Effects of positioning and ventilation strategy on the parameters of respiratory mechanics and blood gases during video-assisted thoracoscopic esophagectomy

Video-yardımlı torakoskopik özofajektomi sırasında ventilasyon stratejisi ve pozisyon değişikliğinin solunum mekaniği ve kan gazı parametrelerine etkileri

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Background: In this study, the effects of positioning and ventilation strategy on respiratory mechanics and blood gases throughout video-assisted thoracoscopic (VAT) esophagectomy were evaluated.

Methods: After obtaining approval from the ethics committee, nine patients (2 females, 7 males; mean age 60 years; range 39 to 74 years) who underwent a VAT-esophagectomy for esophageal cancer with ASA I (Society of Anesthesiologists I) or II physical classification were included in the study. Standard general anesthesia was performed. Dynamic respiratory compliance, airway resistance, and peak inspiratory pressure were monitored. Measurements were recorded in five periods; 10 minutes after intubation (Intubation: T_1, control), 10 minutes after left lateral decubitus position (Left lateral: T_2), 10 minutes after single lung ventilation with left lateral decubitus position (Single lung-initiation: T_3), 10 minutes before single lung ventilation ends (Single lung-end: T_4), and 10 minutes after supine position (Supine: T_5). Samples of arterial blood gases were obtained at the same periods.

Results: Dynamic respiratory compliance records were 66±12 ml. cm. H_2O^{-1}, 53±8 ml. cm. H_2O^{-1}, 49±8 ml. cm. H_2O^{-1}, 48±8 ml. cm. H_2O^{-1} and 52±11 ml. cm. H_2O^{-1}, in T_1, T_2, T_3, T_4 and T_5, respectively. The changes were significant in T_2, T_3, T_4 and T_5 ($p<0.05$).

Conclusion: According to our results, respiratory mechanics, oxygenation and partial oxygen pressures were negatively affected during VAT-esophagectomy compared to the control group, especially during the single lung ventilation period.

Key words: Esophagectomy; left lateral decubitus and supine position; patient positioning; respiratory mechanics; thoracoscopy; video-assisted thoracoscopic esophagectomy.

Amaç: Bu çalışmada video-yardımlı torakoskopik (VYT) özofajektomi süresince hasta pozisyonu ve ventilasyon stratejisinin, solunum mekaniği ve kan gazları üzerine etkileri değerlendirildi.

Çalışma planı: Etik kurul onayı alındıktan sonra fiziksel olarak ASA I (Society of Anesthesiologists I) veya II sınıfında olan özofagus kanseri nedeniyle VYT-özofajektomi ameliyatı uygulanan dokuz hasta, (2 kadın 7 erkek; ort. yaş 60 yıl; dağılım 39-74 yıl) çalışmaya dahil edildi. Standart genel anestezi uygulandı. Dinamik respiratuvar kompliyans, hava yolu direnci, inspiratuvar tepe basıncı monitörize edildi. Ölçümler beş ayrı zamanda kaydedildi; entübasyon sonrası 10. dakika (Entübasyon: T_1, kontrol), sol lateral dekübit pozisyonu sonrası 10. dakika (Sol lateral: T_2), sol lateral dekübit pozisyonunda tek akciğer ventilasyonunu sonrası 10. dakika (Tek akciğer-başlangıç: T_3), tek akciğer ventilasyonu sona ermeden önceki 10. dakika (Tek akciğer-son: T_4) ve yüzüstü pozisyonu sonrası 10. dakika (Yüzüstü: T_5). Arteryal kan gazı örnekleri de aynı aralıklarla alındı.

Bulgular: Dinamik respiratuvar kompliyans kayıtları T_1, T_2, T_3, T_4 ve T_5'te sırasıyla; 66±12 ml. cm. H_2O^{-1}, 53±8 ml. cm. H_2O^{-1}, 49±8 ml. cm. H_2O^{-1}, 48±8 ml. cm. H_2O^{-1} ve 52±11 ml. cm. H_2O^{-1} olarak bulundu. Değişimler T_2, T_3, T_4 ve T_5'te anlamlı bulundu ($p<0.05$).

Sonuç: Sonuçlarımıza göre, solunum mekaniği, oksijenasyon ve kısmi oksijen basınçları, kontrol grubuyla karşılaştırıldığında; VYT-özofajektomi sırasında ölçülen bütün aralıklarda ve özellikle tek akciğer ventilasyon aralığında negatif etkilendi.

Anahtar sözcükler: Özofajektomi; sol lateral dekübit ve sırtüstü pozisyonu; hasta pozisyonu; solunum mekaniği; torakoskopi; video-yardımlı torakoskopik özofajektomi.

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Improved technology and advances in laparoscopic and thoracoscopic surgery have made it possible to perform esophagectomy with a minimally invasive technique.[1,2] The first reports of morbidity and respiratory complications with this approach were discouraging, and it seemed likely that the procedure would have to be abandoned. However, the outcomes of the new series are different from the initial figures, leading to an enormous expansion worldwide. Important factors responsible for this progress are the standardization of the operative technique; the increase in the experience of many surgeons in more advanced laparoscopic procedures, improved optical technology and instruments such as ultrasonic scalpel and endoscopic staplers. Furthermore, a better anesthesia technique, and a better selection of patients for operation are the other factors.[3,4]

Resection of intrathoracic or mediastinal organs with thoracotomy include more postoperative pulmonary complications than with thoracoscopy.[5-8] During video-assisted thoracoscopic (VAT)-esophagectomy, the patient position is changed during the different operation steps. While performing thoracotomy or thoracoscopy, ventilation parameters should be adjusted for single lung ventilation. In an effort to decrease the morbidity associated with esophageal resection, anesthesiologists record respiratory changes to determine perioperative performance of the patient during the surgical procedure. Respiratory mechanics and blood gas values should be monitored to identify the mechanical and ventilatory effects of thoracoscopy. Dynamic changes of respiratory mechanics during the procedure may affect the postoperative pulmonary status.

Herein, the authors designed a study which describes the changes in respiratory mechanics and blood gas measurements during different ventilation periods of VAT-esophagectomy.

PATIENTS AND METHODS

The study was approved by the ethics committee of İstanbul University Cerrahpaşa Medical School and informed consent was obtained from the patients. Nine patients (2 females, 7 males; mean age 60 years; range 39 to 74 years) who underwent a VAT-esophagectomy for esophageal cancer with ASA I (Society of Anesthesiologists I) or II physical status were included. Smokers and patients who had known pulmonary and heart disease or those receiving sympathomimetic or corticosteroid therapy were excluded. Pre- and postoperative pulmonary function tests were done on the first day before the operation and on the third day after the operation, respectively.

Heart rate, invasive blood pressure, central venous pressure (CVP), peripheral blood oxygen saturation (SpO_2), and end expiratory carbondioxide pressure ($EtCO_2$) of patients were monitored by Millenia (Millenia, Orlando, USA). Anesthesia was induced with propofol 2 mg/kg^{-1} and 0.1 mg/kg^{-1} morphine. Patients were intubated after receiving 0.15 mg/kg^{-1} cisatracurium. Double lumen left endotracheal tube (Bronco-Cath™, 37CH, Mallinckrodt Medical, Athlone, Ireland) was inserted. Morphine 0.03 mg/kg^{-1} per one hour and cisatracurium 0.03 mg/kg^{-1} per 20 minutes were given intravenously. Anesthesia was maintained with sevoflurane 1-2% and oxygen-air mixture (2/4 L/min^{-1}). Controlled ventilation was performed in all patients and the ventilator was set to deliver 50% FiO_2, 10 mL/kg^{-1} tidal volume, 10 min^{-1} frequency, I:E 1:3, inspiratory pause 20% of inspiration and a constant inspiratory flow rate. Inspired oxygen content was 50% of oxygen-air mixture and fresh gas flow rate was 8 L/min^{-1}. Tidal volume was adjusted according to flow-time waveforms. Flow-time waveforms were observed during the operation to omit expiratory flow limitation and dynamic hyperinflation using ventilator monitor. Peak airway pressure was monitored constantly to limit the barotrauma, and changes were set to limit the peak pressures.

An internal jugular vein catheter was inserted in all patients. Fluid resuscitation was provided by adjusting central vein pressure 6 to 8 mmHg. We used a respiratory mechanics monitoring system (Ventrak, Model 1550, Respiratory Mechanics Monitoring System, Novametrics Medical Systems Inc. Wallingford, Connecticut, USA). The flow sensor of the monitor was inserted between the endotracheal tube and the Y piece of the respiratory circuit to measure respiratory resistance (Raw), dynamic compliance (Cdyn) and peak inspiratory airway pressure (PIP).

Measurements were recorded in five periods; 10 minutes after intubation (Intubation: T_1, control), 10 minutes after left lateral decubitus position (Left lateral: T_2), 10 minutes after single lung ventilation with left lateral decubitus position (Beginning of single-lung ventilation: T_3), 10 minutes before single lung ventilation ends (Single lung-end: T_4), 10 minutes after supine position (Supine: T_5). Arterial blood samples were taken at the time of respiratory mechanics recorded, and immediately analyzed via a blood gas analyzer (Ciba Corning 890, USA). Neuromuscular blockage was antagonized by 0.01 mg/kg^{-1} atropine and 0.02 mg/kg^{-1} neostigmine at the end of the operation.

During the post-intubation period (T_1, T_2) prior to surgical procedure, the patient was completely relaxed and unstimulated. To provide permanent relaxation during the procedure, an infusion of neuromuscular blocker was administered in strict time intervals in order to provide an optimal effect. Values were recorded at least 10 minutes after the position change. The anesthesiologist made sure that the patient was completely relaxed during this process.

Surgical technique

The patient was intubated with a double lumen tube for single lung ventilation and was positioned in the left lateral decubitus position. Four thoracic ports were inserted. The camera port (10 mm) was placed in the 7th intercostal space at the midaxillary line. A 5 mm port was placed in the eighth intercostal space 2 cm posterior to the posterior axillary line. There were also two 5 mm ports. Of these, one was placed posteriorly close to the tip of the scapula, while the other was placed in the 5th intercostal space at the anterior axillary line. Firstly, the inferior pulmonary ligament was divided and the right mediastinal pleura overlying the esophagus was opened by using ultrasonic coagulating shears (Harmonic ACETM, Ethicon Endo-surgery, Inc. Cincinnati, OH). Circumferential mobilization of the esophagus with surrounding lymph nodes and periesophageal tissue was performed from the diaphragmatic reflection up to the thoracic inlet.[9] The azygos vein was dissected and divided using endo GIA stapler with vascular cartridge (Endo GIA Universal Roticulator 45 2.5, Autosuture, Tyco Healthcare Group LP Boulder, CO). A 28 F chest tube was inserted through the camera port. Port sites were closed and the patient was turned to a supine position.

In the supine position, midline laparotomy was done. The stomach was mobilized by preserving the right gastroepiploic arcade. Lymph nodes lying around celiac and gastric vessels were dissected. The lesser curve fat and nodes were dissected en-bloc with the stomach. The gastric tube was constructed by dividing the stomach using a linear stapler. A 5 cm horizontal neck incision was done along the anterior border of the left sternocleidomastoid muscle and dissection proceeded in a conventional manner. The cervical esophagus was transected and 1-0 silk sutures were tied to the esophagus to help the gastric tube during traction through the mediastinum. The specimen was delivered from the abdominal incision. The stomach was pulled up through the mediastinum with the guidance of 1/0 silk sutures and esophago-gastrostomy was performed in the neck. Closed-suction drain was placed behind the anastomosis. Abdominal and cervical incisions were closed.

Statistical analysis

One way ANOVA test and Tukey for posthocs were used for the statistical analysis of the collected data. Continuous variables were represented as mean and standard deviation (SD) if they were in Gaussian distribution. P value <0.05 was considered as statistically significant. Post test was used only if *p* value was <0.05. Unpaired Student's t-test was used for the statistical analysis of the respiratory function tests. We determined the minimum patient number to be 8 with α: 0.05 and β: 80% and 5 mmHg "difference" in $PaCO_2$ and with a SD of 4.9. Statistical evaluations were performed using standardized software (Statview, SAS Institute Inc, Cary, NC).

RESULTS

Mean operation time was 280 (240-320) minutes. An average of 1350 mL crystalloid and 250 mL colloidal fluid were administered with Central venous pressure maintained at a level of 6-8 mmHg.

Results of pre- and postoperative pulmonary function tests are given in Table 1. Respiratory function tests showed predicted (%) values. There was no statistical difference in the values of respiratory function tests.

Mean value of Cdyn decreased in the left lateral decubitus position (T_2) whereas it was more during single lung ventilation period (T_3, T_4; $p<0.05$). There was a significant decrease at supine position compared with the control (T_1; $p<0.05$). Mean values of Raw and PIP showed parallel changes at the different measurement periods (T_2, T_3, T_4, T_5; $p<0.05$; Table 2).

F values were determined as 4.971, 1.52 and 2.307 for Cdyn, Raw and PIP, respectively. The mean value of $PaCO_2$ increased in left lateral decubitus position and reached the maximum level at the end of single lung ventilation period (T_4) and stayed higher at supine position (T_5) compared to the control (T_1; $p<0.05$). Mean values of PaO_2, pH, HCO_3^- were significantly lower in the periods of T_2, T_3, T_4, T_5 compared to the control (T_1; $p<0.05$).

DISCUSSION

Esophagectomy is a complex surgical procedure which is associated with particularly high mortality and morbidity rates. With advanced technology and increasing experience with laparoscopic and

Table 1. Results of the pre- and postoperative respiratory function tests (mean ± standard deviation)

	Preoperative measure	Postoperative measure
FVC predicted (%)	93.4±11.5	90.3±11.5
FEV1 predicted (%)	92.7±12.1	88.1±11.0
FEV1/FVC (%)	101.2±9.1	96.5±6.7
FEF 25-75 (%)	82.0±24.0	77.5±22.7
PEF predicted (%)	89.3±14.6	84.1±17.3

Preoperative measure: One day before of operation; Postoperative measure: After 3rd day of operation; FVC: Forced vital capacity; FEV1: Forced expiratory volume at first second; FEF: Forced expiratory flow; PEF: Peak expiratory flow.

Table 2. Values of the respiratory mechanics and blood gases (mean ± standard deviation)

Period	Intubation (T_1)	Left lateral (T_2)	Single lung-beginning (T_3)	Single lung-end (T_4)	Supine (T_5)
CDYN (mL cm H_2O^{-1})	66±12	53±8*	49±8*	48±8*	52±11*
RAW (cm H_2O L^{-1} sn^{-1})	12±5	15±5*	17±5*	18±5*	16±4*
PIP (mmHg)	16±6	21±5*	23±6*	20±4*	21±3*
Ph	7.38±0.06	7.36±0.05*	7.35±0.05*	7.34±0.04*	7.35±0.04*
$PaCO_2$ (mmHg)	34±5	40±5*	38±7*	43±5*	39±6*
HCO_3^- (mmol L^{-1})	27±9	24±3*	23±5*	22±6*	21±5*
PaO_2 (mmHg)	130±37	115±35*	105±20*	102±28*	121±3*

CDYN: Dynamic compliance; RAW: Airway resistance; PIP: Peak inspiratory pressure; $PaCO_2$: Partial carbon dioxide pressura; PaO_2: Partial oxygen pressura; HCO_3^- : Bicarbonate; *$p<0.05$ compared with intubation period (T_1).

thoracoscopic techniques, minimally invasive approaches such as VAT-esophagectomy procedure have been explored to determine feasibility, results and potential advantages.[9-11] Reports investigating the effects of VAT-esophagectomy on respiratory mechanics are limited. This study aimed to investigate the effects of patient positioning on the respiratory mechanics and blood gases during VAT-esophagectomy.

Respiratory system complications are the most frequent complications in a conventional open esophagectomy procedure.[3,12] The impact of video-endoscopic procedures on the respiratory mechanics was reported to be minimal.[5-8] There are also papers comparing the effects of thoracotomy and thoracoscopy on respiratory functions and pulmonary complications which support the benefits of VAT-esophagectomy.[13,14] Besides these, respiratory complications are still the main cause of operative morbidity for VAT-esophagectomy protocols. The causes of this negative effect may be the single lung ventilation during the procedure, location of the operative field with adjacent neighbours (heart and lung), mediastinal shift, difficulty of surgical access and relatively longer operation time.[12] The onset of single-lung ventilation is characterized by the development of a significant intrapulmonary shunt through the collapsed lung with the potential for intraoperative hypoxemia. The dependent lung is subjected to the gravitational effects of lateral positioning and surgical compression with the resultant atelectasis further contributing to the magnitude of the shunt during lung isolation. During single-lung ventilation, the dependent lung is susceptible not only to significant atelectasis but also to increased airway pressures.[15]

We found that the values of compliance decreased, while airway resistance and peak inspiratory pressure increased during the left lateral decubitus position and single-lung ventilation compared with those of the control period. These changes persisted even when the patient was turned to the supine position for laparotomy. The values of arterial blood gases were also affected during the procedure.

Oikkonen and Tallgren[16] have studied respiratory mechanics in laparoscopic cholecystectomy (n=20), laparoscopic esophageal hernia (n=8) and laparoscopic inguinal hernia (n=4). They showed that the lung compliance was reduced approximately 20% at Fowler position, the reduction was increased to 40% at Trendelenburg position after pneumoperitoneum. In our study, dynamic compliance decreased to 19% in the position of left lateral decubitus (T_2) and decreased to 27% at the end of the single lung ventilation period (T_4) compared with the control (T_1). The patients in this study did not undergo laparoscopy, but they all underwent thoracoscopic esophageal dissection. We studied respiratory mechanics in VAT-esophagectomy without using CO_2 insufflation.

It has been shown in many studies that the blood gas values change in video-endoscopic operations.[17-19] Similar to these studies, we found a significant difference in blood gas values between the periods of different positions ($p<0.05$). The values of $PaCO_2$ increased and pH values decreased after the intubation period. Single lung ventilation was also another negative factor for the deterioration of respiratory mechanics. When the patients were turned to a supine position, values of respiratory mechanics and arterial blood gases improved. We also found that Cdyn value was 52 mL.cmH_2O^{-1} in the supine position which was still significantly lower than that of intubation (control). The results were also similar to the previously reported studies,[1,19,20] To determine baseline values of respiratory mechanics during VAT-esophagectomy we excluded the patients who had comorbid factors. In patients with esophageal cancer, this was not rare, although it helps to minimize variability in the data and make the population as homogeneous as possible. This study aimed to assess the impact of VAT-esophagectomy on respiratory mechanics and oxygenation during. However, postoperative respiratory complications related to the perioperative respiratory mechanics need to be investigated. This is one of the limitations of our study.

Another limitation of this study is the lack of a control group which includes the patients who underwent thoracotomy. The effects of VAT-esophagectomy could have been easily compared if there was a thoracotomy group.

There were no pulmonary complications such as pneumothorax, atelectasis, effusion or pneumonia etc. in this study, but pulmonary function tests were affected after the operation, compared with the preoperative values. Because this study was not a randomized trial, we can only assume that the possibility is due to the minimally invasive part of VAT-esophagectomy or due to the physical status (ASA I and II) of the patients included to the study.

In conclusion, despite the advances in operative techniques, pulmonary complications continue to be problematic and minimally invasive surgery has not eliminated this risk. Causes of this problem can be explained with the effects of single-lung ventilation, mediastinal shift and relatively longer operation times. Respiratory mechanics and blood gases are affected in VAT-esophagectomy in this study, even without CO_2 insufflation. To improve the respiratory mechanics during the procedure it is necessary to take preventive actions other than applying the position. Applying positive end expiratory pressure and respiratory maneuvers like "recruitment", shortening the operation duration as much as possible, and limiting the applied pressure may be the preventive actions. Randomized controlled trials are needed to determine the effects of VAT-esophagectomy on the respiratory system compared with open esophagectomy.

Declaration of conflicting interests

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