Journal of Multidisciplinary Healthcare

Dovepress
Taylor & Francis Group

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ORIGINAL RESEARCH

THRIVE Prevent Postoperative Hypoxemia in Elderly Patients Undergoing Laparoscopic Surgery in PACU: A Randomized Controlled Clinical Trial

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Background: Postoperative hypoxemia frequently occurs in elderly individuals undergoing laparoscopic procedures, often leading to severe consequences and prolonged stays in the post-anesthesia care unit (PACU). Conventional oxygen therapy methods are not entirely effective in preventing hypoxemia. Transnasal Humidified Rapid Insufflation Ventilatory Exchange (THRIVE) delivers high-flow oxygen at rates up to 60 L/min, potentially enhancing respiratory function and tolerance to hypoxia.

Objective: To assess the effectiveness, safety, and patient tolerance of THRIVE in the early prevention of postoperative hypoxemia in elderly patients following laparoscopic surgery with general anesthesia.

Methods: This prospective, multicenter, randomized controlled trial enrolled 200 elderly patients undergoing laparoscopic surgery who were safely extubated after general anesthesia. Participants were randomly allocated to receive either conventional nasal cannula oxygen therapy or THRIVE. Between January 2023 and December 2023, cases were recruited from three participating centers. The main outcome measured was the occurrence of hypoxemia in the PACU. Secondary outcomes encompassed lung ultrasound scores after oxygen therapy, frequency of jaw lifting, reintubation rate, adverse events, and subjective patient comfort.

Results: The incidence of hypoxemia was significantly lower in the THRIVE group compared to the standard oxygen therapy group (0% vs 29.2%; $\chi^2 = 35.245$; $P < 0.001$). The need for jaw lifting was also significantly reduced in the THRIVE group (5.1% vs 29.2%; $P = 0.019$). Moreover, patients receiving THRIVE demonstrated better lung aeration, as indicated by improved lung ultrasound scores ($z = 3.016$; $P = 0.003$), and reported significantly higher comfort levels in the PACU ($z = 3.141$; $P = 0.002$).

Conclusion: THRIVE is an effective strategy for reducing postoperative hypoxemia in elderly individuals undergoing laparoscopic procedures with general anesthesia. It facilitates pulmonary function recovery, enhances patient comfort, and may serve as a valuable intervention in the PACU setting.

Keywords: THRIVE, laparoscopic surgery, elderly patients, hypoxemia

Introduction

Postoperative hypoxemia is a frequent postoperative complication in elderly patients undergoing laparoscopic surgery under general anesthesia.[1] Studies report that hypoxemia occurs in approximately 10.02% of patients in the PACU, with incidence rising to 22.5% in those over 65 years of age.[2] The etiology of postoperative hypoxemia following laparoscopic surgery is multifactorial. Residual effects of general anesthesia, in combination with the physiological impact of pneumoperitoneum—including elevated intra-abdominal pressure and cephalad displacement of the diaphragm—can significantly impair diaphragmatic excursion and reduce functional residual capacity. These changes contribute to ventilation-perfusion mismatch and atelectasis, particularly in the dependent lung regions. Additionally, surgical trauma and postoperative pain may further compromise effective ventilation by limiting deep breathing and promoting shallow respiratory patterns. This condition not only delays recovery but may also lead to severe complications, including respiratory failure and cardiac arrest.[3–5]

Received: 14 February 2025
Accepted: 5 May 2025
Published: 10 May 2025

With the rising number of surgical procedures performed under general anesthesia and an aging population, the demand for minimally invasive laparoscopic surgery in elderly patients has increased significantly.[6,7] However, postoperative hypoxemia remains a challenge, often prolonging PACU stays and delaying recovery. Effective strategies for its prevention and management are urgently needed.

The World Health Organization recommends perioperative oxygen therapy, with conventional nasal cannula oxygen supplementation being the most widely used method in the PACU.[1] However, its efficacy is limited by inconsistent oxygen delivery, inadequate humidification, and suboptimal patient comfort. Furthermore, traditional oxygen therapy does not specifically address hypoxemia resulting from anesthetic-induced respiratory depression, pulmonary atelectasis, airway obstruction, or neuromuscular impairment.[8] To overcome these limitations, various forms of noninvasive respiratory support have been developed, including high-flow nasal oxygen (HFNO), noninvasive positive pressure ventilation (NIPPV), and continuous positive airway pressure (CPAP), each offering distinct physiological benefits in improving oxygenation and reducing the work of breathing.

Transnasal Humidified Rapid Insufflation Ventilatory Exchange (THRIVE) is an emerging, non-invasive oxygen therapy modality that overcomes these limitations. By providing a steady, elevated flow of heated and humidified oxygen with precisely regulated concentration, THRIVE improves oxygenation and aids in the elimination of carbon dioxide. Initially introduced for managing acute respiratory failure, it has shown promise in various perioperative applications.[9–12] In this study, we assess the effectiveness of THRIVE in preventing postoperative hypoxemia among elderly patients undergoing laparoscopic procedures.

Methods

This multicenter, prospective, randomized clinical trial was conducted in a single-blind manner across three tertiary hospitals located in Wenzhou and Taizhou, Zhejiang Province, China. The study received approval from the Clinical Research Ethics Committee of The First Affiliated Hospital of Wenzhou Medical University (Approval No. 2022–105) and was registered in the Chinese Clinical Trial Registry (ChiCTR2200066499). Investigators underwent rigorous training and a comprehensive assessment on oxygen therapy-related theoretical knowledge, with only those who successfully passed the evaluation permitted to take part in the trial.

Participants

During recruitment, considering the higher risk of postoperative hypoxemia in this population and the need to ensure an adequate sample size, the study was conducted from January 2023 to December 2023. The inclusion criteria were refined to include patients aged 65 years and older who underwent laparoscopic surgery under general anesthesia and experienced uneventful postoperative extubation. Informed consent was obtained from all patients or their legal representatives prior to surgery. Exclusion criteria encompassed: (1) having been diagnosed with obstructive sleep apnea; (2) severe cardiac insufficiency or respiratory dysfunction precluding routine extubation; (3) cognitive impairment or communication difficulties; (4) hemodynamic instability necessitating direct postoperative transfer to the intensive care unit; (5) radiologic or clinical evidence of pulmonary alveolar consolidation, atelectasis, or severe pulmonary infection; (6) psychiatric or neurological disorders, congenital anomalies, or a documented history of drug allergy; (7) significant nasal obstruction, chronic rhinorrhea, or a history of facial trauma; (8) impaired airway protection with a high risk of aspiration; (9) a definitive diagnosis of COPD, bronchiectasis, or another persistent pulmonary condition; (10) increased intracranial pressure; and (11) pregnancy, lactation, or a positive pregnancy test. Discontinuation criteria included severe respiratory depression or any condition necessitating reintubation after extubation.

Study Design

Our study implements perioperative management based on the concept of promoting rapid postoperative recovery for patients. Preoperative anesthesia evaluations are routinely conducted, and anesthetic agents are precisely titrated during surgery to optimize patient outcomes. All patients underwent general anesthesia with endotracheal intubation. Anesthesia induction was achieved using intravenous agents such as propofol (1.5–2.5 mg/kg), sufentanil (0.3–0.5 μg/kg), and rocuronium (0.6–1.0 mg/kg). Maintenance of anesthesia was performed with sevoflurane in an oxygen/air mixture,

supplemented with opioids (eg, remifentanil or sufentanil) and muscle relaxants as required, based on intraoperative monitoring and clinical judgment. BIS monitoring and routine airway management were employed throughout the procedure. After intubation, patients received volume-controlled mechanical ventilation. Tidal volume was set at 6–8 mL/kg of predicted body weight, and respiratory rate was adjusted to maintain normocapnia (end-tidal CO_2: 35–45 mmHg). Positive end-expiratory pressure (PEEP) was typically maintained at 3–5 cmH_2O unless clinical conditions dictated otherwise. Inspired oxygen concentration (FiO_2) was adjusted to ensure adequate oxygenation (SpO_2 > 95%). Intraoperative fluid therapy followed a goal-directed strategy informed by standard hemodynamic parameters, including blood pressure, heart rate, and urine output. Crystalloid solutions (eg, lactated Ringer's or normal saline) were routinely administered, while colloids were used as clinically indicated. Blood loss and urine output were carefully monitored to guide fluid replacement, and vasoactive medications were administered as needed to maintain hemodynamic stability.

Patients were randomly allocated to either the conventional nasal catheter oxygen therapy group (General Nasal Catheter Group) or the THRIVE oxygen therapy group (Transnasal Humidified Rapid-Insufflation Ventilatory Exchange, THRIVE oxygen group). Upon completion of laparoscopic surgery under general anesthesia, an anesthesiologist evaluated each patient for extubation readiness. Once extubation criteria were met, PACU nurse assisted in the procedure by connecting the suction device and coordinating with the anesthesiologist for tracheal tube removal. In the THRIVE group, oxygen flow was dynamically adjusted according to the patient's tolerance and oxygenation status, maintaining a minimum SpO_2 of 96%. Following extubation, the initial flow rate was set at 50 L/min, with fractional inspired oxygen concentration (FiO_2) and flow adjustments made incrementally (1–5 L/min) in response to SpO_2 levels. Other ventilatory parameters were fine-tuned in real-time, guided by vital signs, patient-reported comfort, and objective monitoring indices, maintaining SpO_2 above 96%. Approximately 15 minutes post-extubation, oxygen concentration was gradually reduced, followed by a period of deoxygenation monitoring.

Standard perioperative monitoring—including pulse oximetry (SpO_2), heart rate, blood pressure, and respiratory rate, was performed and documented for all patients. Pulmonary ultrasound scores were assessed and recorded post-extubation and upon discharge from the PACU in both study groups. Hypoxemia was classified according to the latest criteria:[13] mild hypoxemia was defined as SpO_2 between 90% and 95%, moderate hypoxemia as SpO_2 between 75% and 90% for more than 60 seconds, and severe hypoxemia was defined as either an SpO_2 of 75% or lower at any point or an SpO_2 within the 75–90% range lasting more than 60s. In the nasal cannula group, episodes of mild hypoxemia were managed by increasing oxygen flow from 2 L/min to 6 L/min and applying a mandibular thrust maneuver to maintain airway patency. In cases of severe hypoxemia, the anesthesiologist determined the need for endotracheal intubation. For patients receiving THRIVE, mild hypoxemia was addressed with mandibular thrusting, while refractory severe hypoxemia necessitated escalation to mask ventilation and, if required, tracheal intubation.

Main Outcome Indicators

Incidence of hypoxemia: in this study, the data were based on the presence of patients at least once before discharge from the PACU, with $SpO_2 \leq 90\%$ for 60 seconds as the criterion for hypoxemia.[14]

Secondary Outcome Indicators

Pulmonary Ultrasound Score: Pulmonary ultrasound assessments were performed at three predefined time points: preoperatively (as a baseline), immediately following tracheal extubation, and upon the patient's discharge from the PACU. Only the scores from the post-extubation and PACU discharge assessments were recorded for analysis. All examinations were performed using a Hitachi digital color ultrasound diagnostic system equipped with an EUP-C715 convex array probe (1–5 MHz). All lung ultrasonography is performed and recorded by the same anesthesiologist using the same ultrasound machine to ensure consistency. The lung fields were systematically divided into eight zones—four per side—using anatomical landmarks such as the parasternal line, anterior and posterior axillary lines, and the nipple plane as boundaries. A thorough evaluation of each intercostal space in both longitudinal and transverse planes was performed, with at least one complete respiratory cycle recorded per region. The images were subsequently analyzed and scored based on established pulmonary ultrasound scoring criteria,[15] Aeration was categorized as follows: 0 for normal, 1 for moderate reduction, 2 for

severe reduction, and 3 for total loss. The cumulative pulmonary ultrasound score, which ranges from 0 to 24, was employed to assess the extent of lung involvement, with elevated scores reflecting greater severity of pulmonary pathology.

Additional perioperative variables assessed included the number of jaw lifting required, the incidence of reintubation, and the frequency of oxygen therapy-related adverse events (eg, sore throat, abdominal distension, facial injury). Furthermore, patient comfort was evaluated using the Visual Analog Scale (VAS), which employs a scoring system from 0 to 10, where 0 is "very uncomfortable" and 10 is "completely comfortable". This method is often used in clinical studies to assess subjective experiences, such as comfort, anxiety, or satisfaction.[16–18] In this study, both the evaluation of oxygen therapy-related adverse events and the VAS comfort assessment were performed after the intervention was completed and prior to the patient's discharge from the PACU.

Randomization, Blinding, and Sample Size Estimation

An independent statistician utilized a computer algorithm to generate the randomization sequence, ensuring a 1:1 allocation ratio. Randomization results were sealed, sequentially numbered, and placed in opaque envelopes, which were drawn by the patient's PACU nurse upon arrival in the PACU to determine assignment to either the conventional nasal cannula group or the THRIVE group. Patients were single-blinded and managed within the same PACU at each center, with THRIVE oxygenation equipment stationed bedside. To maintain blinding, the conventional nasal cannula group received oxygen through a THRIVE nasal cannula, which was concealed beneath a standard nasal cannula supplying oxygen at a flow rate of 2 L/min.

Sample Size Calculation

Based on preliminary data, the occurrence of hypoxemia, characterized by an SpO_2 level between 75% and 90% for less than 60 seconds, was estimated at 0% (P_1) in the intervention group and 20% (P_2) in the control group. Using a two-sided α of 0.05 ($Z_{0.05} = 1.96$) and a β of 0.1 (corresponding to 90% power, Zβ = 1.28), the required sample size was calculated using the formula:

$$N = \frac{2\bar{p}\bar{q}\left(Z_\alpha + Z_\beta\right)^2}{\left(P_1 - P_2\right)^2}$$

Considering a projected dropout rate of 20–25% resulting from follow-up losses or participant withdrawals, at least 200 participants (100 per group) were required to ensure statistical robustness.

Statistical Analysis

All statistical analyses were performed using SPSS version 23.0. The overall enrollment status of participants was summarized, including the number of exclusions and reasons for withdrawal. Baseline demographic and clinical characteristics, including smoking history and history of snoring, were recorded and analyzed. Continuous variables were assessed for normality using the Shapiro–Wilk test. Variables with a normal distribution were expressed as mean ± standard deviation ($\bar{x} \pm s$) and compared between groups using the independent samples *t*-test (eg, height and weight). Non-normally distributed variables were reported as median (interquartile range) [M (P25, P75)] and compared using the Mann–Whitney *U*-test (eg, age, preoperative albumin and hemoglobin levels, and lung ultrasound scores before and after oxygen therapy). Categorical variables were presented as frequencies and percentages (%) and analyzed using the chi-square test, such as ASA physical status classification and medical history. The incidence of hypoxemia between groups was compared using Fisher's exact test due to small expected counts. The incidence of jaw lifting was analyzed using the chi-square test, while other oxygen therapy-related adverse events were compared using continuity-corrected chi-square tests when appropriate. All tests were two-tailed, and a P value of < 0.05 was considered statistically significant.

Results

General Information

One patient from each group withdrew due to surgical factors, and an additional patient in the experimental group withdrew due to intolerance. Baseline demographics and intraoperative variables were comparable between the two groups, including age, sex, weight, height, BMI, preoperative albumin and hemoglobin levels, ASA classification, preoperative pulmonary function, smoking history, hypertension, snoring history, and surgical type ($P > 0.05$; Table 1).

Incidence of Hypoxemia

The occurrence of hypoxemia was markedly reduced in the THRIVE group compared with the conventional nasal cannula group (0% vs 29.2%; $\chi^2 = 35.245$; $P < 0.001$; Table 2), demonstrating a substantial decrease in postoperative hypoxemic events associated with THRIVE.

Pulmonary Ultrasound Scores Before and After Oxygen Therapy

The median lung ultrasound scores (LUSS1) prior to initiating oxygen therapy showed no significant difference between the groups ($z = 0.237$, $p = 0.813$). However, following oxygen therapy, a statistically significant difference emerged in the

Table 1 Comparison of Basic Data and Intraoperative Data Between the Two Groups of Patients

General Characteristics of the Patient	General Nasal Catheter Group(N=99)	THRIVE Group (N=98)	T-value /c^2/z-value	*P*-value
Age (years)	70(67,76)	71(66,75)	0.192[c]	0.848
Male/Female (case)	70/29	71/27	1.457[a]	0.483
Weight(kg)	63.31±8.86	61.39±9.12	1.406[b]	0.162
Height(cm)	164.15±7.41	163.3±7.57	0.748[b]	0.455
BMI	22.76±3.05	23.12±2.86	0.794[b]	0.428
ASA Classification I/II/III	10/62/27	12/68/18	1.758[a]	0.446
Preoperative Albumin(g)	40.8(38.8,43.8)	40.8(38.9,43.5)	0.191[c]	0.848
Pre-operative Hemoglobin(g)	132(125,138.5)	130(125,140)	0.541[c]	0.588
Preoperative SPO_2(%)	97.9±2.3	98.2±1.4	1.152[b]	0.251
Smoking History(case)	6	8	0.337[a]	0.562
Hypertension(case)	19	17	0.113[a]	0.737
Snoring History(case)	5	10	2.524[a]	0.112
$LUSS_0$(score)	0(0,1)	0(0,0)	1.241[c]	0.215
Type Of Surgery/Case			4.427[a]	0.881
Laparoscopic Gastrectomy	14(14.14)	17(17.34)		
Laparoscopic Hepatectomy	5(5.05)	4(4.08)		
Laparoscopic Colectomy	9(9.09)	16(16.32)		
Laparoscopic Proctectomy	10(10.10)	7(7.14)		
Laparoscopic Prostatectomy	8(8.08)	6(6.12)		
Laparoscopic Nephrectomy	11(11.11)	8(8.16)		
Laparoscopic Cystectomy	1(1.01)	1(1.02)		
Laparoscopic Hysterectomy	2(2.02)	1(1.02)		
Laparoscopic Ventral Hernia Repair	28(28.28)	30(30.61)		
Other Surgery	10(10.10)	13(13.27)		
Anesthesia Duration(min)	170(93,210)	150(100,200)	0.236[c]	0.814
Surgery Duration(min)	132(70,180)	120(78,175)	0.434[c]	0.665
Extubation Duration(min)	8(6,10)	7(5,10)	1.839[c]	0.066
Recovery Duration(min)	54(40,61)	50(38,60)	1.228[c]	0.220

Notes: a is the x2 value; b is the t-value; c is the z-value; data descriptions consistent with normality are expressed as mean ± standard deviation; data descriptions consistent with skewness are expressed as median M (P25,P75); Other surgery: uncategorized laparoscopic procedures, such as appendectomy, cholecystectomy, or ovarian cystectomy; Extubation duration: the time interval from cessation of anesthetic agents to successful tracheal extubation; Recovery duration: the time from tracheal extubation to the patient's discharge from PACU.

Table 2 Incidence of Hypoxemia in Both Groups

Group	Total(case)	Occurrence [case(%)]	Non-Occurrence [case(%)]	χ2	P value
General Nasal Catheter Group	99	29(29.9%)	70(70.71%)	35.245	0.000*
THRIVE Group	98	0(0)	98(100%)		

Notes: Comparisons between groups were performed using the chi-square test; *indicates $P < 0.05$.

Table 3 Comparison of Lung Ultrasound Scores Before and After Oxygen Therapy in Two Groups

	$LUSS_1$(score)	$LUSS_2$(score)	Z value	*P* value
General Nasal Catheter Group(N=99)	5(3,7)	5(3,6)	1.097	0.273
THRIVE Group(N=98)	5(3,7)	4(2,5)	3.016	0.003*
Z value	0.237	2.254		
P value	0.813	0.024*		

Notes: $LUSS_1$ and $LUSS_2$ represent lung ultrasound scores before and after oxygen therapy, respectively; Non-normally distributed data are presented as median (interquartile range) M (P25, P75); Between-group comparisons were performed using the Mann–Whitney *U*-test, and within-group comparisons were also analyzed using the Mann–Whitney *U*-test; *indicates $P < 0.05$.

median lung ultrasound scores (LUSS2) between the groups (z = 2.254, p = 0.024). In the conventional nasal cannula group, LUSS showed no significant change before and after oxygen therapy (z = 1.097, p = 0.273). In contrast, patients in the THRIVE group exhibited a significant reduction in LUSS following oxygen therapy (z = 3.016, p = 0.003), indicating a notable improvement in pulmonary aeration with THRIVE (Table 3).

Incidence of Double-Handed Jaw Lifting

The need for double-handed jaw thrust was considerably less frequent in the THRIVE group than in the conventional nasal cannula group (5.1% vs 29.2%, P = 0.019; Table 4).

Other Complications

No notable differences were observed between the two groups in terms of the occurrence of additional complications, including oral dryness, sore throat, choking sensation, abdominal distention, and facial injury (P > 0.05; Table 5), indicating that the use of THRIVE did not increase the risk of these complications.

Table 4 Incidence of Jaw Lifting in Both Groups

Group	Total(Case)	Occurrence [Case(%)]	Non-Occurrence [Case(%)]	χ2	P value
General Nasal Catheter Group	99	45(45.5%)	54(54.5%)	10.005	0.019*
THRIVE Group	98	5(5.1%)	93(94.9%)		

Notes: Comparisons between groups were performed using the chi-square test; *indicates $P < 0.05$.

Table 5 Other Complications in Both Groups

Group	Dry Mouth [Case(%)]	Sore Throat [Case(%)]	Sense Of Suffocation [case(%)]	Bloating [Case(%)]	Facial Injuries [Case(%)]
General Nasal Catheter Group (N=99)	4(4.0%)	8(8.0%)	3(3.0%)	0	0
THRIVE Group (N=98)	1(1.0%)	2(2.0%)	0	0	0
Correction X2	1.628	2.715	3.343	0.000	0.000
P	0.202	0.099	0.067	1	1

Note: Comparisons between groups were performed using the corrected chi-square test.

Table 6 Comfort VAS Scores Between Two Groups of Patients

Group	VAS(score)	Z value	*P* value
General Nasal Catheter Group (N=99) THRIVE Group (N=98)	3(2,3) 3(3,4)	3.141	0.002*

Notes: VAS refers to the Visual Analog Scale. Non-normally distributed data are presented as median (interquartile range) M (P25, P75); Between-group comparisons were performed using the Mann–Whitney *U*-test, and within-group comparisons were also analyzed using the Mann–Whitney *U*-test; *indicates $P < 0.05$.

Patient Comfort Comparison Between Groups

Patients in the THRIVE group reported significantly higher levels of comfort compared to those in the nasal cannula group ($z = 3.141$, $P = 0.002$; Table 6).

Discussion

In our study, we observed that (1) THRIVE markedly lowered the occurrence of post-extubation hypoxemia compared to conventional nasal cannula oxygen therapy (0% vs 29.2%); (2) real-time lung ultrasound assessments demonstrated that THRIVE facilitated pulmonary recruitment, mitigated atelectasis, increased end-expiratory lung volume, and enhanced oxygenation; and (3) patients receiving THRIVE reported greater comfort compared with those receiving conventional nasal cannula oxygen therapy.

Despite the widespread use of conventional oxygen delivery methods—such as standard nasal cannulae, face masks, and nasal oxygen tubing—in the clinical management of postoperative hypoxia, the incidence of hypoxemia following extubation remains high. In high-risk patients, increased oxygen demand, inadequate flow rates, and potential bronchoconstriction contribute to persistent hypoxemia.[19] Our findings demonstrate that THRIVE provides superior oxygenation support compared with conventional modalities, effectively mitigating hypoxia. In contrast, 29 cases of varying degrees of hypoxia were observed in the standard nasal cannula group, necessitating either an increase in oxygen flow or the application of mask-assisted positive pressure ventilation to correct the condition. We hypothesize that THRIVE exerts a physiological effect analogous to continuous positive airway pressure (CPAP), generating a sustained and predictable partial pressure of oxygen that promotes alveolar recruitment, facilitates end-expiratory alveolar reopening, and optimizes gas exchange efficiency.[20,21] The reopening of alveoli is pressure-dependent, requiring a critical threshold to be achieved for atrophic alveoli to remain open. This pressure differential is primarily influenced by the set inspiratory flow and the patient's exhalatory flow dynamics.[22,23] Additionally, the higher FiO_2 in the THRIVE group likely plays a crucial role in mitigating hypoxemia. By delivering oxygen at a flow rate exceeding the patient's peak inspiratory requirement, THRIVE ensures adequate gas exchange during active inspiration, effectively flushes anatomical dead space in the upper airway, and establishes an oxygen reservoir. The high-flow nature of THRIVE allows patients to inhale nearly 100% oxygen, unlike conventional oxygen therapy, where lower flow rates fall short of meeting peak inspiratory demand, leading to dilution with ambient air. Notably, a multicenter randomized controlled trial by Hernández et al,[24] encompassing over 600 extubated patients, revealed a significant improvement in PaO_2 levels within the THRIVE group ($P < 0.05$), aligning with our findings. Furthermore, the nasal prong design of THRIVE creates a relatively sealed oxygen delivery system compared with standard nasal cannula therapy, thereby minimizing ambient air entrainment and ensuring a stable, high-concentration oxygen supply.

Bedside lung ultrasound has been established as a valuable tool for real-time assessment of pulmonary status.[25] In this study, THRIVE oxygen therapy demonstrated a beneficial effect in facilitating tracheal extubation following general anesthesia for elderly individuals undergoing laparoscopic procedures. Notably, the postoperative LUSS1 scores showed no significant difference between the two groups. However, both LUSS1 and LUSS2 scores were markedly elevated, suggesting varying degrees of pulmonary ventilation impairment in most patients, consistent with the findings of Hedenstierna et al.[26] Several factors may contribute to this phenomenon: (1) the effects of general anesthesia, including inotropic drug use, diaphragmatic elevation, and postoperative challenges in pulmonary recruitment; (2) declining

functional residual capacity with age and the absorption of remaining airway gas contribute to absorptive atelectasis; and (3) the mechanical impact of laparoscopy, which elevates the diaphragm and compromises lung expansion. Monastesse et al[27] similarly reported a significant increase in LUSS following pneumoperitoneum.

In the control group, the variation between LUSS1 and LUSS2 did not reach statistical significance, and the LUSS score decreased, potentially due to the relatively short ventilation duration. Conventional low-flow nasal cannula oxygen therapy did not appear to mitigate postoperative pulmonary atelectasis following general anesthesia. Conversely, in the THRIVE group, a significant intra-group reduction in LUSS scores was observed, and the inter-group difference in LUSS2 scores reached statistical significance. This improvement is likely attributable to THRIVE's continuous positive airway pressure (CPAP)-like effect, which promotes lung recruitment by producing positive airway pressure and expanding end-expiratory lung volume. Additionally, THRIVE facilitates nasopharyngeal dead space clearance, allowing upper airway carbon dioxide to exit through the oral cavity, thereby establishing an alveolar concentration gradient that enhances CO_2 elimination. While some researchers have suggested that high-flow oxygen therapy inhibits carbon dioxide accumulation, our findings differ. This discrepancy may be due to variations in the studied patient populations and the inherent clinical heterogeneity across studies. Moreover, the sample size in our study remains relatively limited, underscoring the need for a large, multi-center randomized trial to validate these findings.

THRIVE has been shown to enhance patient comfort. A systematic review by Pettenuzzo et al[28] reported that patients found THRIVE to be more comfortable than both noninvasive ventilation (NIV) and conventional oxygen therapy (COT). Several factors may contribute to this advantage: (1) The specialized nasal cannula used in THRIVE features a large-diameter, soft, and flexible design with a specific curvature, mitigating discomfort from high-velocity airflow impacting the frontal sinuses. Additionally, the soft texture of the delivery tubing minimizes the formation of mobile condensate, thereby improving patient tolerance. (2) The delivery of warmed, humidified gas enhances overall comfort, reduces dyspnea, and alleviates oral dryness. (3) THRIVE facilitates secretion clearance by heating inspired gas to 37°C, optimizing physiological conditions for airway function. This temperature promotes ciliary activity and mucus transport, maximizing mucociliary clearance. Post-anesthesia patients frequently experience increased airway secretions, the clearance of which depends on the absorptive capacity of airway epithelial cells via Na^+ and Cl^- secretion. Inhalation of dry gas can impair epithelial integrity, whereas heated, fully humidified gas at core body temperature (37°C) preserves mucosal function, maintains optimal secretion rheology and volume, and enhances clearance without the risk of thermal injury or excessive humidification. (4) The use of heated and humidified gas reduces friction between the nasal mucosa and airflow, thereby decreasing airway resistance and respiratory effort. By conserving the metabolic energy otherwise required for active humidification and thermoregulation, and through its adjustable oxygen delivery and flow-dependent CO_2 removal, THRIVE effectively reduces the work of breathing. Based on our findings, as well as prior studies from domestic and international researchers, THRIVE offers superior comfort compared with conventional mask-based oxygen therapy.

In addition to its benefits in laparoscopic procedures, THRIVE may also play a critical role in the postoperative management of hypoxia in patients undergoing open surgery. These patients often experience more pronounced postoperative pain, impaired respiratory mechanics, and a higher risk of atelectasis due to larger incisions and reduced mobility. THRIVE's ability to deliver humidified high-flow oxygen with mild positive airway pressure can help maintain airway patency and improve oxygenation, particularly during the early postoperative period. Furthermore, by supporting mucociliary clearance and reducing the work of breathing, THRIVE may contribute to better pulmonary outcomes and enhanced recovery in this population.

Our study has several limitations. First, the assessment of hypoxemia was based solely on the minimum oxygen saturation recorded from a stable pulse waveform, without incorporating other key parameters such as arterial partial pressure of oxygen (PaO_2), which could provide a more comprehensive evaluation. Second, due to the postoperative positioning of patients, lung ultrasound assessment was limited to the anterior eight lung regions, excluding posterior areas, which may have led to an incomplete evaluation of pulmonary aeration. Third, a standardized flow management strategy was implemented in all patients in the THRIVE group, potentially overlooking individual variations in oxygenation needs. Additionally, the study lacks sufficient data to characterize patients at high risk for hypoxia, as individuals with severe pulmonary disease, obstructive sleep apnea–hypoventilation syndrome, and other preexisting

respiratory conditions were excluded. This selection criteria heterogeneity may have contributed to baseline disparities, limiting the generalizability of our findings and making direct comparisons more challenging.

Conclusions

Early application of THRIVE following extubation in elderly patients undergoing laparoscopic surgery under general anesthesia significantly reduced the incidence of postoperative hypoxemia and the need for airway interventions such as jaw lifting. In addition, patients receiving THRIVE demonstrated improved lung ultrasound scores and reported higher comfort levels in the PACU. These findings support the use of THRIVE as an effective noninvasive respiratory support modality in this patient population.

Data Sharing Statement

De-identified participant data will be shared upon reasonable request via the corresponding author's email, available for five years following publication. No additional study documents will be provided.

Ethics Approval and Consent to Participate

The study received approval from the local ethics committee (Approval No. 2022-105, Approval Date: May 5, 2022) and was registered in the Chinese Clinical Trial Registry (ChiCTR2200066499). Written informed consent was obtained from all participants, who also agreed to take part in the research. The study was conducted in compliance with the Declaration of Helsinki (1964) and its subsequent revisions.

Funding

This research received funding from two projects of the Wenzhou Science and Technology Bureau under grant number Y20220617 and Y2020625.

Disclosure

The authors declare no relevant competing interests related to this article.

References

1. Suzuki S. Oxygen administration for postoperative surgical patients: a narrative review. *Journal of Intensive Care*. 2020;8(1):79. doi:10.1186/s40560-020-00498-5
2. Berhanu M, Dadi N, Mengistu B, et al. Magnitude of early postoperative hypoxemia and its associated factors among adult patients who undergo emergency surgery under general anesthesia at Jimma Medical Center, Jimma, Southwest Ethiopia, 2021: a prospective observational study. *Perioperative Medicine*. 2023;12(1):1. doi:10.1186/s13741-022-00288-7
3. Karcz M, Papadakos PJ. Respiratory complications in the postanesthesia care unit: a review of pathophysiological mechanisms. *Canadian Journal of Respiratory Therapy*. 2013;49(4):21.
4. Liu K, Scott JB, Jing G, et al. Management of postoperative hypoxemia. *Respiratory Care*. 2021;66(7):1136–1149. doi:10.4187/respcare.08929
5. Junaidi B, Hawrylak A, Kaw R. Evaluation and management of perioperative pulmonary complications. *Medical Clinics*. 2024;108(6):1087–1100. doi:10.1016/j.mcna.2024.04.003
6. Bates AT, Divino C. Laparoscopic surgery in the elderly: a review of the literature. *Aging and Disease*. 2015;6(2):149. doi:10.14336/AD.2014.0429
7. Staheli B, Rondeau B. Anesthetic considerations in the geriatric population; 2021.
8. Park S. High-flow nasal cannula for respiratory failure in adult patients. *Acute and Critical Care*. 2021;36(4):275–285. doi:10.4266/acc.2021.01571
9. Hua Z, Liu Z, Li Y, et al. Transnasal humidified rapid insufflation ventilatory exchange vs. facemask oxygenation in elderly patients undergoing general anaesthesia: a randomized controlled trial. *Scientific Reports*. 2020;10(1):5745. doi:10.1038/s41598-020-62716-2
10. Sud A, Patel A. THRIVE: five years on and into the COVID-19 era. *British Journal of Anaesthesia*. 2021;126(4):768–773. doi:10.1016/j.bja.2020.12.030
11. Hermez LA, Spence CJ, Payton MJ, et al. A physiological study to determine the mechanism of carbon dioxide clearance during apnoea when using transnasal humidified rapid insufflation ventilatory exchange (THRIVE). *Anaesthesia*. 2019;74(4):441–449. doi:10.1111/anae.14541
12. Toner AJ. Carbon dioxide clearance during apnoea with high-flow nasal oxygen: epiphenomenon or a failure to THRIVE? *Anaesthesia*. 2020;75(5):580–582. doi:10.1111/anae.14848
13. Lin Y, Zhang X, Li L, et al. High-flow nasal cannula oxygen therapy and hypoxia during gastroscopy with propofol sedation: a randomized multicenter clinical trial. *Gastrointestinal Endoscopy*. 2019;90(4):591–601. doi:10.1016/j.gie.2019.06.033
14. Sun Z, Sessler DI, Dalton JE, et al. Postoperative hypoxemia is common and persistent: a prospective blinded observational study. *Anesthesia & Analgesia*. 2015;121(3):709–715. doi:10.1213/ANE.0000000000000836
15. Rouby J-J, Arbelot C, Gao Y, et al. Training for lung ultrasound score measurement in critically ill patients. *American Journal of Respiratory and Critical Care Medicine*. 2018;198(3):398–401. doi:10.1164/rccm.201802-0227LE

16. Doulaptsi M, Prokopakis E, Seys S, et al. Visual analogue scale for sino-nasal symptoms severity correlates with sino-nasal outcome test 22: paving the way for a simple outcome tool of CRS burden. *Clinical and Translational Allergy*. 2018;8:1–6. doi:10.1186/s13601-018-0219-6
17. Ozdemir S, Parlakyıldız Gokce A, Unver T. Simulation of three intraoral radiographic techniques in pediatric dental patients: subjective comfort assessment using the VAS and Wong-Baker FACES Pain Raiting Scale. *BMC Oral Health*. 2020;20:1–7. doi:10.1186/s12903-020-1011-2
18. Chooi CSL, White AM, Tan SGM, et al. Pain vs comfort scores after Caesarean section: a randomized trial. *British Journal of anaesthesia*. 2013;110(5):780–787. doi:10.1093/bja/aes517
19. O'Driscoll BR, Howard LS, Earis J, et al. British Thoracic Society Guideline for oxygen use in adults in healthcare and emergency settings. *BMJ Open Respiratory Research*. 2017;4(1). doi:10.1136/bmjresp-2016-000170
20. Biselli P, Fricke K, Grote L, et al. Reductions in dead space ventilation with nasal high flow depend on physiological dead space volume: metabolic hood measurements during sleep in patients with COPD and controls. *European Respiratory Journal*. 2018;51(5):1702251. doi:10.1183/13993003.02251-2017
21. Arkin N, Bushell E. Surviving and THRIVE-ing the difficult airway: gaining calm, control, and time during an emergent tracheostomy. *Journal of Head and Neck Anesthesia*. 2017;2(2):23–27.
22. Roca O, de Acilu MG, Caralt B, et al. Humidified high flow nasal cannula supportive therapy improves outcomes in lung transplant recipients readmitted to the intensive care unit because of acute respiratory failure. *Transplantation*. 2015;99(5):1092–1098. doi:10.1097/TP.0000000000000460
23. Kollisch-Singule M, Satalin J, Blair SJ, et al. Mechanical ventilation lessons learned from alveolar micromechanics. *Frontiers in Physiology*. 2020;11:233. doi:10.3389/fphys.2020.00233
24. Hernández G, Vaquero C, González P, et al. Effect of postextubation high-flow nasal cannula vs conventional oxygen therapy on reintubation in low-risk patients: a randomized clinical trial. *JAMA*. 2016;315(13):1354–1361. doi:10.1001/jama.2016.2711
25. Moreno-Aguilar G, Lichtenstein D. Lung ultrasound in the critically ill (LUCI) and the lung point: a sign specific to pneumothorax which cannot be mimicked. *Critical Care*. 2015;19:1–2. doi:10.1186/s13054-015-1030-6
26. Hedenstierna G, Tokics L, Reinius H, et al. Higher age and obesity limit atelectasis formation during anaesthesia: an analysis of computed tomography data in 243 subjects. *British Journal of Anaesthesia*. 2020;124(3):336–344. doi:10.1016/j.bja.2019.11.026
27. Monastesse A, Girard F, Massicotte N, et al. Lung ultrasonography for the assessment of perioperative atelectasis: a pilot feasibility study. *Anesthesia & Analgesia*. 2017;124(2):494–504. doi:10.1213/ANE.0000000000001603
28. Pettenuzzo T, Boscolo A, Pistollato E, et al. Effects of non-invasive respiratory support in post-operative patients: a systematic review and network meta-analysis. *Critical Care*. 2024;28(1):152. doi:10.1186/s13054-024-04924-0