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OBARA, HIDEFUMI

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HIGH FREQUENCY JET VENTILATION OF THE UPPER NONDEPENDENT LUNG DURING THORACIC SURGERY

HIDEFUMI OBARA, OSAMU TANAKA, YUKO HOSINO,
HIROSHI KAETSU, AND SEIZO IWAI

Department of Anesthesiology
Kobe University School of Medicine

INDEXING WORDS

one-lung ventilation; jet ventilation

SYNOPSIS

Recently, there has been a great deal of interest in high-frequency jet ventilation for thoracic surgery. According to previous studies, HFJV was delivered by an open system using a small tube. However, open system procedures run the risk of spreading blood and infected debris to the dependent lung. Therefore, we applied high frequency jet ventilation (HFJV) to the nonventilated, nondependent lung during one-lung ventilation using a double-lumen tube. We also investigated various other techniques such as increasing tidal volume, increasing the inspired oxygen concentration and insufflating continous oxygen with positive end-expiratory pressure (PEEP) in the nondependent lung. HFJV significantly improved arterial oxygenation, compared when the nondependent lung was opened to atmosphric pressure. Insufflation with oxygen at PEEP to the nondependent lung and ligation of the pulmonary artery as early as possible in the nondependent lung were also useful for improving arterial oxygeation during one-lung ventilation.

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Authors' names in Japanese : 尾原秀史　田中　修　星野裕子
悦　博　岩井誠三

INTRODUCTION

One-lung ventilation using an endobronchial tube during thoracic surgery is a beneficial procedure that provides good surgical exposure and prevents the contamination of the lower dependent lung by either secretions or blood, which might gravitate from the operated lung into the lower dependent lung. However, the disadvantage of this technique is that arterial hypoxemia can develop due to the increase in intrapulmonary shunt in the operated nondependent lung. To minimize arterial hypoxemia during one-lung ventilation, various techniques have been investigated; increasing tidal volume, applying positive end-expiratory pressure (PEEP) to the dependent or nondependent lung, and increasing the inspired oxygen concentration to the dependent lung, and occluding the pulmonary artery. Recently there has been a great deal of interest in high frequency jet ventilation (HFJV), which has been used successfully for thoracic surgery and other operations. In this study we examined the efficacy of HFJV of the nondependent lung in preventing arterial hypoxemia during one-lung ventilation.

MATERIALS AND METHODS

Forty-nine patients with lung cancer were studied; five underwent pneumonectomy and fourty-four lobectomy. They ranged in age from 47 to 77 years. All patients were premedicated with 0.5mg atropine and hydroxyzine hydrochloride (50 to 100mg) given intramuscularly. Anesthesia was induced with sodium thiopental (200 to 300mg), after which 1mg per kg of succinylcholine was given prior to intubation with a Carens or Robershow double-lumen tube. The correct position of the tube was confirmed by auscultation before and after placing the patients in the lateral position. Anesthesia was maintained with oxygen (50%) and 1% enflurane. Pancuronium bromide was used intermittently as needed for muscle relaxation. Ventilation was maintained with a Manley Servo-Ventilator at a constant rate (12-15/min) and constant tidal volume (10ml/kg) in both lungs during two-lung ventilation. Continuous oxygen insufflation and PEEP to the nondependent lung were provided by another anesthesia apparatus. To deliver PEEP to the dependent lung, the PEEP valve was placed on the circuit of the expiratory limb.

The patients were divided into six groups according to the procedure studied. After thoracotomy, two-lung ventilation (TLV) was done in the lateral position. Next, the upper nondependent lung was allowed to deflate by opening the lumen of the tube to the atmosphere, and the lower dependent lung was ventilated with a tidal volume of 10ml/kg body weight and at a rate of 12-15 breaths per minute. The inhalational oxygen concentration was kept at 50%.

In Group 1, the upper lung was deflated to atmospheric pressure and tidal volume in the lower lung was increased to more than 13ml/kg with zero end-expiratory pressure (ZEEP), while maintaining constant respiratory frequency. In Group 2, the oxygen concentration ventilating the dependent lung was increased to 100%, while maintaining constant respiratory frequency and tidal volume. In Group 3, the upper lung was insufflated with oxygen at 5L/min with 10 cmH_2O PEEP using an anesthesia apparatus and the dependent lung was ventilated with ZEEP. In Group 4, the nondependent lung was ventilated using a high frequency jet ventilator (Senko Corp., Osaka, Japan). The inspiratory gases mixed to the desired oxygen concentration by a N_2O-O_2 blender were delivered at a driving pressure of 15 to 20 psig and at a frequency of 7 to 9Hz. The injector circuit was connected to the end of the upper lung tube. The dependent lung was ventilated with ZEEP. In Group 5, lobectomy was performed and the parameters were measured before and after the ligation of the pulmonary arteries. In Group 6, pneumonectomy was done, and measurements were taken before and after ligation of the pulmonary arteries.

Before induction of anesthesia, 22-gauge indwelling cannula was inserted into the radial artery under local anesthesia. Blood samples were taken from radial artery and right atrium through the indwelling catheter inserted from the internal jugular vein. The alveolar-arterial oxygen tension gradient $(A\text{-}a)DO_2$ and the intrapulmonary shunt ($\dot{Q}s/\dot{Q}t$) were calculated using the standard shunt equation.

The above data were statistically analyzed using the student t test, with $p<0.05$ being considered significant.

Table 1 Cardio-pulmonary data at various respiratory maneuvers

		PaO_2 (mmHg)	$PaCO_2$ (mmHg)	$(A\text{-}a)DO_2$ (mmHg)	$\dot{Q}_S/\dot{Q}_T$ (%)	BP (mmHg)	HR (/min)
Group 1: (n=9)	UL deflated LL ZEEP ventilated	93 ± 19.0	37 ± 5.8	218 ± 25.0	28 ± 4.1	118 ± 8.2	99 ± 5.8
	UL deflated LL ZEEP ventilated by TV↑	85 ± 25.0	34 ± 5.1	229 ± 30.4	31 ± 5.5	122 ± 4.6	87 ± 9.2
Group 2: (n=10)	UL deflated LL ZEEP ventilated	65 ± 5.1	34 ± 2.2	250 ± 7.2	32 ± 2.2	122 ± 6.4	86 ± 6.4
	UL deflated LL ZEEP ventilated by $100\%O_2$	120 ± 14.8*	38 ± 3.0	185 ± 21.6*	23 ± 3.7*	118 ± 6.8	88 ± 6.0
Group 3: (n=10)	UL deflated LL ZEEP ventilated	70 ± 6.0	35 ± 2.5	239 ± 6.3	30 ± 4.7	116 ± 8.3	86 ± 5.4
	UL $PEEP_{10}$ insufflated LL ZEEP ventilated	207 ± 17.8	34 ± 2.8	118 ± 15.5*	9.5 ± 1.6*	129 ± 6.3	84 ± 5.0
Group 4: (n=8)	UL deflated LL ZEEP ventilated	86 ± 4.7	37 ± 2.7	245 ± 5.0	30 ± 1.5	125 ± 7.0	84 ± 2.7
	UL HFJV LL ZEEP ventilated	148 ± 18*	36 ± 2.5	166 ± 18.2*	14 ± 1.5*	119 ± 11.0	107 ± 13.6
Group 5: (n=7)	UL deflated LL ZEEP ventilated	78 ± 4.5	29 ± 1.9	312 ± 23.3	32 ± 2.4	124 ± 10.2	96 ± 2.0
	UL lobectomy LL ZEEP ventilated	210 ± 24.0*	27 ± 1.1	221 ± 8.9*	19 ± 4.4*	128 ± 4.8	85 ± 4.1
Group 6: (n=5)	UL deflated LL ZEEP ventilated	87 ± 6.4	42 ± 5.3	252 ± 27.6	27 ± 2.9	122 ± 11.7	104 ± 7.2
	UL pneumonectomy LL ZEEP ventilated	229 ± 15.6*	40 ± 4.9	156 ± 46*	14 ± 5.7*	129 ± 4.6	108 ± 6.7

Mean ± SE

UL: upper lung, LL: lower lung, HFJV: high frequency jet ventilation, ZEEP: Zero endo-expiratory pressure, TV: tidal volume, PEEP: positive endo-expiratory pressure, $PEEP_{10}$: 10cm H_2O PEEP, BP: systolic blood pressure, HR: heart rate

*shows significant difference compared with one-lung ventilation (UL deflated, LL ZEEP ventilated).

RESULTS

The mean PaO_2, $PaCO_2$, $(A\text{-}a)DO_2$ and $\dot{Q}s/\dot{Q}t$ of the six groups during two-lung ventilation with 50% oxygen were respectively 234 ± 9.3mmHg, 32 ± 0.9mmHg, 113 ± 8.8mmHg and 7.8 ± 1.1%. Changing from two-lung ventilation to one-lung caused a significant decrease in PaO_2 to less than 100mg, and a significant increase in $(A\text{-}a)DO_2$ and $\dot{Q}s/\dot{Q}t$, as shown in Table 1 (UL deflated, LL ZEEP ventilated).

In Group 1, PaO_2 was decreased slightly when the tidal volume in the lower dependent lung increased while the upper lung was deflated to atmospheric pressure after thoracotomy. Changing the inspired oxygen concentration from 50% to 100% oxygen in the dependent lung caused a significant rise in PaO_2. Insufflation of oxygen with 10 cmH_2O PEEP resulted in a significant increase in PaO_2 and a significant decrease in $(A\text{-}a)DO_2$ and $\dot{Q}s/\dot{Q}t$ (Group 3).

The application of HFJV in the upper lung caused a significant rise in PaO_2. $\dot{Q}s/\dot{Q}t$ and $(A\text{-}a)DO_2$ was also reduced significantly during HFJV in the nondependent lung (Group 4).

In the patients who underwent lobectomy and pneumonectomy (Groups 5 and 6), ligation of the pulmonary artery caused a significant rise in PaO_2, a significant reduction in $(A\text{-}a)DO_2$ and $\dot{Q}s/\dot{Q}t$.

DISCUSSION

There are several indications for one-lung ventilation in order to isolate the two lungs during thoracic surgery. Isolation of one lung is useful in preventing contamination by secretion or blood in the dependent lung. The presence of a bronchopleural fistula, and gigantic unilateral cyst also requires the isolation of one lung to provide adequate ventilation to the noninvolved lung.

The use of a double-lumen endobronchial tube can be facilitated by providing good surgical exposure. However, one-lung ventilation often causes hypoxemia, usually as a result of increased right-to-left transpulmonary shunt through the operated nondependent lung.[1, 2, 3, 4, 5] This increase in intrapulmonary shunt is mainly due to the perfusion of pulmonary blood through the upper collapsed lung. Therefore, reduction of pulmonary perfusion in the nondependent collapsed lung improved significantly arterial oxygenation, as shown in the result of Groups 5 and 6.

Hypoxic pulmonary vasoconstriction (HPV) has been reported to improve oxygenation by redistributing the blood flow from the nondependent lung to the dependent lung.[11, 12] The degree of HPV, however, is modified by the action of anesthetics.[12] Inhalation anesthetics such as halothane and enflurane have been found to either inhibit or preserve HPV.[13, 14] Intravenously administered ketamine and fentanyl have been shown to preserve HPV.[15] Therefore, these drugs are thought to be beneficial to patients undergoing thoracotomy with one-lung ventilation.

The present study was undertaken to investigate pulmonary gas exchange with various techniques reported recently and high-frequency jet ventilation during one-lung ventilation. The application of HFJV to the nondependent lung caused a significant increase in PaO_2, resulting in a significant reduction in $(A\text{-}a)DO_2$ and Qs/Qt. HFJV has been used successfully for thoracic surgery such as tracheoplasty, bronchoplasty and sleeve pneumonectomy.[17] HFJV delivers a small tidal volume resulting in a low inspiratory airway pressure. It provides a quiet surgical field compared with conventional ventilation using intermittent lung inflation. During HFJV, however, the lung appeared to be vibrating and some surgeons in our hospital complained of the vibratory movement of the thoracic surgical field.

It was reported that HFJV could provide adequate alveolar ventilation in the open system even if a small tube was used. El-Boz et al found that HFJV through a small uncuffed endobronchial tube provided better oxygenation and optimal surgical access compared to conventional ventilation.[7] Hildebrand et al also obtained satisfactory result by using HFJV through a small gas-monitoring tube.[18] Isolation of the dependent lung from the nondependent lung is essential during the resection of an infected or bleeding lung. According to our clinical experience, however, these procedure in the open system run the risk of spreading lung blood and infected debris to the lower dependent lung, even if there is a continous outflow of gas from the dependent lung during HFJV. Therefore, we are now applying HFJV to the nondependent lung through the double-lumen endobronchial tube.

Various techniques to minimize arterial hypoxemia during one-lung ventilation have been investigated. In our study, increased tidal volume of the dependent lung did not improve arterial oxygenation (Group 1), as other investigators have reported.[1] In contrast to the study by Torda[4] and Tarhan,[18] our study showed that the use of high inspired oxygen concentration caused a significant rise in PaO_2 while the nondependent lung was deflated to atmospheric pressure. Our results suggest that dependent lung atelectasis or maldistribution of ventilation and pulmonary circulation is also related to the decreased arterial oxygenation in addition to the increased intrapulmonary shunt in the dependent lung. During lateral thoracotomy, dependent lung atelectasis may be caused by the mediastinal shift by gravity and the compression of the abdominal contents due to the paralysis of the diaphragmatic muscles.[19, 20]

The application of the PEEP to the nondependent lung in Group 3 also improved arterial oxygenation due to the reduction of $\dot{Q}s/\dot{Q}t$ and $(A-a)DO_2$. On the contrary, some studies have found that the application of PEEP to the dependent lung did not maintain adequate arterial oxygenation and caused diversion of blood flow away from the dependent lung to the nondependent lung and increased intrapulmonary shunting in the atelectatic lung.[18]

From the present study, it was concluded that the application of HFJV in the nondependent lung improved significantly arterial oxygenation. However, the use of HFJV was not superior compared to other procedures such as the application of PEEP or the ligation of the pulmonary artery in the nondependent lung.

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