Treatment of Hypoxemia during Esophagectomy by High Frequency Jet Ventilation

Kyoji TSUNO, Yuji SAKANASHI, Morimasa MATSUMOTO, Yasuyuki KAKIUCHI* and Hisayoshi MIYAZAKI*

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Severe hypoxemia due to lung collapse on the operation side sometimes occurs during thoracotomy. It can usually be counteracted with a high $F_{I_{O_2}}$. But, we have experienced a patient who showed refractory hypoxemia even under intermittent positive pressure ventilation (IPPV) through a single lumen endotracheal tube at an $F_{I_{O_2}}$ of 1.0 during esophagectomy. The collapsed lung was inflated and the bilateral lungs were ventilated manually or with mechanical ventilation (MV) to maintain Pa_{O_2} at a physiologic range. However, the inflated lung hid the operation field. When the lung was placed aside with a retractor for continuing the operation, the Pa_{O_2} fell again below an acceptable level. Therefore, we superimposed high frequency jet ventilation (HFJV) on IPPV. Superimposed HFJV resulted in good pulmonary oxygenation as well as providing satisfactory operative conditions.

Case Report

A 66-years-old male, with a past history of hypertension and cerebral apoplexy, underwent esophagectomy for esophageal carcinoma. He had worked as a miner for 15 years since he was 31-years-old, and had smoked 20 cigarettes per day over 40 years. He received a pre-operative radiation therapy of a total of 30 Gy. Pulmonary fibrotic changes were seen on his chest X-rays. The lung function tests showed VC 2930 ml, %VC 94.2%, $FEV_{1.0\%}$ 78.6%, $RV_{\%}$ 27.2%, %DLCO 58.4%, and arterial blood gases (ABG) at spontaneous breathing of room air were pH 7.449, P_{O_2} 79.8 mmHg, and P_{CO_2} 35.1 mmHg.

The patient was premedicated with 0.5 mg of atropine sulfate and 50 mg of Pethilorfan®. Under spontaneous air breathing in a supine position in the operating room, his ABG showed pH 7.431, P_{O_2} 53.6 mmHg, and P_{CO_2} 42.1 mmHg. The ABG at an $F_{I_{O_2}}$ of 1.0 showed pH 7.435, P_{O_2} 556.1 mmHg, and P_{CO_2} 42.9 mmHg. He was anesthetized with thiamylal, and orotracheally intubated with a single lumen endotracheal tube after succinylcholine chloride injection. Anesthesia was maintained with 0.7–1.0% halothane in nitrous oxide and oxygen. He was placed in a left recumbent position. After the right chest cavity was opened and the right lung was placed aside with a retractor, the ABG remarkably aggravated to pH 7.354, P_{O_2} 44.5 mmHg, and P_{CO_2} 54.1 mmHg at an $F_{I_{O_2}}$ of 0.6 under manual ventilation with a minute volume of 7–8*l*. Anesthesia was switched to morphine hydrochloride, diazepam, and low concentrations of halothane. The $F_{I_{O_2}}$ was raised to

Department of Anesthesiology, Kumamoto University Medical School, Kumamoto, Japan

**Department of Anesthesiology, Kumamoto National Hospital, Kumamoto, Japan*

Address reprint requests to Dr. Tsuno: Department of Anesthesiology, Kumamoto University Medical School, 1-1-1 Honjyo, Kumamoto, 860 Japan

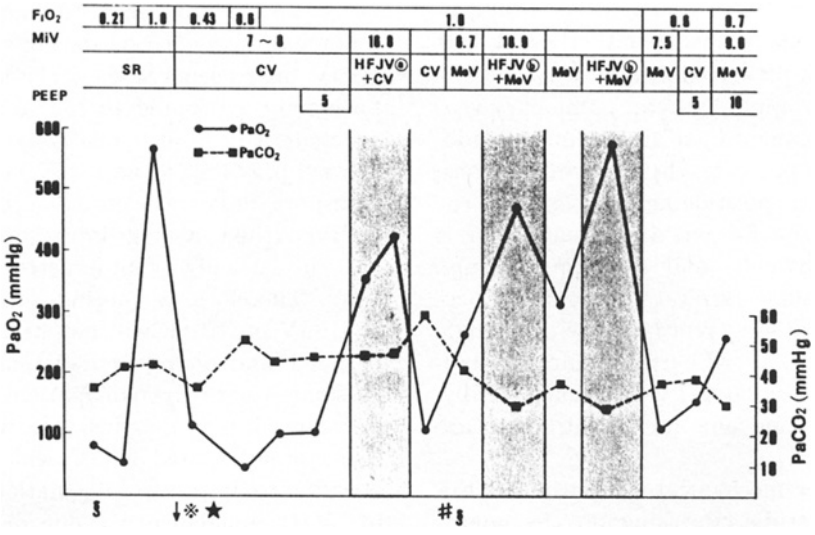

Fig. 1. Arterial blood gases during the course of the operation. SR, spontaneous respiration; CV, manual controlled ventilation; HFJV, high frequency jet ventilation; MeV, mechanical ventilation; MiV, minute volume ($l \cdot min^{-1}$); HFJV Ⓐ, working pressure 0.6 $kg \cdot cm^{-2}$, frequency 5 Hz, stroke volume 30 ml; HFJV Ⓑ, working pressure 0.8 $kg \cdot cm^{-2}$, frequency 5 Hz, stroke volume 40 ml; PEEP, positive end-expiratory pressure (cmH_2O); §, supine position; ※, left side position; ↓, intubation; ★, thoracotomy; #, chest closed.

1.0, and a positive end-expiratory pressure (PEEP) of 5 cmH_2O was employed to improve pulmonary oxygenation. However, the Pa_{O_2} was still 102.5 mmHg, and the Pa_{CO_2} was 44.1 mmHg. Then, HFJV, at a working pressure of 0.6 $kg \cdot cm^{-2}$, a frequency of 5 Hz, and a stroke volume of 30 m*l* (Mera-HFO Jet Ventilator, Senko, Japan) was superimposed on the manual ventilation. The right lung became well aerated without disturbing the surgical procedures. The minute volume increased to 16.8*l*. The Pa_{O_2} improved to 422.8 mmHg, but little change was seen in the Pa_{CO_2} (fig. 1). When the working pressure of HFJV was further increased, the aerated lung expanded into the operation field and disturbed the surgical procedures. When HFJV was turned off, the Pa_{O_2} fell to 108.7 mmHg with a rise of the Pa_{CO_2} to 59.4 mmHg.

After the chest wall was closed and the patient was returned to a supine position, the Pa_{O_2} rose to 266.4–318.3 mmHg under MV at a V_T of 550 m*l*, a respiratory rate of 12 times$\cdot min^{-1}$, a minute volume of 6.7*l*, and an F_{IO_2} of 1.0. When HFJV, at a working pressure of 0.8 $kg \cdot cm^{-2}$, a frequency of 5 Hz, and a stroke volume of 40 m*l* was superimposed on MV, the Pa_{O_2} further improved to between 473.3 and 577.1 mmHg. The ventilator was changed to a Servo-900 B (Siemens-Elema, Sweden), and the Pa_{O_2} was maintained around 250 mmHg with a PEEP of 10 cmH_2O at an F_{IO_2} of 0.7. The patient was nasotracheally intubated and transferred to the ICU.

Discussion

Hypoxemia during intrathoracic surgery is mostly attributable to V/Q imbalance due to lung collapse on the operation side. This hypoxemia can be usually counteracted by raising F_{IO_2}. Under a high F_{IO_2}, acceptable Pa_{O_2} usually can be maintained even in one lung ventilation. Therefore, one lung ventilation will be utilized to afford a better surgical field. If hypoxemia develops under one lung ventilation with a high F_{IO_2}, HFJV

is often applied to the non-ventilated lung to facilitate pulmonary oxygenation[1]. But this procedure is a little complex.

We usually apply bilateral pulmonary ventilation with an ordinal single lumen endotracheal tube based on the following reasons. Firstly, proper positioning of a special endotracheal tube for one lung ventilation is technically difficult, and sometimes results in life-threatening respiratory problems. Secondly, bilateral lung ventilation with a single lumen tube can afford better pulmonary oxygenation than unilateral ventilation. Thirdly, special tubes for one lung ventilation are very expensive.

Even under mechanical ventilation with a single lumen tube, the lung on the operative side tends to collapse by alveolar surface tension and mechanical compression. If hypoxemia due to lung collapse occurs, lung inflation on the operation side will be necessary to improve pulmonary oxygenation. But, the inflated lung will protrude into the surgical field and disturb the surgical procedures. To keep the lung inflated to some degree, but not to an extent to disturb the operation, and improve pulmonary oxygenation, we superimposed HFJV on IPPV.

In this patient, a large discrepancy of Pa_{O_2} between air breathing and 100% oxygen breathing suggested a presence of V/Q imbalance in the lung prior to the operation. A HFJV at a working pressure of 0.6 $kg \cdot cm^{-2}$, a frequency of 5 Hz, and a tidal volume of 30 m*l* was satisfactory in providing good pulmonary oxygenation. During superimposed HFJV, continuous lung inflation on the operation side would have removed the V/Q imbalance[2,3]. But, when the working pressure of HFJV was increased more than 0.6 $kg \cdot cm^{-2}$, the lung inflation became excessive and disturbed the operation. A proper setting of HFJV was the prerequisite for good results.

After the chest wall was closed and the patient was put in a supine position, the working pressure of HFJV was increased to 0.8 $kg \cdot cm^{-2}$. The vibratory movement of the patient's chest wall was well observed and pulmonary oxygenation improved conspicuously. The mechanism of the improvement of pulmonary oxygenation during superimposed HFJV on patients with a closed chest may be mainly attributed to the so-called PEEP effect derived from a relatively higher mean airway pressure[4,5], and the facilitated gas transport due to accelerated turbulence[6].

Hypoxemia during intrathoracic surgery can be usually counteracted by raising $F_{I_{O_2}}$. Therefore, a routine superimposition of HFJV on IPPV will not be necessary for patients undergoing thoracotomy. However, in some severe hypoxic patients with V/Q imbalance due to lung collapse even at a high $F_{I_{O_2}}$, superimposed HFJV will have special benefits to improve oxygenation by reducing V/Q imbalance without disturbing the surgical field.

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