The effects of humidified ventilation on arterial oxygenation and respiratory mechanics during one-lung ventilation: a randomized controlled study

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The effects of humidified ventilation on arterial oxygenation and respiratory mechanics during one-lung ventilation: a randomized controlled study

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ABSTRACT

The effects of humidified ventilation on arterial oxygenation and respiratory mechanics during one-lung ventilation: a randomized controlled study

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Introduction: We compared the effect of heated humidifier (HH) and heat and moisture exchanger (HME) on intra-pulmonary shunt, oxygenation and respiratory mechanics during one-lung ventilation (OLV).

Methods: Sixty-two patients undergoing lobectomy of the lung were randomly applied of heated humidifier (HH group) or heat and moisture exchanger (HME group) during OLV. Arterial and central venous blood gas analyses and respiratory variables were recorded 10 minutes after two-lung ventilation (TLV) in the lateral decubitus position ($TLV_{baseline}$), at 30 minutes (OLV_{30}), 60 minutes (OLV_{60}) during OLV.

Result: PaO_2 is higher in the HH group than in the HME group. However, there was no statistically significant difference between the two groups. In addition, intra-pulmonary shunt (Qs/Qt) increased significantly in group HME compared with $TLV_{baseline}$ during OLV. However, Qs/Qt in group HH did not increase compared with $TLV_{baseline}$ during OLV. There was no significant difference of Qs/Qt between the two groups during OLV. During OLV, HH group demonstrated lower peak airway pressure (P_{peak}), plateau airway pressure (P_{plat}) and mean airway pressure (P_{mean})

with higher dynamic compliance (C_{dyn}) compared with HME group. There were no significant differences in hemodynamic variables measured throughout the study period.
Conclusion: Although HH did not result in substantial improvement in oxygenation, HH affected respiratory mechanics by reducing airway pressure and by improving lung compliance during OLV in the lateral decubitus position.

Key words: one-lung ventilation, heated humidifier, heat and moisture exchanger, oxygenation, respiratory mechanics

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I. INTRODUCTION

One-lung ventilation(OLV) is used widely in thoracic surgery because of the advantage of making clear the operation sight at operating lung part or preventing blood and secretion overflow to normal lung. However, 20% of patients who had surgical operations with OLV demonstrate heavy hypoxemia.[1] Intra-pulmonary shunt and imbalance of ventilation-perfusion caused by deoxygenated blood passing through unventilated lung during OLV results in decreased PaO_2.[2] During one-lung anesthesia, PaO_2 is affected by hypoxic pulmonary vasoconstriction (HPV). HPV decrease the rate of intra-pulmonary shunt (Qs/Qt) removing pulmonary blood flow from the unventilated lung to the ventilated lung. It is the key defense mechanism that prevents imbalance of ventilation-perfusion.[3]

It could help maintain PaO_2 level and reduce the frequency of heavy hypoxemia if the response to HPV is well maintained or increased during anesthesia managing the patient who has surgical operations with OLV.[4] This hypoxic pulmonary vasoconstriction response is affected by not only the basic diseases of the patient but also the physique of the patient, anesthetic drugs, vasodilator and method of ventilation.[3]

The upper airway of adult in normal condition makes the air that inhale 7000-10000L per a day heated as well as doing humidification and adding moisture of 1L to filtered breathing.[5] However, if the upper airway is detoured by endotracheal intubation, the air is heated as well as doing humidification unless heat or doing humidification beforehand and the 10% of basal metabolic rate is consumed in this process. Continuous inhalation of cold and dry air causes disorder of ciliary movement in the bronchus and produces drying up of secretions that are not discharged which leads to not only ventilatory disorder but also small air blockage. Consequently, the rate of atelectasis and pneumonia increases as the bronchus become narrow.[5]

Therefore, in case of long ICU stays, there are many uses of humidification to the breathing circuit using a humidifying device. Currently utilized humidifying devices during general anesthesia under mechanical ventilation include traditionally used heated humidifier (HH), heat and moisture exchanger (HME). The use of HME is increasing in trend due to current simplicity of usage and price efficiency. HH heats and humidifies the breathing circuits artificially. In comparison, HME is a remarkable device that has a function that defends the spread of germs and viruses, although it is inferior in preserving heat and moisture.[6]

Mechanical ventilated using humidifying devices, blockage by secretions in the endotracheal tube reduced remarkably,[6] reduces airway dead space from the acute respiratory distress syndrome patient so that it is known as reducing $PaCO_2$.[7] Furthermore, it is reported that in case of non-invasive ventilation and continuous positive airway pressure application, hyper-responsiveness of the bronchus is reduced by adding moisture to inhaled air and thus reduces consequent risk of atelectasis.[8]

Therefore humidification of breathing circuits using humidifying devices is anticipated to reduce imbalance of ventilation-perfusion that is possibly caused during OLV leading to improvement of oxygenation. Yet, there are no studies regarding the effect of humidification of breathing circuits to hypoxic pulmonary vasoconstriction response during OLV.

Accordingly, patients were divided into the group with heated humidifier and the group with heat and moisture exchanger as comparison groups. The aim of our study was to investigate the effect of humidified breathing circuits using humidifying devices on intra-pulmonary shunt, pulmonary oxygenation and respiratory mechanics during OLV.

II. MATERIALS AND METHODS

After written informed consent was obtained from all participants, 62 patients aged 30–79 years with American Society of Anesthesiologists physical status I and II scheduled for lobectomy of the lung requiring OLV under general anesthesia were enrolled in this study. Patients with a history of coronary artery occlusive disease, chronic obstructive or restrictive pulmonary disease, cerebrovascular disease, renal insufficiency, heavy smoking or obesity (body mass index >30 kg/m2) were excluded. All patients underwent preoperative lung spirometry. Patients with less than 60% of the predicted value forced expiratory volume in one second, forced vital capacity and diffusion capacity of carbon monoxide were also excluded.

This randomized controlled trial was conducted at the operation center of Severance Hospital in Seoul, Korea, from June to December 2011. Patients were randomly assigned to one of the two groups according to a computer-generated random numbers table. Patients received either a HH group (Fisher & Paykel RT Breathing Circuit ™, Fisher & Paykel Healthcare Ltd., UK) or HME group (Hygrobac ™, Tyco Healthcare, Italy) during OLV.

Standard monitoring devices were applied upon arrival at the operating room. Anesthesia was induced with 1.5 mg/kg propofol and 1.0 μg/kg remifentanil. Tracheal intubation with a left-sided double-lumen tube (Broncho-Cath®;

Mallinckrodt Medical Inc., Athlone, Ireland) was facilitated with 0.9 mg/kg rocuronium and the position of the double-lumen tube was confirmed with a fibroptic bronchoscope before and after turning the patient to the lateral decubitus position. After induction of anesthesia, a 20-gauge radial artery catheter was placed and a 7-Fr central venous catheter (Arrow International, Reading, PA, USA) was inserted via the right internal jugular vein. The central venous catheter length to be inserted was calculated using a height-based formula for its constant placement near the right atrium. The placement of the tip of the central venous catheter was confirmed by portable chest X-ray. Anesthesia was maintained with 1.0–2.0% sevoflurane and 0.1–0.3 μg/ kg/min remifentanil.

The lungs of all patients were initially ventilated with a constant-flow volume-controlled ventilation (VCV) mode (Zeus ventilator, Dräger Medical, Lübeck, Germany) with a tidal volume of 8 ml/kg. The respiratory rate was adjusted to maintain an end-tidal CO_2 tension ($PE'CO_2$) of 38 ± 2 mmHg. All patients were turned to the lateral decubitus position and two-lung ventilation (TLV) was conducted for 10 minutes before OLV. The ventilator settings were the same for TLV and OLV. All measurements were performed with the patient in the lateral decubitus position. Hemodynamic variables, respiratory variables, and arterial and central venous blood gas analyses were recorded at three time points: 10 minutes after placing the patient in the lateral decubitus position under TLV before OLV ($TLV_{baseline}$), 30 minutes after initiation of OLV (OLV_{30}), 60 minutes after initiation of OLV (OLV_{60}).

Hemodynamic measurements included heart rate, mean arterial pressure and central venous pressure. Respiratory variables included peak airway pressure (P_{peak}), plateau airway pressure (P_{plat}), mean airway pressure (P_{mean}) and dynamic compliance (C_{dyn}). $PE'CO_2$ was measured by capnography implemented in the ventilator. The oxygen content (CxO_2) in arterial and central venous blood was calculated using the following equation: $CxO_2=(1.3xHbxSxO_2)+(0.0031xPxO_2)$, in which Hb=hemoglobin concentration (g/dl) and SxO_2=oxygen saturation. The alveolar-arterial O_2 gradient ($A\text{-}aO_2$) was calculated as the difference between alveolar oxygen tension (PAO_2) and arterial oxygen tension (PaO_2). Qs/Qt was determined using the following formula: $Qs/Qt=(CcO_2–CaO_2)/(CcO2–CvO_2)$, where CcO_2=calculated capillary O_2 content, assuming that the pulmonary capillary O_2 partial pressure is equal to PAO_2 and the central venous oxygen saturation ($ScvO_2$) is equal to the mixed venous oxygen saturation (SvO_2).[13] Physiological dead space (Vd/Vt) was calculated according to the Hardman and Aitkenhead equation: $Vd/Vt =1.14\times(PaCO_2–PE'CO_2)/PaCO_2–0.005$.[14] Arterial and central venous blood samples were analyzed using an automated blood gas analyzer (Stat Profile® CCX, Nova Biomedical, MA, USA). This study was designed to be terminated if mean arterial pressure decreased more than 20% relative to the post-induction value, requiring administration of vasoactive drugs, or if SpO_2 as measured by pulse oximetry declined to less than 90%, or if PaO_2 decreased to less than 80 mm Hg during OLV.

Statistical analyses were performed with the Statistical Package for the Social Sciences 17.0 (SPSS Inc, Chicago, IL, USA). All data are expressed as mean ± standard deviation or the number of patients. For inter-group comparisons, Chi-square test or Fisher’s exact test and independent t-test were used. For intra-group comparisons, repeated measures ANOVA with Bonferroni correction were used. A p-value <0.05 was considered statistically significant.

III. RESULTS

Physical characteristics, results of the preoperative pulmonary function studies and surgical data of the 62 patients enrolled in the study (31 in group HME and 31 in group HH) are presented in Table 1. There were no statistically significant differences between the two groups. None of the patients developed life-threatening hypoxemia or hypotension during OLV and the study was successfully completed in all patients.

Table 1. Patient characteristics, results of preoperative pulmonary function studies and surgical data

	Group HME (n=31)	Group HH (n=31)	*P* value
Age, years	60.0 (25-80)	62.0 (42-78)	0.457
Male/Female	15/17	15/16	0.906
Height, cm	160.2 (9.1)	160.6 (7.9)	0.873
Weight, kg	63.2 (10.4)	59.3 (8.0)	0.107
Body mass index, Kg/m2	24.5 (2.9)	23.1 (3.0)	0.055
FEV_1, %	99.0 (21.1)	98.5 (18.4)	0.933
FVC, %	95.9 (12.8)	96.6 (13.1)	0.829
FEV_1/FVC, %	76.7 (7.4)	73.2 (9.6)	0.117
Hemoglobin, g/dl	11.9 (1.3)	12.0 (1.1)	0.678
OLV time, min	135.3 (110.3)	134.1 (37.8)	0.955

Values are mean (range), mean (standard deviation) or number. FEV_1=forced expiratory volume in one second, FVC=forced vital capacity, DLCO=diffusion capacity of lung for carbon monoxide, OLV=one-lung ventilation

The arterial and venous blood gas data at each point of time and changes in pH, PaO_2, $PaCO_2$, and Qs/Qt are shown in Table 2. There were no significant differences in pH, $PaCO_2$, Qs/Qt and estimated Vd/Vt between the two groups during TLV and OLV. Compared with $TLV_{baseline}$, both groups were associated with a significant decrease in PaO_2 at OLV_{30} and OLV_{60} (Fig. 1). PaO_2 is higher in the HH group than in the HME group. However, there was no statistically significant difference between the two groups.

In addition, Qs/Qt increased significantly in group HME compared with $TLV_{baseline}$ during OLV (Fig. 1). However, Qs/Qt in group HH did not increase compared with $TLV_{baseline}$ during OLV. There was no significant difference of Qs/Qt between the two groups during OLV.

Table 2. Arterial and venous blood gas analysis data.

	$TLV_{baseline}$		OLV_{30}		OLV_{60}	
	HME	HH	HME	HH	HME	HH
pH	7.42 (0.04)	7.42 (0.03)	7.41 (0.04)	7.41 (0.03)	7.40 (0.04)	7.41 (0.03)
PaO_2 (mm Hg)	395.0(65.8)	404.8 (100.9)	192.4 (67.0)*	226.0(75.0)*	224.9(77.5)*	252.4 (86.6)*
$PaCO_2$ (mm Hg)	37.1 (4.8)	37.7(4.4)	39.5 (5.5)	38.7 (5.3)	40.1 (4.3)*	39.1 (5.7)
Qs/Qt (%)	19.5 (7.7)	19.0 (9.4)	26.7 (8.0)*	23.4 (8.8)	25.0 (6.9)*	22.0 (8.6)
Estimated Vd/Vt (%)	6.3 (14.6)	8.0 (12.4)	11.5 (12.9)	10.6 (12.6)	14.2 (7.5)*	9.6 (11.9)

PaO_2, arterial oxygen tension; $PaCO_2$, arterial carbon dioxide tension; Qs/Qt, intrapulmonary shunt fraction(assuming that central venous oxygen saturation is equal to mixed venous oxygen saturation); Vd/Vt, physiological dead space (estimated according to the Hardman and Aitkenhead equation). $TLV_{baseline}$, 10 min after TLV in lateral decubitus position; OLV_{30}, after 30 min of OLV; OLV_{60}, after 60 min of OLV.

* $p < 0.05$ vs. $TLV_{baseline}$ in each group

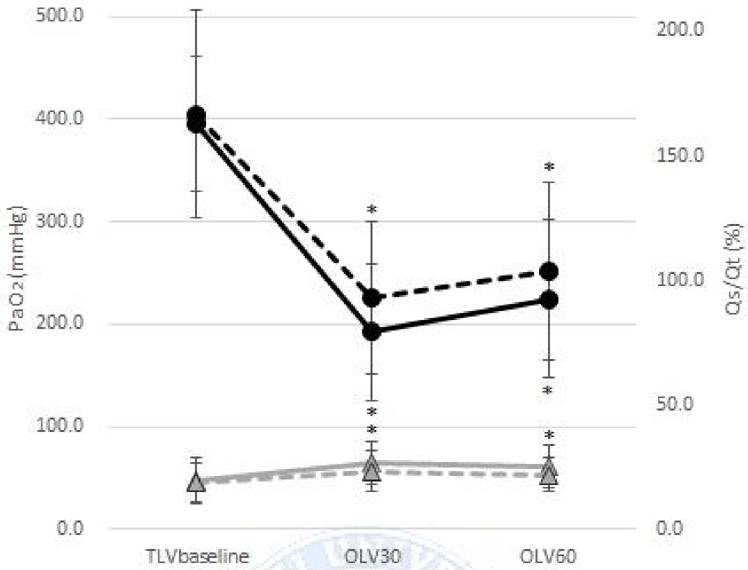

Figure 1. Changes in arterial oxygen tension (PaO_2, *black line with circle*) and intrapulmonary shunt fraction (Qs/Qt, *gray line with triangle*). Changes were measured under TLV before OLV ($TLV_{baseline}$), 30 minutes after initiation of OLV (OLV_{30}), and 60 minutes after initiation of OLV (OLV_{60}) between group HME (*solid line*) and group HH (*dashed line*). * $P < 0.05$ compared with $TLV_{baseline}$.

Respiratory mechanics and hemodynamic data at each point of time and alterations in airway pressures and dynamic compliance are shown in Table 3. Compared with $TLV_{baseline}$, both groups were associated with a significant increase in P_{peak}, P_{plat}, P_{mean} and a significant decrease in C_{dyn} at OLV_{30} and OLV_{60}. During OLV, airway pressure (P_{peak}, P_{plat}, and P_{mean}) were significantly lower in HH group than in HME group (Fig. 2). Also, C_{dyn} was significantly higher in the HH group than in the HME group (Fig. 3). There were no significant differences between the two groups in terms of respiratory rate and hemodynamic variables measured throughout the study period.

Table 3. Respiratory mechanics and hemodynamic data.

	$TLV_{baseline}$		OLV_{30}		OLV_{60}	
	HME	HH	HME	HH	HME	HH
RR (breaths min^{-1})	9.8 (1.4)	9.6 (1.4)	9.8 (1.4)	9.3 (1.3)	10.1 (1.4)	9.4 (1.4)
P_{peak} (cm H_2O)	14.4 (2.5)	13.0 (3.0)	23.7 (3.9)*	20.8 (5.8)*†	24.1 (4.7)*	20.9 (5.6)*†
P_{plat} (cm H_2O)	13.8 (2.4)	12.2 (3.5) †	21.5 (3.5)*	18.9 (5.5)*†	21.6 (4.0)*	18.8 (5.3)*†
P_{mean} (cm H_2O)	4.2 (1.6)	3.4 (0.9)	6.3 (1.6)*	5.2 (1.0)*†	6.2 (1.9)*	5.2 (1.2)*†
C_{dyn} (ml cm H_2O^{-1})	37.5 (9.5)	43.3 (8.5)	25.0 (6.1)*	30.8 (8.0)*†	25.8 (5.7)*	30.5 (8.0)* †
HR (beats min^{-1})	67.5 (10.6)	67.3 (12.3)	75.2 (11.8)*	71.5 (11.0)	76.8 (10.1)*	74.5 (11.8)*
MAP (mm Hg)	84.1 (10.4)	85.5 (14.1)	82.7 (11.4)	85.8 (10.5)	81.1 (13.8)	87.1 (8.7)
CVP (mm Hg)	7.8 (3.4)	8.6 (2.6)	9.4 (3.7)	9.5 (2.7)	8.6 (2.8)	9.2 (3.0)

RR, respiratory rate; P_{peak}, peak airway pressure; P_{plat}, plateau airway pressure; P_{mean}, mean airway pressure; C_{dyn}, dynamic compliance; HR, heart rate; MAP, mean arterial pressure; CVP, central venous pressure. $TLV_{baseline}$, 10 min after TLV in the lateral decubitus position; OLV_{30}, after 30 min of OLV; OLV_{60}, after 60 min of OLV.

* $p < 0.05$ vs. $TLV_{baseline}$ in each group ; † $p < 0.05$ vs. HME

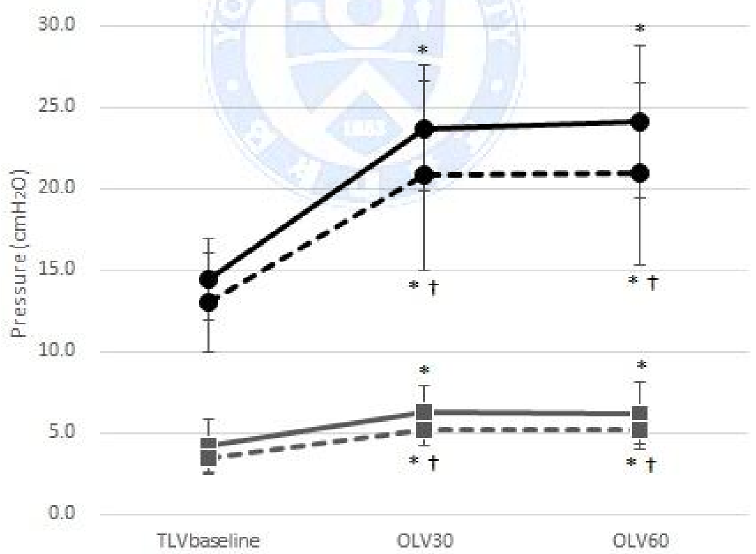

Figure 2. Changes in peak (*black line with circle*), mean airway pressure (*dark gray line with square*) between group HME (*solid line*) and group HH (*dashed line*). Measured times ($TLV_{baseline}$, OLV_{30}, and OLV_{60}) are the same as for Figure 1. * $P < 0.05$ compared with $TLV_{baseline}$, † $P < 0.05$ compared with HME.

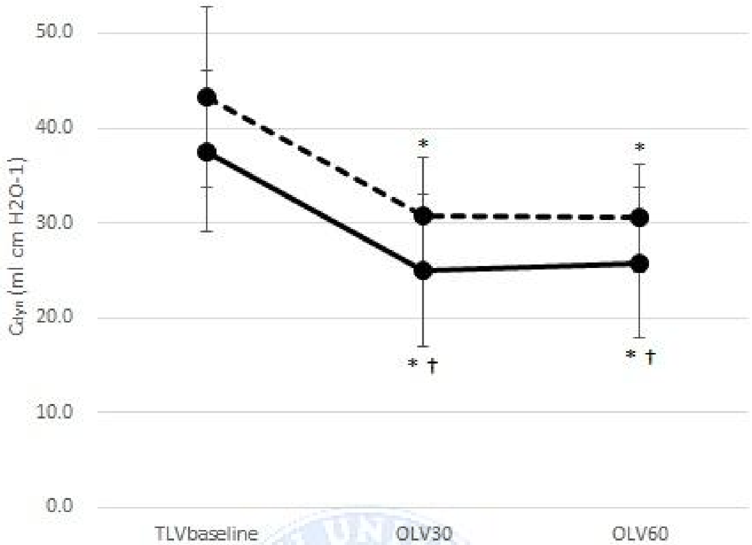

Figure 3. Changes in dynamic compliance (C_{dyn}) between group HME (*solid line*) and group HH (*dashed line*). Measured times ($TLV_{baseline}$, OLV_{30}, and OLV_{60}) are the same as for Figure 1. * $P < 0.05$ compared with $TLV_{baseline}$, † $P < 0.05$ compared with HME.

IV. DISCUSSION

The present study investigated alterations in oxygenation and respiratory mechanics during OLV according to different humidification methods. Oxygenation did not differ between group HH and group HME. However, HH group showed advantage of respiratory mechanics by a decrease of airway pressure and a increase of lung compliance.

Accordingly in previous studies, when the double-lumen tube was well-positioned, OLV resulted in an approximately 55% increase in P_{peak} and a 41% increase in P_{plat} compared with TLV.[15] The increase in P_{peak} may be a sign of conditions associated with increased endotracheal tube resistance, decreased compliance and increased flow resistance.[15] Although P_{peak} does not reflect peak alveolar pressure,[15,16] clinically high P_{peak} may contribute to hyperinflation injury of the ventilated lung during OLV.[21] P_{plat} reflects small airways and alveolar pressure, and there is a significant correlation between P_{plat} and mechanical ventilation-induced barotrauma.[15]

The compliance of the dependent lung is decreased by a reduction in chest wall compliance, lung compression due to gravitational effects, surgical stimuli and high airway pressure in the lateral decubitus position during OLV. For these reasons, atelectasis and alveolar collapse may readily occur in a dependent lung.[16] Inhalation of dry gas results in micro atelectasis from obstruction of small airways and reduced surfactant secretions leading to reduced lung compliance.[22] This may result in greater work of breathing.

During OLV, airway pressure (P_{peak}, P_{plat}, and P_{mean}) was significantly lower in HH group than in HME group. In addition, C_{dyn} was significantly higher in HH group than in HME group. Therefore, considerable advantages have been observed with HH compared to HME. This simple ventilatory strategy effectively increased P_{peak}, P_{plat} and C_{dyn} and improved the efficiency of alveolar ventilation during OLV. Accordingly in previous studies, HME have the lowest volume and lowest resistance.[23] The resistance of HME does not demonstrate notable increase after 24h of clinical use.[27] However, airway pressure (P_{peak}, P_{plat}, and P_{mean}) increased significantly in HME group during OLV. The pure humidifying function is compatible with just a moderate increase in apparatus dead space and resistance. On the contrary, the combination of a filtering function with humidifying function may critically increase the volume and the resistance.[23] Therefore HME have been associated with greater dead space, resistance, and possibly CO_2 retention.[23] Occlusive pressure was significantly higher with HME than with HH.[22,23,24]

However, as HH is more expensive compared to HME[26], physicians should take into account the physical characteristics as well as the temperature and moisture in OLV when choosing between available humidification devices.

This study has several limitations. First, this study was conducted in patients with normal preoperative pulmonary function. None of the patients included in the study had any significant airflow obstruction preoperatively that would increase the risk of air trapping during OLV. Also, patients were ventilated with 100% oxygen without the application of extrinsic PEEP. Second, we calculated the intrapulmonary shunt fraction based on $ScvO_2$, not SvO_2, and did not measure cardiac output since patients included in the study had normal cardiac function and did not require a pulmonary artery catheter. Third, the amount of intrinsic positive end-expiratory pressure by airway occlusion technique was not measured during surgery.[25] Fourth, due to the short operation time, there was no significant difference on intra-pulmonary shunt and oxygenation during OLV. Further, study is necessary regarding alterations in oxygenation during OLV.

V. CONCLUSION

This study demonstrates that HH is beneficial regarding oxygenation and respiratory mechanics during OLV compared with HME. During OLV, patients may have higher work of breathing with HME in comparison with HH. HH reduces peak airway pressure, plateau airway pressure and mean airway pressure, and improves dynamic compliance. HH increases without significant hemodynamic changes during OLV in the lateral decubitus position, although it did not result in substantial improvement in oxygenation. These results may be useful to choose the type of humidification device during OLV.

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ABSTRACT(IN KOREAN)

일측 폐환기 시 가습이 동맥혈 산소화와 호흡역학에 미치는 영향

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서론: 일측 폐환기시 heated humidifiers(HHs)와 heat and moisture exchanger(HME)가 폐 내 단락(Qs/Qt)과 산소화, 호흡 역학에 미치는 영향을 알아보고자 한다.

방법: 일측 폐환기로 폐엽절제술을 받는 62명의 환자에서 무작위로 heated humidifier(HH group)와 heat and moisture exchanger(HME group)으로 나누어 연구하였다. 동맥혈 가스분석법과 정맥혈 가스분석법, 호흡변수들을 분석하여 옆으로 누운 자세에서 양측 폐환기 10분 후와 일측 폐환기 30분 후, 일측 폐환기 60분 후를 기록하였다.

결과: PaO_2 평균값은 HME group 보다 HH group 에서 높은 값을 보였으나, 두 군 사이에 통계적으로 유의한 차이는 없었다. 또한 Qs/Qt 값은 양측 폐환기 10분 후와 비교했을 때 일측 폐환기시 HME group 에서 통계적으로 유의하게 증가하는 양상을 보였으나, 일측 폐환기시 HME group 과 HH group 두 군 사이에서는 통계적으로 유의한 차이는 없었다. 일측 폐환기시, HME group 과 비교하여 HH group 에서 peak airway pressure (P_{peak}), plateau airway pressure (P_{plat}) 와 mean airway pressure(P_{mean})에서 더 낮았고, dynamic compliance (C_{dyn})는 더

높았다. 이 연구에서 두 군간의 혈역학적인 통계학적 차이는 없었다. 결론: HME group 과 비교하여, HH group 에서 산소화의 현저한 향상은 보이지 않았으나, 호흡 역학적인 측면에서 airway pressure 는 감소하고, lung compliance 는 증가하였다. 이는 옆으로 누운 자세로 일측 폐환기를 시행할 때 HH 사용이 더 유용함을 보여준다.

핵심되는 말: 일측 폐환기, heated humidifier, heat and moisture exchanger, 산소화, 호흡 역학