RESEARCH ARTICLE

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Analyzing Hemodynamic Impacts of Two-Lung versus One-Lung Ventilation in Thoracotomy Patients: Insights from Pleth Variability Index and Ultrasonic Cardiac Output Monitoring in a Comparative Study

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ABSTRACT

Objective: The current study aimed to investigate the relationship between resiliency and the prevalence and severity of prenatal anxiety and depression in the context of high-risk pregnancies.

Methods: A descriptive cross-sectional correlational survey design was used. A convenience sample of 404 high-risk pregnant women from a maternity department at the National Guard Health Affairs hospital, in Jeddah completed three online scales: the Connor-Davidson Resilience Scale, the Patient Health Questionnaire-9, and the Generalized Anxiety Disorder-7.

Results: Most women (89.85%) had low resilience, while only 1.98% had high resilience. There was a strong negative correlation between resilience and depression ($r = -0.81$, $p < 0.001$) and between resilience and anxiety ($r = -0.79$, $p < 0.001$). Women with low resilience had higher levels of depression and anxiety than women with high resilience. Additionally, women with high-risk pregnancies who have higher levels of resilience are more likely to have normal vaginal delivery, to be employed, and to have fewer pregnancy complications than those who have lower levels of resilience

Conclusion: Resilience is an important factor for the mental health of women with high-risk pregnancies. Interventions to enhance resilience may help reduce the psychological burden of high-risk pregnancies and improve maternal and fetal outcomes. Further research is needed to explore the causal mechanisms and the modifiable factors that influence resilience.

Keywords: Resilience, High-Risk pregnancy, Prenatal anxiety, Prenatal depression, Mental health.

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INTRODUCTION

Thoracotomy is a major open-chest surgical procedure that calls for chest wall incisions and is imperative to establish contact with thoracic organs for either diagnostic or therapeutic purposes. The difficulty levels in thoracotomy command the use of Two-Lung Ventilation (TLV) or One-Lung Ventilation (OLV) techniques to assist both surgical conditions and patient safety. In this situation, the lung that is not being ventilated (but still receives blood flow) contributes to a right-to-left shunt. Normally, the body tries to mitigate this effect through Hypoxic Pulmonary Vasoconstriction (HPV), a mechanism where blood vessels in the non-ventilated lung constrict, redirecting blood to the ventilated lung for better oxygenation. Additionally, gravity assists in redistributing blood flow to the ventilated lung when the patient is positioned appropriately. Therefore, changing the mode of ventilation from one to another, may cause hemodynamic changes that may be dramatic, affecting cardiac output, vascular resistance, and general patient stability. Of all these hemodynamic changes, it is imperative to know that some may affect the outcome of the patient in a very significant manner both in the intraoperative and postoperative period of thoracic surgeries[1-3].

Newer tools in the pipeline for development include the Pleth Variability Index (PVI) and Ultrasonic Cardiac Output Monitors (USCOM); these provide a front-line real-time view of cardiovascular function under a non-invasive mode of hemodynamic monitoring. PVI by plethysmography is based on pulse oximetry, which uses perfusion index variation in response to the respiratory cycle to measure alteration in intravascular volume status and fluid responsiveness. On the other hand, USCOM uses an ultrasonic method to measure directly derived means of the body's cardiac output parameters and allows the clinician to functionally assess the heart and rather scrupulously check for hemodynamic stability. When making a therapeutic decision during thoracotomy, these tools probably provide a comprehensive view of hemodynamic status for the clinician to consider[4-6].

Recent reports emphasize the importance of strict hemodynamic monitoring and management during thoracic surgery to improve outcomes. However, there is a gap in the literature regarding the transition from TLV to OLV and its effects on hemodynamic parameters. Currently, it is difficult to quantify these effects using PVI and USCOM. Additionally, most published literature focuses either on the broader implications of the ventilation change or the isolated effect of these monitoring tools, without a combined approach. Furthermore, inconsistencies in the reported outcomes and methodologies underscore the need for a thorough and focused study to elucidate these dynamics comprehensively[7-10].

This research aims to bridge this gap by providing a detailed analysis of the hemodynamic changes associated with transitions between TLV and OLV in patients undergoing thoracotomy, as measured by PVI and USCOM. By integrating these sophisticated monitoring techniques, the study seeks to offer new insights into the optimal management of ventilation and hemodynamic parameters, thereby enhancing patient care.

The findings of this study are anticipated to have significant clinical implications. By offering a clearer understanding of the hemodynamic shifts associated with different ventilation strategies, this research could inform the development of optimized protocols for managing ventilation and monitoring during thoracotomy. Ultimately, this could lead to improved patient outcomes, reduced complications, and a more nuanced approach to patient care in thoracic surgery settings[11].

MATERIALS & METHODS

Study Design: This was a pre-and-post-intervention study aimed at analyzing the impact of transitioning from two-lung to one-lung ventilation and vice versa on hemodynamic parameters among patients undergoing thoracotomy.

Setting: The study was carried out at Imam Khomeini Hospital Complex, affiliated with Tehran University of Medical Sciences, from 2018 through 2019.

Population and Sampling:

- **Population:** Patients scheduled for elective thoracotomy requiring temporary one-lung ventilation during the procedure.
- **Sampling Method:** A non-random simple sampling technique was utilized to select participants.
- **Sample Size:** Determined based on a pilot study involving ten patients, with calculations made using a standard formula considering an alpha of 0.05 and power (p) of 0.2, the final sample size was determined to be 50 patients. This size was deemed sufficient to detect clinically relevant changes in the primary outcome measures while also allowing for potential dropouts.

Exclusion Criteria: Patients were excluded if they had cardiac, liver, or renal insufficiency; obstructive or restrictive lung diseases; uncontrolled thyroid disorders; unmanaged diabetes; uncontrolled hypertension; sepsis; psychiatric disorders; were over the age of 65; or required a right-sided double-lumen tube for one-lung ventilation.

Ethical Considerations: The study adhered to the Helsinki Declaration principles. Informed consent was obtained from all participants. The research protocol was approved by the Ethics Committee of Tehran University of Medical Sciences (Ethical Code: IR.TUMS.IKHC.REC.1397.051).

Procedure: Patients are assessed preoperatively and optimized for the procedure. During admission for surgery, detailed information about the surgical procedure and anesthetic procedure is given to the patient as well as the relatives. The monitoring setup for the patients included Heart Rate (HR), non-invasive blood pressure, Electrocardiography (ECG), and measurements of SpO2, Pleth Variability Index (PVI), and Perfusion Index (PI), all obtained using a pulse oximeter manufactured by Masimo. Additional parameters monitored included End-Tidal Carbon Dioxide (ETCO2), body temperature, depth of neuromuscular blockade, and depth of anesthesia assessed with the BiSpectral Index (BIS).

Premedication included 0.015mg/kg of midazolam administered intravenously and the patients were pre-hydrated with 3-5 ml/kg of crystalloid solution before the induction of anesthesia. Approximately 20 to 30 minutes prior to induction of anesthesia, an epidural catheter was placed at the T5-T6 interspace. After administering a test dose, a 0.125% bupivacaine infusion was started through the epidural catheter at a rate of 6ml/h to manage pain during and after surgery. For the induction of anesthesia, fentanyl was administered at a dosage of 2-3 μg/kg, followed by propofol at a rate of 10 mg/sec, until the Bispectral Index (BIS) decreased to below 50. Subsequently, to facilitate intubation, 0.5 mg/kg of atracurium was administered intravenously after ensuring adequate ventilation using a face mask and bag. The dose was repeated at 0.1 mg/kg based on neuromuscular monitoring to ensure optimal conditions. Patients were intubated using a left-sided double-lumen endotracheal tube, with tube placement confirmed by auscultation and fiberoptic bronchoscopy. Ventilation was started at a tidal volume of 7ml/kg and a frequency of 12/min with a PEEP of 5 cmH2O, and adjusted based on maintaining ETCO2 between 30-35 and Arterial Blood Gas (ABG) results.

Anesthesia maintenance was achieved with isoflurane, Maintaining the BIS within the range of 45±5. An arterial line was inserted in the radial artery for continuous Invasive Blood Pressure (IBP) monitoring and ABG sampling (ABGs were taken every 30 minutes). In the event of a 20% increase in heart rate or blood pressure, additional doses of fentanyl (0.5-1μg/kg) were administered at minimum intervals of 30 minutes. The epidural catheter placement, general anesthesia induction, arterial line insertion, and ultrasonic probe placement were performed by an expert and consistent anesthesiologist.

Baseline cardiac output indices were measured non-invasively using the Ultrasonic Cardiac Output Monitors (USCOM, USCOM Ltd., Sydney, Australia) placed at the suprasternal notch. Fluid administration was conducted by providing 3-4 ml/kg/h of crystalloid solutions. Additionally, boluses of 250 milliliters were administered if the Stroke Volume Variation (SVV), as measured by the USCOM, rose above 13%. Following this intervention, if the stroke volume increased by more than 10%, the fluid administration was continued until the SVV decreased to below 13%.

Following the adjustment of the patient's posture from supine to lateral position, the position of the tube was verified again using fiberoptic bronchoscopy. When the surgeon suggested the need for one-lung ventilation, various hemodynamic parameters including Stroke Volume Variation (SVV), Cardiac Output (CO), Pleth Variability Index (PVI), Invasive Blood Pressure (IBP), and Heart Rate (HR) were thoroughly recorded. Additionally, the mean airway pressure (Pmean) was also documented. The tidal volume was reduced to 5 ml/kg, PEEP was adjusted to 8 cmH2O, and the respiratory rate was increased to maintain the ETCO2 level of 30-35. The tracheal or bronchial lumen of the endotracheal tube, depending on whether the surgery was on the right or left lung, was clamped. Five minutes later, all the earlier mentioned hemodynamic indices along with the Pmean were documented once again. Following the surgeon's instruction to switch back to two-lung ventilation, every hemodynamic index, along with the Pmean was meticulously recorded again. The clamp was then removed, and the ventilation settings were restored to their original states used at the beginning of the surgery to facilitate bilateral lung ventilation. Adjustments were made to ensure the EtCO2 levels remained within the target range of 30 to 35 mmHg. Subsequently, after five minutes, all hemodynamic metrics were meticulously noted for the last instance.

This comprehensive account ensures detailed documentation and monitoring of the patient's condition throughout the surgical procedure, adhering to the standards for high-quality patient care and research integrity.

DATA COLLECTION AND ANALYSIS:

Throughout the surgical procedure, comprehensive patient monitoring was conducted. Data collected included Heart Rate (HR), Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), Mean Arterial Pressure (MAP), Pleth Variability Index (PVI), Cardiac Output (CO), Stroke Volume Variation (SVV), and mean airway pressure (Pmean). These parameters were recorded at four critical time points: Before the surgical incision, immediately following the transition to one-lung ventilation, before reverting to two-lung ventilation, and subsequent to the initiation of two-lung ventilation. Additionally, the duration of the surgery, intraoperative blood loss, and the use or non-use of inotropic drugs were documented. All data were collected by an anesthesia technician unaware of the study's hypothesis to maintain objectivity.

The data were analyzed using SPSS Version 21. Initially, the Shapiro-Wilk test was applied to assess the normality of the distribution of each variable, considering the sample sizes involved. This step was crucial to determine the appropriate statistical tests for comparison.

For variables that followed a normal distribution, Paired T-tests were conducted to compare the mean values before and after the intervention, specifically the transition from two-lung to one-lung ventilation and back again. Conversely, for variables that did not exhibit normal distribution, Wilcoxon signed-rank tests were utilized to compare the median values between the two conditions.

Statistical significance was determined at a p-value less than 0.05. This threshold was selected to reduce the probability of Type I errors, while still allowing for the identification of clinically significant differences. All statistical tests were conducted in a two-sided manner.

Results were presented as mean ± standard deviation for data adhering to normal distribution and as median with interquartile range for data that were not normally distributed. Graphical representations such as line graphs and box plots were employed to illustrate the temporal changes in hemodynamic parameters throughout the surgical procedure.

RESULTS

Patient Background Characteristics

A total of 50 patients were enrolled in this study. The mean age of the patients was 47.33 ± 13.89 years, ranging from 23 to 65 years, indicating a normal distribution of ages within the studied population. This normal age distribution is essential for the interpretation of study outcomes, as data derived from a diverse age group may have broader clinical applicability.

Regarding gender distribution, the cohort comprised 21 males (42%) and 29 females (58%), reflecting a balanced representation of both genders within the study population. This diversity is crucial for understanding potential gender-specific responses to thoracotomy and associated hemodynamic changes.

The average Body Mass Index (BMI) of the patients was 25.62 ± 5.64 kg/m², indicating a generally healthy weight status among the majority of participants. A history of controlled hypertension was observed in 10 cases (20%), and controlled diabetes was noted in 3 cases (6%). Gender Distribution of Study Participants showed 58% are females and 42% mails.

Changes in Hemodynamic Indices with the Transition from TLV to OLV (**Table 1**).

Abbreviations: HR, heart rate (beats/min); SBP, systolic blood pressure (mmHg); DBP, diastolic blood pressure (mmHg); MAP, mean arterial pressure (mmHg); SVV, stroke volume variation (%); CO, cardiac output (L/min); PVI, Pleth Variability Index (%). Data are presented as mean ± standard deviation. P-values indicate the statistical significance of changes observed during the transition.

The data summarized in (**Table 1)** indicate that the transition from TLV to OLV did not result in statistically significant alterations in the primary hemodynamic indices: Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), Mean Arterial Pressure (MAP), Stroke Volume Variation (SVV), Cardiac Output (CO), and Pleth Variability Index (PVI), all with p-values exceeding the conventional significance threshold of 0.05. However, a notable, albeit not statistically significant, decrease in Heart Rate (HR) was observed post-transition from TLV to OLV, with a mean decrease of 3.70 beats per minute ($p = 0.097$). Similarly, trends toward a decrease in MAP ($p = 0.062$) and CO ($p = 0.057$) were noted, suggesting potential clinical relevance despite lacking statistical significance. Crucially, the mean airway pressure (Pmean) showed negligible variation when transitioning from TLV to OLV, with an insignificant change (from 18.3 ± 5.1 to 18.1 ± 4.9, $p = 0.430$), indicating a clear stability in airway pressure despite the shift in ventilation condition.

Changes in Hemodynamic Indices with the Transition from OLV to TLV (**Table 2).**

Abbreviations: HR, heart rate (beats/min); SBP, systolic blood pressure (mmHg); DBP, diastolic blood pressure (mmHg); MAP, mean arterial pressure (mmHg); SVV, stroke volume variation (%); CO, cardiac output (L/min); PVI, Pleth Variability Index (%). Data are presented as mean ± standard deviation. P-values assess the significance of differences observed post-transition.

As detailed in Table 2, reverting from OLV to TLV was not associated with statistically significant shifts in SBP, DBP, MAP, SVV, CO, or PVI (all p-values > 0.05). However, the

Table 1: Hemodynamic Indices Before and After Transition from Two-Lung to One-Lung Ventilation.

Index	TLV	OLV	Difference	P-value
HR	82.28 ± 13.97	78.58 ± 13.54	-3.70 ± 1.32	0.097
SBP	101.84 ± 21.42	103.18 ± 18.95	-2.66 ± 3.29	0.332
DBP	64.60 ± 13.01	60.94 ± 14.34	-3.66 ± 2.28	0.112
MAP	80.42 ± 15.58	73.37 ± 15.73	-5.06 ± 2.58	0.062
SVV	24.94 ± 11.57	27.58 ± 10.26	2.63 ± 2.06	0.207
CO	5.47 ± 8.38	3.18 ± 1.17	-2.29 ± 1.17	0.057
PVI	15.28 ±5.78	15.32 ± 5.46	0.21 ± 1.06	0.97

Table 2: Hemodynamic Indices Before and After Transition from One-Lung to Two-Lung Ventilation.

Index	OLV	TLV	Difference	P value
HR	87.96 ± 12.54	82.28 ± 13.97	-5.68 ± 2.14	0.091
SBP	108.08 ± 12.86	111.84 ± 21.42	3.76 ± 3.15	0.24
DBP	63.06 ± 12.45	64.60 ± 13.01	1.54 ± 2.44	0.532
MAP	78.15 ± 10.83	80.42 ± 15.58	2.27 ± 2.51	0.371
SVV	29.51 ± 18.62	24.94 ± 11.56	-4.56 ± 3.28	0.172
CO	3.38 ± 1.25	5.47 ± 1.38	2.09 ± 1.22	0.094
PVI	10.98 ±3.46	15.28 ± 5.78	4.30 ± 1.15	0.097

transition was characterized by a marginal yet noteworthy reduction in HR (mean decrease of 5.68 beats per minute, $p = 0.091$), alongside suggestive increases in CO ($p = 0.094$) and PVI ($p = 0.097$), hinting at underlying hemodynamic adjustments despite the absence of overt statistical significance. Importantly, the mean airway pressure demonstrated no significant shifts, remaining stable from OLV to TLV (from 18.3 ± 4.6 to 18.4 ± 5.7, $p = 0.510$), affirming the consistency of airway pressure throughout the changes in ventilation.

DISCUSSION

Our study meticulously investigated the hemodynamic impacts of transitioning between Two-Lung Ventilation (TLV) and One-Lung Ventilation (OLV) during thoracotomy, emphasizing changes measured by Pleth Variability Index (PVI) and Ultrasonic Cardiac Output Monitors (USCOM). The results demonstrated no significant alterations in the primary hemodynamic indices including Systolic and Diastolic Blood Pressure (SBP, DBP), Mean Arterial Pressure (MAP), Stroke Volume Variation (SVV), Cardiac Output (CO), and PVI, across transitions from TLV to OLV and back. Moreover, we observed a consistent pattern in the mean airway pressure (Pmean), which remained stable during transitions, showing negligible variation (from 18.3 ± 5.1 to 18.1 ± 4.9; $p = 0.430$), thus emphasizing airway pressure stability amidst changing ventilation conditions.

These findings are only marginally consistent with existing literature, which has documented diverse effects of OLV on hemodynamic parameters. The stability of hemodynamic indices might be attributed to the unaltered Pmean, suggesting that the intrathoracic pressure stability, despite variations in tidal volume and PEEP, could contribute to the overall hemodynamic steadiness observed in our study. Thus, variations in tidal volume and PEEP from different studies might lead to differing results. Additionally, the independent role of Hypoxic Pulmonary Vasoconstriction (HPV) in mediating hemodynamic changes amidst various confounding factors remains unclear.

Our study explored the hypothesis that transitioning from TLV to OLV and vice versa could potentially lead to significant hemodynamic and cardiovascular changes, suggesting possible risks during surgery. Despite the anticipated pathophysiological changes in cardiovascular function associated with switching between these ventilation modes which theoretically could predict serious hemodynamic a alterations in this context our findings with the specified ventilatory settings indicated the contrary. What we discovered, however, was that the alteration in ventilation status from TLV to OLV did not induce significant changes in hemodynamic conditions nor in cardiac and vascular function. Furthermore, reverting from OLV back to TLV did not cause substantial fluctuations in these parameters. This revelation is particularly critical in cases of unilateral lung collapse, as it implies that relying on independent lung ventilation could still anticipate favorable outcomes post-surgery, maintaining stable hemodynamic and cardiac function despite the shifts in ventilation strategy.

Strengths and limitations of our study further elucidate its value and delineate the scope for future research. A major strength lies in the simultaneous utilization of two non-invasive hemodynamic assessment tools, enhancing the comprehensiveness of our analysis. Nonetheless, limitations such as the small sample size and the potential influence of thoracotomy itself on the accuracy and quality of monitoring should be acknowledged. These factors may have affected the interpretation of our data and underline the necessity for caution when generalizing the results[3].

Future research should aim to incorporate larger sample sizes and more reliable monitoring techniques, as well as explore different tidal volumes and levels of PEEP. This could provide clearer insights into the hemodynamic impacts associated with varying ventilation strategies during thoracotomy.

CONCLUSION

In sum, our study contributes to the body of knowledge on the hemodynamic implications of ventilation strategies during thoracotomy, underscoring the stability of cardiovascular function despite the shift from TLV to OLV and vice versa. The findings affirm the critical importance of continuous, real-time hemodynamic monitoring, particularly employing PVI and USCOM. They suggest that these shifts in ventilation modes may not significantly perturb the hemodynamic stability in thoracic surgeries, paving the way for improved patient management and outcomes. Further research in this area, particularly involving larger sample sizes and varying ventilation parameters, is essential for refining and expanding upon these findings, thus enhancing patient care in thoracic surgical settings.

Conflicts of Interest: The authors declare that there are no known competing interests that could affect this work.

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