IV – KEY TO MASTERCHART

BMI	Body Mass Index
ASA	American Society of Anesthesiologists
LUS	Lung Ultrasound

ANNEXURE V - MASTERCHART

Sl. No.	IP No.	Grp allotted	Grp. Sl. No.	Age	Gender	BMI	ASA grade	T1 LUS Score	T2 LUS Score	T3 LUS Score	Total LUS Score
1	1206866	C	1	55	M	22.3	1	0	12	7	19
2	1206934	C	2	34	F	21.9	1	0	10	5	15
3	1207422	R	1	20	M	22.6	1	0	6	1	7
4	1202344	R	2	45	M	22	1	0	7	2	9
5	1208157	C	3	20	M	22.9	1	0	13	8	21
6	1207716	C	4	59	M	21	1	0	13	9	22
7	1207752	C	5	31	F	23	1	0	11	7	18
8	1207010	C	6	40	F	21.3	1	0	13	9	22
9	1208955	R	3	46	F	18.5	2	0	8	2	10
10	10000213	R	4	34	F	19.5	1	0	7	1	8
11	1209207	R	5	54	M	23	2	0	8	2	10
12	10000223	R	6	44	M	18.5	1	0	6	1	7
13	10000378	C	7	20	F	19.8	1	0	10	5	15
14	10000953	R	7	19	F	21	1	0	5	1	6
15	10000672	C	8	35	M	22	1	0	11	8	19
16	10001078	R	8	26	M	18	1	0	4	1	5
17	10001341	C	9	60	F	22	2	0	14	9	23
18	10001598	R	9	29	F	18.4	1	0	6	2	8
19	10001219	R	10	27	F	19.5	1	0	5	1	6
20	10001622	C	10	18	F	20.1	1	0	10	5	15
21	10001355	R	11	55	M	19.7	2	0	8	3	11
22	10002491	C	11	55	F	22.5	2	0	12	7	19
23	10003531	R	12	28	F	21.9	1	0	6	1	7
24	10004070	C	12	30	M	22.9	1	0	11	7	18
25	10003862	R	13	47	F	20.7	2	0	7	2	9
26	10004779	C	13	25	M	18.6	1	0	9	4	13
27	10006253	R	14	38	F	19.4	2	0	7	2	9
28	10006525	C	14	34	F	20.5	1	0	10	4	14
29	10036965	R	15	25	M	21.6	1	0	5	1	6
30	10036826	C	15	22	M	23	1	0	8	4	12
31	10052878	R	16	42	F	22.8	2	0	7	2	9
32	10099945	C	16	34	M	21.9	1	0	11	7	18
33	10099978	R	17	58	M	22.4	2	0	8	2	10
34	10102080	C	17	31	F	21.4	1	0	10	5	15
35	10114130	R	18	23	M	20.4	1	0	4	1	5
36	10129446	C	18	60	F	22.5	2	0	13	9	22
37	10130455	R	19	51	F	21.4	2	0	9	3	12
38	10132079	C	19	26	M	21.9	1	0	9	5	14
39	10131100	R	20	21	M	18.4	1	0	5	1	6
40	10130682	C	20	36	M	19.2	1	0	8	5	13
41	10131234	R	21	38	F	19.4	2	0	6	2	8
42	10130703	C	21	59	M	21.9	2	0	9	2	11
43	10132079	R	22	26	M	20.6	1	0	4	1	5
44	10130046	C	22	40	F	21.7	2	0	10	6	16
45	10130487	R	23	43	F	23.1	2	0	6	1	7
46	10130417	C	23	44	F	22.8	2	0	11	8	19
47	10130427	R	24	35	F	21.5	1	0	4	1	5
48	10130455	C	24	51	F	22.9	2	0	12	9	21
49	10129719	R	25	60	M	21.5	2	0	8	2	10
50	10129446	C	25	60	F	22.3	2	0	13	8	21
51	10129524	R	26	20	M	20.7	1	0	4	1	5
52	10129407	C	26	59	M	19.7	2	0	12	8	20
53	10129542	R	27	50	F	21.4	2	0	8	2	10
54	10129360	C	27	30	M	18.2	1	0	10	6	16
55	10128504	R	28	21	M	19.4	1	0	4	1	5
56	10127724	C	28	33	F	22.9	1	0	9	6	15
57	10127569	C	29	24	F	23.2	1	0	9	7	16
58	10128206	R	29	58	M	21.5	2	0	8	2	10
59	10127925	C	30	29	M	20.5	1	0	8	5	13
60	10128168	R	30	55	M	22	2	0	7	1	8
61	10128057	R	31	60	F	21	2	0	9	2	11
62	10128122	C	31	59	F	20.7	2	0	14	10	24
63	10128161	R	32	46	F	19.6	1	0	7	1	8
64	10120768	C	32	58	M	19.3	2	0	13	9	22
65	10128190	R	33	50	F	22.4	2	0	9	2	11
66	10128127	C	33	49	M	21.2	2	0	13	7	20
67	10128171	R	34	37	M	23	1	0	8	1	9
68	10127273	C	34	50	M	21	2	0	14	9	23