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ORIGINAL ARTICLE

Smoking as a risk factor for intraoperative hypoxemia during one lung ventilation

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Abstract
Background Smoking is associated with many intra and postoperative events, especially respiratory complications. Hypoxemia and airway damage are found to aggravate any pre-existing respiratory pathology among smokers. One lung ventilation (OLV) carries a 4–10 % risk of development of hypoxia.
Aim The purpose of this study was to predict the incidence of hypoxemia for smokers during OLV for patients undergoing video-assisted thoracoscopic surgery (VATS).
Patients and methods Sixty patients undergoing VATS using OLV by double lumen tube were included in this pilot cross-sectional study. These patients were divided into 2 groups, group S which included 30 heavy smoker patients (smoking more than 20 cigarettes per day for more than 20 years) and group NS which included 30 non-smoker patients. Intra and postoperative arterial oxygen tension (PaO_2), arterial carbon dioxide tension ($PaCO_2$), and intraoperative peak airway pressure were compared between the 2 groups.
Results PaO_2 was significantly higher in the non-smoker group than in the smoker group, both at the start and end of OLV. It was 173 ± 68 mmHg for NS compared with 74 ± 10.8 mmHg for S at the start of OLV; at the end of OLV it was 410 ± 78 mmHg for the former and 360 ± 72 mmHg for the latter ($P < 0.05$).
Conclusion From this study it can be concluded that for heavy smoker patients there was a significant reduction in arterial oxygen tension (PaO_2) in comparison with non-smokers. However, hypoxemia reported for both groups was comparable.

Keywords Smoking · One-lung ventilation · Video assisted thoracoscopic surgery (VATS) · Hypoxemia

Introduction

It has long been understood that smoking may have a detrimental effect on oxygenation, particularly during OLV. However, by searching the literature, no study was found which investigated the effect of heavy smoking on oxygenation during OLV for patients with normal preoperative pulmonary function. Current heavy smoking has been found to be associated with some perioperative events, particularly respiratory complications [1]. It has also been found that there is a strong relationship between cigarette smoking and such respiratory diseases as bronchial asthma and chronic obstructive pulmonary disease (COPD) [2, 3]. Also, "the lung disease", an index used to evaluate respiratory function, is significantly higher for smokers than for non-smokers [4]. Cigarette smoking accelerates respiratory system damage and hypoxia, and increases airway resistance and reactivity, which might aggravate any preexisting respiratory disease or pathology [5].

Consequently, it had been recommended that smoking cessation would have a beneficial effect on reducing many postoperative complications [6–8].

One-lung ventilation (OLV) is often essential for non-cardiac thoracic intervention. Also, with the recent development of video-assisted thoracoscopic surgery

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(VATS), which has become widespread, and because of the increased experience of anesthesiologists in inserting and monitoring double lumen tubes (DLTs), OLV has become widely used [9]. However, during OLV there is a risk of hypoxemia with an SaO_2 (arterial hemoglobin saturation) of less than 90 %, which occurs in approximately 4 % of patients [10]. Other studies had revealed that the incidence of hypoxemia may reach 5–10 % [11–14]. Consequently, the development of hypoxemia during OLV might threaten patient safety and pose a major challenge to both anesthetist and surgeon. Therefore, prediction, prevention, and good treatment of hypoxemia during OLV is mandatory [9].

It has long been known that heavy smokers, even with preoperative normal pulmonary function, suffer from more severe hypoxia during OLV; as far as we are aware, however, no previous studies have investigated the tolerance of OLV by heavy smoker patients. The purpose of this study was to assess the effect of smoking on hypoxia during OLV, which is regarded as a critical period during thoracic anesthesia for patients undergoing VATS.

Materials and methods

Patient population

This prospective, cohort, clinical study was performed in the period between June 2010 and December 2011, at Saad Specialist Hospital, Saudi Arabia. After institutional approval and informed written consent, 60 ASA physical status II and III patients undergoing elective video assisted thoracoscopic surgery (VATS) in the lateral position, were enrolled in the study. These patients were divided into two groups, group S ($n = 30$) which included the heavy smokers (smoking more than 20 cigarettes per day for more than 20 years, a product of year and cigarette number of more than 400) and group NS ($n = 30$), which included the non-smoker patients. Patients in group S had been assessed in the pre-anesthesia clinic within less than 1 week preoperatively. All these patients were recommended to stop smoking to optimize their preoperative pulmonary conditions. So, it is supposed that stopping smoking was for a duration of no more than 1 week.

Included patients were those scheduled for pleural and mediastinal biopsy, pleurectomy, lung wedge resection, lung biopsy, and treatment of spontaneous pneumothorax (bullectomy).

Excluded patients were those with COPD, patients with less than 70 % of predicted forced expiratory volume in 1 s (FEV1), those with less than 80 % of predicted forced vital capacity (FVC) or those with arterial oxygen tension (PaO_2) less than 70 mmHg on room air. Also patients with asthma, recent chest infection, morbid obesity, and those with renal, hepatic, or ischemic heart disease were also excluded from the study.

Anesthetic management

All patients have been premedicated with 0.05 mg/kg midazolam, intravenously, in the holding area, after insertion of a 16-G peripheral venous cannula under local anesthesia. In the operating theater, routine monitoring included electrocardiogram, invasive arterial blood pressure monitoring through an arterial radial catheter for continuous arterial pressure monitoring and blood gas analysis (Siemens, Rapidpoint 405, Automatic QC cartridge, ref. 05293926, UK), pulse oximetry (Nellcor Oximax adult reusable finger sensor, Model DS-100 A Nellcor Durasensor, USA), and capnography.

A standard anesthetic technique for induction and maintenance of anesthesia, was used. General anesthesia was induced with propofol 1.5 mg/kg intravenously, fentanyl 2 μg/kg intravenously, and cisatracurium 0.15 mg/kg intravenously. Anesthesia was maintained with 2 % sevoflurane in oxygen 100 %. OLV was achieved by intubating the trachea and bronchus with a left-sided DLT. The exact size of the tube was chosen according to the patient's trachea measurement from the antero-posterior view of a recent chest X-ray [15]. However, this size may be varied on the basis of such criteria as a small air leak when the endobronchial cuff become deflated and when no air leak could be detected when the cuff became inflated with 3 ml air. Confirmation of correct placement of the tube was achieved by auscultating the chest and by fibreoptic bronchoscopy. After positioning the patient in the lateral position, the correct position of the tube was checked again. After confirmation of correct placement, the DLT was taped securely.

Ventilation of both lungs was achieved by use of a Dräger machine (Dräger, Zeus, ref. MK 03000-27, Germany); the pressure-controlled mode of ventilation was used. The inspiratory pressure and the respiratory rate were adjusted to maintain a $PaCO_2$ between 35 and 40 mmHg. Peak airway pressure (PAP) and inspiratory and expiratory volumes were monitored. OLV was initiated immediately before opening the pleura, according to the surgeon's instructions. Adequate OLV was assessed immediately after the pleura was opened and, to facilitate the lung collapse, the lung was suctioned through the fibreoptic scope. During OLV, ventilatory settings were adjusted to achieve a peak inspiratory pressure not exceeding 40 cm H_2O with an exhaled tidal volume of 6–8 ml/kg, respiratory rate 8–12/min, and *I*/*E* ratio 1/2.5. PEEP was instituted only with the development of hypoxia. Near the end of surgery and with the closure of the pleura, OLV was stopped, the deflated lung was suctioned and adequately

inflated together with deflation of the bronchial cuff. Initial ventilatory settings were then re-adjusted.

In cases of development of hypoxemia during OLV, when the SaO_2 was less than 90 % [9], measures were used to correct it. The first measure was applying a 5 cm H_2O positive end expiratory pressure (PEEP). The second measure was to stop OLV, start two-lung ventilation (TLV). In cases of persistent hypoxemia (persistent SaO_2 less than 90 % or PaO_2 less than 60 %) despite instituting PEEP, the patient was excluded from the study. If any of the above mentioned measures was used, serial blood gas analysis was performed to check for adequate oxygenation and ventilation. Routine assessment of blood gases, airway pressure, and oxygen saturation was conducted regularly, 10 min after induction of general anesthesia, 10 min after starting OLV, 10 min after finishing OLV, and after surgery, just before moving the patient to the intermediate care unit (IMC). Further assessments were made in cases of development of intractable hypoxemia during OLV. By the end of surgery, all patients were moved to the IMC, with postoperative oxygenation through an oxygen face mask at 5 l/min for 2 h postoperation.

Postoperative course

In the IMC, all patients arrived with face mask ventilation which was continued for approximately 2 h in the postoperative period. Routine monitoring continued in the postoperative period with ECG, pulse oximetry, and continuous arterial blood pressure monitoring. In addition, arterial blood gas samples were withdrawn to assess adequate oxygenation and ventilation. Another sample was withdrawn 6 h after in the IMC. However, in cases of development of any postoperative hemodynamic alteration or hypoxia, an additional arterial blood gas sample was withdrawn for further assessment. Also, in cases of development of resistant hypoxia, not responding for face mask ventilation, immediate endotracheal intubation and ventilation were performed, and such patients were excluded from the study. Postoperative pain was treated with patient-controlled analgesia (PCA; morphine) with a bolus dose of 5 mg followed by continuous infusion of 1 mg/h with a PCA bolus of 1 mg/injection and lockout period of 10 min.

Statistical methods

Results are reported as mean ± standard deviation (±SD), or frequency (number of cases), and percentages when appropriate. Comparison of numerical variables between the study groups was performed by use of the Student *t* test for independent samples for comparison of 2 groups when normally distributed, and the Mann–Whitney *U* test for independent samples when not normally distributed. For comparing categorical data, the chi-squared (χ^2) test was performed. The exact test was used instead when the expected frequency was less than 5. *P* values less than 0.05 was considered statistically significant. All statistical calculations were performed with the computer software SPSS (Statistical Package for the Social Sciences; SPSS, Chicago, IL, USA) version 15 for Microsoft Windows.

Results

Concerning demographic and preoperative data, there was no statistically significant difference between the 2 groups (Table 1).

During the OLV, there was a statistically significant difference between the 2 groups concerning the arterial oxygen tension (PaO_2) and arterial carbon dioxide tension (PCO_2). PAP was also statistically significantly different.

The significant difference between the 2 groups included the PaO_2 after the start and after the end of OLV. These were 173 ± 68 and 410 ± 78 mmHg, respectively, for the non-smoker group compared with 74 ± 10.8 and 360 ± 71 mmHg, respectively, for the smoker group ($P < 0.05$) (Table 2).

Arterial carbon dioxide tension was significantly higher in the smoker group. It was 48.1 ± 6 and 44.8 ± 5 mmHg, during and after OLV, respectively, in comparison with 41.9 ± 4 and 40.6 ± 4 mmHg, respectively, in the non-smoker group ($P < 0.05$) (Table 2).

PAP was also statistically significantly different between the groups. After the start of OLV it was 35.5 ± 4.51 cm H_2O in group S in comparison with 22.8 ± 1.67 cm H_2O in group NS. After the end of OLV this significant difference continued—PAP was 24.3 ± 1.83 cm H_2O in group S compared with 18.5 ± 1.22 cm H_2O in group NS ($P < 0.05$) (Table 2).

Table 1 Demographic and preoperative data

	Group S ($n = 30$)	Group NS ($n = 30$)	*P* value
Age (years)	59.8 ± 10	58.9 ± 10	0.729
Sex (M/F)	23/7	25/5	0.747
Weight (kg)	69.7 ± 10	72.6 ± 10	0.266
Height (cm)	167.8 ± 5.9	163.5 ± 5.4	0.326
FEV1 (%)	83.2 ± 23	89.2 ± 23	0.317
FVC (%)	90.1 ± 17	94.7 ± 18	0.313
PaO_2	82.5 ± 10	84.3 ± 11	0.510

Values are presented as mean ± SD

FEV1 forced expiratory volume in 1 s, *FVC* forced vital capacity, *PaO_2* arterial oxygen tension

Table 2 Intra and postoperative data

	Group S ($n = 30$)	Group NS ($n = 30$)	P value
PaO_2 (mmHg)			
After Induction	400 ± 75	420 ± 61	0.262
After start OLV	74 ± 10.8	173 ± 68[a]	<0.001
After end OLV	360 ± 72	410 ± 78[a]	0.012
End of surgery	385 ± 73	415 ± 67	0.103
Arrival in IMC	120 ± 67	136 ± 56	0.320
After 6 h in IMC	141 ± 62	160 ± 64	0.248
$PaCO_2$ (mmHg)			
After induction	35.7 ± 4	35.5 ± 4	0.847
After start OLV	48.1 ± 6	41.9 ± 4[a]	0.012
After end OLV	44.8 ± 5	40.6 ± 4[a]	0.016
End of surgery	39.8 ± 5	38.4 ± 4	0.236
Arrival in IMC	40.1 ± 5	39.9 ± 5	0.877
After 6 h in IMC	39.8 ± 4	38.8 ± 3	0.278
PAP (cm H_2O)			
After induction	18.3 ± 0.91	17.9 ± 0.72	0.064
After start OLV	35.5 ± 4.51	22.8 ± 1.67[a]	<0.001
After end OLV	24.3 ± 1.83	18.5 ± 1.22[a]	<0.001
End of surgery	20.2 ± 1.54	19.6 ± 0.86	0.068

Values are presented as mean ± SD

OLV one-lung ventilation, *IMC* intermediate care unit; PaO_2 arterial oxygen tension, *PaCO*$_2$ arterial carbon dioxide tension, *PAP* peak airway pressure

[a] Significant difference between the 2 groups

Table 3 Surgical procedures and postoperative course

	Group S ($n = 30$)	Group NS ($n = 30$)	P value
Duration of IMC stay (h)	18.7 ± 0.73	17.9 ± 0.86[a]	<0.001
Total hospital stay (days)	4.2 ± 0.56	3.9 ± 0.59[a]	0.048
Chest infection	3	1	0.605
Atelectasis	2	1	1.000
Surgical procedures			
Lung biopsy	7	6	1.000
Pleural biopsy	5	4	0.718
Pleurectomy	6	5	1.000
Bullectomy	4	6	0.729
Mediastinal biopsy	3	4	1.000
Lung wedge resection	5	5	0.729

Values are presented as mean ± SD

IMC intermediate care unit

[a] Significant difference between the 2 groups

Hypoxemia, i.e. PaO_2 less than 60 mmHg, developed in three patients in group S in comparison with only 1 patient in group NS. In group S, after fibreoptic examination after the development of hypoxemia, tube repositioning corrected this deterioration in oxygen saturation, in 1 patient only; 2 patients required PEEP of 10 cm H_2O. However, in group NS, the patient who developed hypoxemia, required only PEEP, without tube repositioning ($P > 0.05$).

As regards postoperative course, there was a significant difference between both groups concerning the duration of IMC stay and total hospital stay ($P < 0.05$) (Table 3).

Concerning the postoperative complications, no statistically significant difference between the 2 groups was detected (Table 3). There was no mortality and all screened patients continued the study with no exclusion.

Discussion

This study showed there was a statistically significant difference between the smoker and the non-smoker groups as regards arterial oxygen tension (PaO_2) and arterial carbon dioxide tension ($PaCO_2$) during OLV. Similarly, there was a significant difference between the two groups as regards PAP during the OLV. There was also a significant difference between the 2 groups as regards IMC and total hospital stays. However, no significant difference was detected between the 2 groups as regards postoperative complications.

Smoking had been implicated in many surgical complications, including surgical-site infection, death, and such pulmonary complications as postoperative pneumonia [1]. Not only that, it has also been stated that smoking is an important causal factor in development of COPD and has a deleterious effect on asthma [2, 3]. It has also been reported that smoking is the most important factor impairing pulmonary function [4].

In the study by Olea et al. [5], they concluded there is a strong association between cigarette smoking, chronic hypoxia, and the development of respiratory system damage. This is evident from increased airway resistance and increased bronchial wall thickness. Although this was an experimental study, its results were in accordance with ours—there was an increased airway resistance in the smoker group of patients during the OLV. Also, a study by Chang et al. [16] to evaluate the relationship between smoking and exacerbation of respiratory disease revealed a strong relationship between both of these, particularly for patients under aspirin treatment. This was also in agreement to our results—we observed increased airway pressure and reduction in PaO_2 among the smoker patients.

A relationship between cigarette smoking and inhibition of alveolar repair has been suggested by many investigators. In the study by Stephen et al. [17], they concluded that cigarette smoke resulted in occlusion of the small pores of Kohn; in most cases occlusion was by surfactant. The pores

of Kohn have also been found to be sites of tissue injury and repair. All these will result in emphysematous changes and the development of hypoxemia. However, enlargement of these pores had been suggested as a mechanism for the development of emphysema [18, 19].

A study by Masuko et al. [20] concluded that low FEV_1 might be a marker of a gradual drop in FEV_1 together with increased risk of lung diseases, for example asthma and COPD. It might be of great importance to recognize reduction in FEV_1 in intervention with both smokers and non-smokers. These results were in accordance to ours; although our smokers had a preoperative FEV_1 within normal levels, they developed intraoperative lower arterial oxygen tension (PaO_2) in comparison with non-smokers and raised PAP, indicating increased susceptibility to increased airway hyper reactivity among smoker patients.

Today OLV is becoming mandatory for all thoracic procedures, especially VATS, and because anesthetists' experience in the insertion and monitoring DLT is increasing, OLV is widely used to collapse the lung which is operated upon and to improve the surgery field [9]. Owing to the transpulmonary shunting which happens during OLV, there is a tendency toward impairment of oxygenation and occasionally hypoxemia [9].

Although some studies have reported that the incidence of hypoxemia during OLV is from 5 to 10 % [11–13], another more recent study [10], showed that the incidence might occur in only 4 % of patients. According to our results, the incidence of hypoxemia varied also within this range; however, the incidence was the maximum among the smoker patients (10 %) in contrast with only (4 %) among the non-smoker group.

DLT malpositioning can cause intraoperative hypoxemia during OLV, as was detected by fibreoptic bronchoscopy immediately after the development of hypoxia. This conclusion was reached in a study by Inoue et al. [21], who made this diagnosis after putting the patient with the DLT in the lateral position; during OLV this patient required more intervention to correct the hypoxia which developed. This was in agreement with our study, in which adjustment of the DLT position corrected the hypoxia which developed after OLV for one patient in the smoker group of the 3 who developed hypoxia. Although, in our study, there was no significant difference between the 2 groups regarding intraoperative hypoxia during OLV because of tube malpositioning, some studies have shown the importance of the design of airway devices to enable correct lung isolation, ventilation, and suction [22], and the availability of fibreoptic bronchoscopy to check the correct position of the DLT [23].

Concerning management of hypoxia during OLV, PEEP was effective in managing this complication for approximately 66 % of smoker patients and 100 % of non-smokers. This was also shown by Michelet et al. [24] who studied the importance of PEEP for oxygenation and respiratory mechanics during OLV. Moreover, studies have shown the importance of lung recruitment strategy during OLV [25, 26]. However, although this technique may be beneficial to the atelectatic lung, Kilpatrick et al. [27] concluded it may be harmful to patients with hyperinflated lung.

Although we used the strategy of high tidal volume (10–12 ml/kg) [28, 29] to reduce the likelihood of hypoxia during OLV, low arterial oxygen tension (PaO_2) was maximum among the smoker patients and minimum among the non-smokers. Although the large tidal volume will open the lung during the inspiration phase, and most of the expiration period, there may be a risk of acute lung injury for susceptible patients [30, 31]. Also, in the presence of airway obstruction, a large tidal volume carries the risk of intrinsic PEEP [32–34]. However oxygenation was no different between patients with large tidal volume without PEEP and those with small tidal volumes with PEEP; this was also proved in a study by Wrigge et al. [35].

Because it was proved in this study that low arterial oxygen tension is more prevalent during OLV among smokers than among non-smokers, we should predict the prevalence of this respiratory complication in the smoker population. In addition, because it was very clear there was a prevalence of high PAP among smokers rather than non-smokers, good and thorough improvement of preoperative lung function is mandatory. This can be readily achieved by proper physical therapy and drugs to produce good bronchodilatation and to soften bronchial secretions. A study by Warner et al. [36] proved the importance of such measures in reducing the incidence of postoperative complications. Moreover, cessation of preoperative smoking might be important in reducing the risk of intraoperative hypoxemia [7, 8].

The statistically significant reduction in arterial oxygen tension in group S compared with group NS suggests a decrease in the safety margin or an increase in the vulnerability to hypoxemia, especially in patients with compromised pulmonary function. However, further studies are needed to support this suggestion.

Limitations in this study were the limited number of patients, because the study was conducted as a pilot cross-sectional study. Therefore, other studies with a larger number of patients are needed for more in-depth evaluation of the detrimental effect of smoking during OLV. Furthermore, it would be better if smokers were categorized by carbon monoxide measurement. This was difficult in our study. Additionally, more risky patients as smokers with hyper reactive airways or those with COPD should be studied to obtain more data about the effects of smoking on oxygenation during OLV for such of patients. Also, study

of the effect of smoking during OLV in more complicated surgery, for example lobectomy or pneumonectomy, is recommended in the future. Our recommendations are to optimize respiratory condition by adequate respiratory therapy and cessation of smoking, which might be beneficial in reducing intraoperative hypoxia during OLV. This can be studied in the future by comparing smoker patients with other smokers who had stopped smoking for a short period of more than 2 weeks, and so had the possibility of improved respiratory airway condition during the preoperative period.

In conclusion, smoking carries more risk of intraoperative deterioration of arterial oxygen tension (PaO_2) in comparison with non-smokers during OLV for patients undergoing VATS. Prediction of such intraoperative respiratory complication should be considered for such patients.

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