The Ventilation Management during the Reconstruction of the Tracheo -Bronchial Tree in Adults

Takashi OGAWA, Takanori MURAYAMA*,
Koh SHINGU** and Kenjiro MORI*

The most important point of anesthetic management during the reconstruction of the tracheo-bronchial tree (TBT) is to secure the airway and to maintain adequate ventilation. We experienced 17 cases of reconstruction of the TBT. Various methods of ventilation were achieved; one-lung ventilation, right middle and lower lobes ventilation, and combinations of these. We used double-lumen tubes, single-lumen tubes with or without blocker, spiral tubes, and intravenous catheters. We selected an appropriate ventilation method suitable for the diverse operative modes and achieved satisfactory managements during operation. (Key words: tracheo-bronchial plasty, ventilation, one-lung ventilation)

(Ogawa T, Murayama T, Shingu K, et al.: The ventilation management during the reconstruction of the tracheo-bronchial tree in adults. J Anesth 4: 9–19, 1990)

Among the important points of anesthetic management during the reconstruction of the tracheobronchial tree (TBT), it is essential to secure the airway and to maintain adequate ventilation. Because of the diversity of surgical approaches and procedures, various ventilation methods are required to meet these objectives. Several types of endotracheal tubes (ETTs) are used such as commonly used tubes, spiral tubes, left or right double-lumen tubes, tubes with a bronchial cuff, and endobronchial tubes. Spiral tubes or endobronchial tubes are sometimes inserted directly into bronchi in an operating field. Using these tubes, various ventilation modes are followed, such as two-lung ventilation (TLV), left or right one-lung ventilation (OLV), isolated lung ventilation, segmental ventilation, or combinations of these. The efficacy of these ventilation methods can be assessed by analyzing arterial blood gases.

We collected and reviewed our experiences to evaluate the ventilation methods we have used. Here we discuss problems in using such complicated techniques.

Materials and Methods

Seventeen patients who underwent reconstruction of the TBT during 2 years, from October 1986 to August 1988, in Himeji National Hospital, are reviewed. Four females and thirteen males ranging in age from 20 to 77 were included. Their age, sex, height, weight, diagnoses and names of the operation performed are shown in table 1. Thiamylal (3–5 mg·kg^{-1} iv) was used for anesthesia.

Department of Anesthesia, Himeji National Nospital, Himeji, Japan

**Department of Anesthesia, Kyoto University Hospital, Kyoto, Japan*

***Division of Emergency Medicine and Critical Care Medicine, Kyoto University Hospital, Kyoto, Japan*

Address reprint requests to Dr. Shingu: Department of Anesthesia, Kyoto University Hospital, Kawahara-cho 54, Shogoin, Sakyo-ku, Kyoto, 606 Japan

Table 1. Clinical features of patients undergoing the reconstruction of tracheobronchial trees

No.	Age (y.o.)	Sex	Height (cm)	Weight (kg)	Diagnosis	Name of Operation
1	72	Male	158	50	L-SCC	Rt-upper sleeve lobectomy
2	72	Male	164	44	L-SCC	Rt-upper sleeve lobectomy
3	69	Male	156	43	L-SCC	Rt-upper sleeve lobectomy
4	20	Male	172	59	TBS	Rt-upper sleeve lobetomy
5	72	Male	169	55	Adenoca	Rt-upper sleeve lobectomy
6	60	Male	165	69	L-SCC	Rt-middle & lower sleeve lobectomy
7	72	Male	163	47	L-SCC	Rt-middle & lower sleeve lobectomy
8	64	Male	157	60	L-SCC	Rt-middle sleeve lobectomy
9	71	Male	160	45	L-SCC	Lt-upper sleeve lobectomy
10	61	Male	161	56	L-LCC	Lt-upper sleeve lobectomy
11	73	Male	161	56	L-SCC	Lt-upper sleeve lobectomy
12	69	Male	158	47	L-SCC	Lt-lower sleeve lobectomy
13	55	Female	151	39	Carcinoid	Lt-sleeve pneumonectomy
14	65	Female	157	60	T-PAC	Cervical tracheal reconstruction
15	55	Female	154	83	T-PAC	Cervical tracheal reconstruction
16	77	Female	152	56	Carcinoid	Intrathoracic tracheal reconstruction
17	74	Male	157	47	L-SCC	Reconstruction of the carina

L-SCC: Squamous cell carcinoma of the lung, TBS: Traumatic bronchial stenosis, Adenoca: Adenocarcinoma of the lung, Carcinoid: Carcinoid tumor of the lung, T-PAC: Papillary adenocarcinoma of the thyroid gland, L-LCC: Large cell carcinoma of the lung

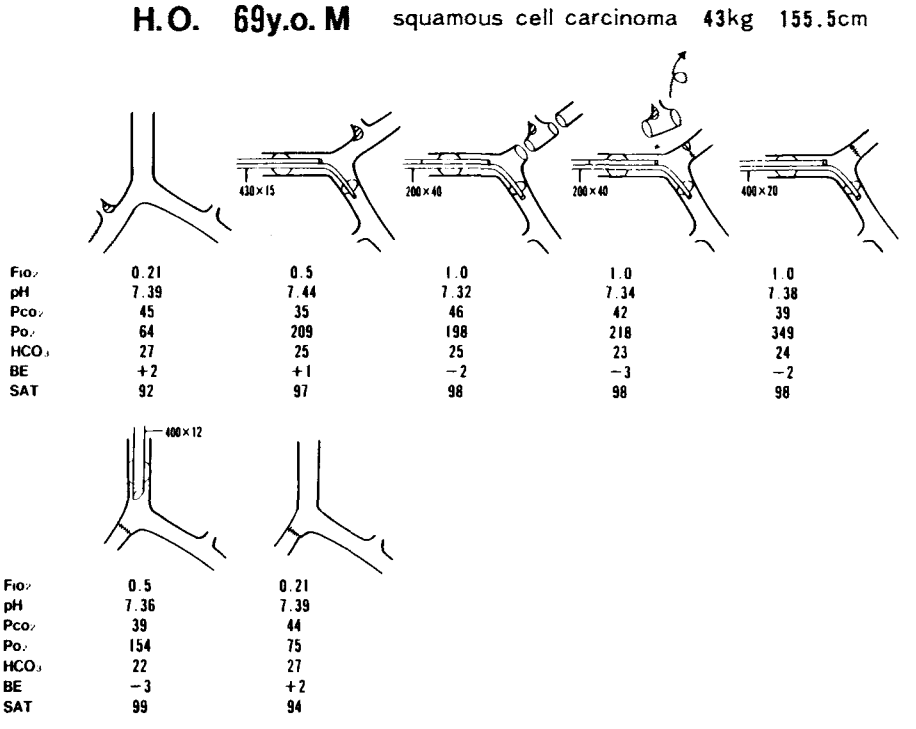


Fig. 1. The ventilation method for the case 3 (right upper sleeve lobectomy) and blood gas values.

Table 2. The ventilation methods and blood gas values

Case No.	Ventilation Methods	T.V. (ml)	R.R. (bpm)	Pa_{O_2} (mmHg)	Pa_{CO_2} (mmHg)
1	Lt-one-lung (Bronchocath)	300	20	78	36
2	Lt-one-lung (Bronchocath)	270	25	129	42
3	Lt-one-lung (Bronchocath)	200	40	218	42
4	Lt-one-lung (Bronchocath)	280	30	129	42
5	Lt-lung (Tracheron)	300	20	97	36
	Rt-lung (Spiral tube)	200	20		
6	Lt-one-lung (Bronchocath)	400	20	309	36
7	Lt-one-lung (Spiral tube)	270	25	155	39
8	Lt-one-lung (Bronchocath)	300	20	338	43
9	Rt-one-lung (Bronchocath)	400	15	484	38
10	Rt-one-lung (Univent)	320	21	339	37
11	Rt-one-lung (Univent)	260	30	251	40
12	Rt-one-lung (Forley cath.)	400	15	352	32
13	Rt-middle & lower (Spiral tube)	300	20	144	37
	Rt-one-lung (Bronchocath)	300	20	217	33
14	Two-lung ($FI_{O_2} = 0.5$)	270	20	114	39
15	Two-lung	500	10	200	30
16	Two-lung (Separately)	300	20	83	31
17	Two-lung — Lt-main bronchus	300	20	153	29
	Two-lung — Rt-middle trunk	200	20		
	Two-lung — Lt (Bronchocath)	300	20	217	22
	Two-lung — Rt (HFJV)		360		

Endotracheal intubation was done with pancuronium (0.1 $mg \cdot kg^{-1}$ iv), except in one case, in which awake intubation was applied because of severe tracheal stenosis caused by carcinoid tumor. Anesthesia was maintained with enflurane, nitrous oxide, oxygen and pancuronium. The appropriate ventilation methods were selected according to the operation performed. The ventilation was evaluated with arterial blood gas values.

Results

The ventilation methods and blood gas values are shown in table 2. We set the ventilator conditions, $FI_{O_2} = 1.0$, tidal volume = 4.6–8.9 $ml \cdot kg^{-1}$, respiratory rate = 15–40/min. Three cases showed hypoxemia (Pa_{O_2} below 80 mmHg) during the operation. These hypoxemic episodes developed under left OLV during right upper sleeve lobectomy (cases 1 and 5) and reconstruction of intrathoracic trachea (case 16).

1. Right upper sleeve lobectomy

In cases 1–4, reconstruction of the bronchus (anastomosis of the truncus intermedius to the right main bronchus) was uneventfully performed under left OLV using a double-lumen ETT (Broncho-cath™, NCC

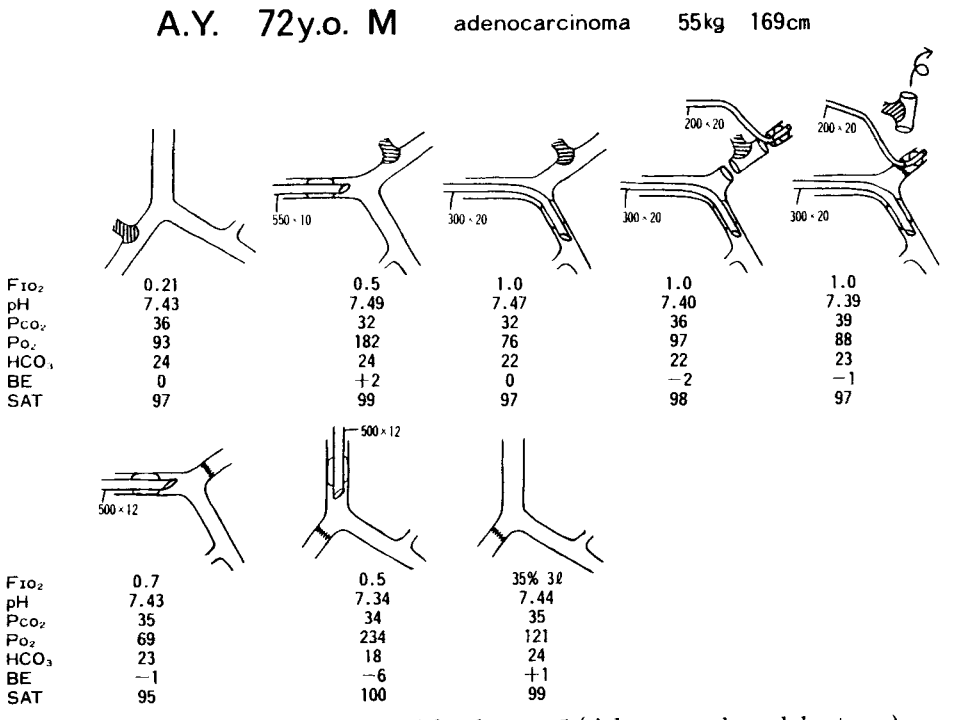


Fig. 2. The ventilation method for the case 5 (right upper sleeve lobectomy) and blood gas values.

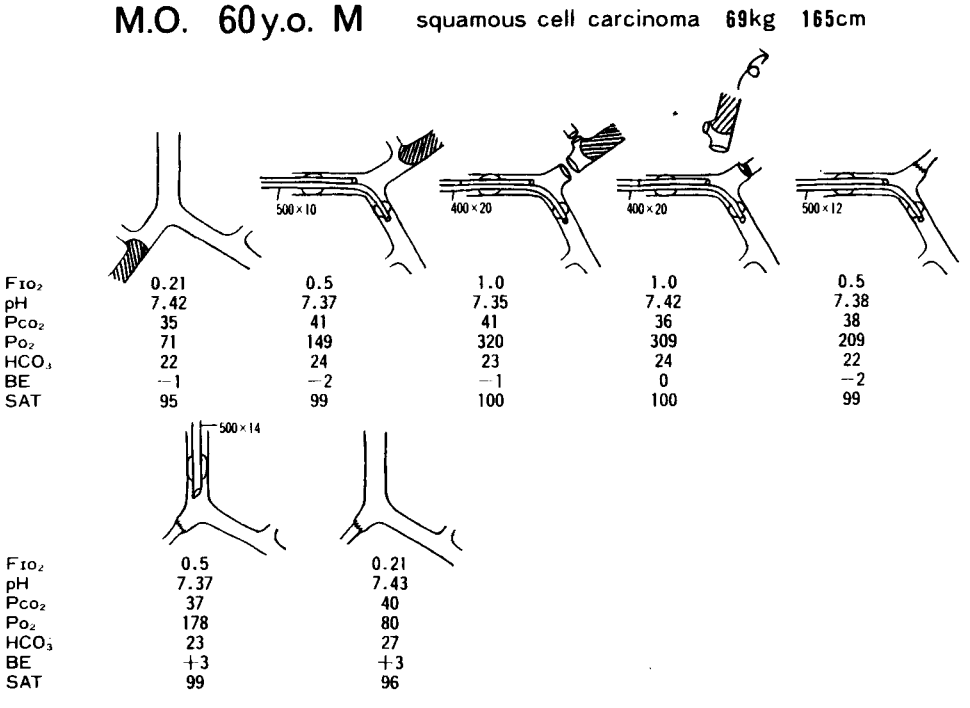


Fig. 3. The ventilation method for the case 6 (right middle and lower sleeve lobectomy) and blood gas values.

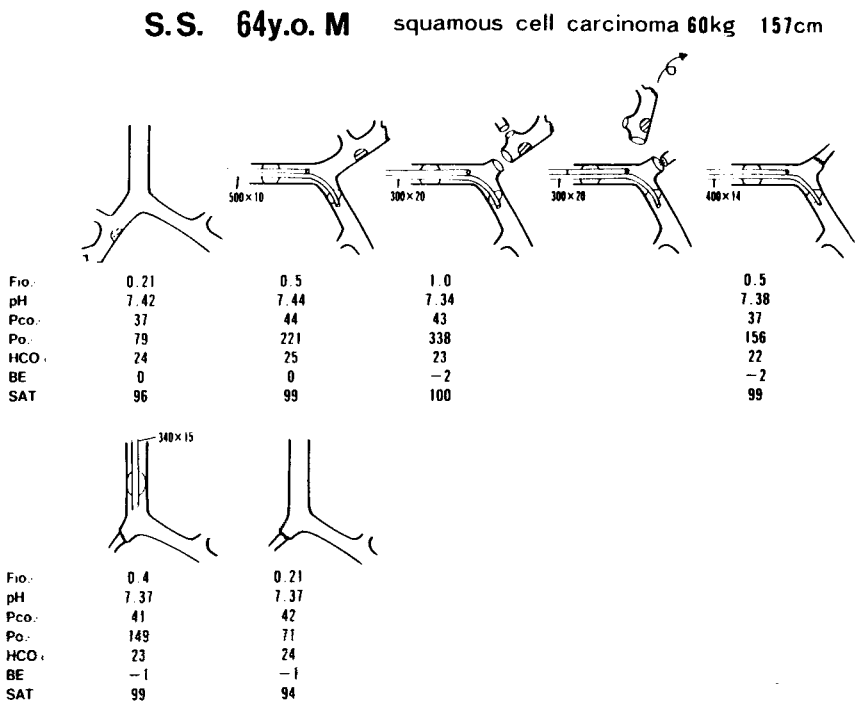


Fig. 4. The ventilation method for the case 8 (right middle sleeve lobectomy) and blood gas values.

Division, Mallinckrodt Inc., Argyle, NY, for left bronchus, 35 Fr) (fig. 1).

In case 5 (fig. 2), it was decided to reconstruct the bronchus intraoperatively. For left OLV the already inserted ETT (Tracheron^{TM}, Terumo Co., Tokyo, single lumen with one cuff, Magill type, I.D. 9.0 mm) was advanced into the left main bronchus under bronchofiberscopic (BFS) guidance. Since its large cuff, easily dislocated by surgical manipulation, might block the orifice of left upper bronchus, hypoxemia was expected. After sectioning the right main bronchus, a second tube (spiral, Rusch, West Germany, 22 Fr) was inserted surgically into the truncus intermedius to add right middle and lower lobe ventilation. The reconstruction (anastomosis of trunchus intermedius to right main bronchus) was started under the combination of left OLV and right segmental ventilation. The spiral tube was removed after the anastomosis was about 2/3 completed. The remaining anastomosis was completed under only the left OLV using the first tube. Thereafter, the first tube was drawn back in the trachea, and the operation was continued under TLV.

2. *Right middle and lower sleeve lobectomy*

In case 6 (fig. 3), the reconstruction of bronchus (anastomosis of right upper bronchus to right main bronchus) was accomplished uneventfully under left OLV using a Broncho-cath ETT (for left bronchus, 35 Fr).

In case 7, a tracheostomy and total laryngectomy had been performed for laryngeal carcinoma one month before. A spiral tube (Rusch, 32 Fr), which was placed in the trachea via tracheostomy, was advanced into the left main bronchus under BFS guidance prior to the reconstruction. Then the reconstruction was uneventfully performed under left OLV.

3. *Right middle sleeve lobectomy*

Right lower lobectomy had been performed for squamous cell carcinoma one year before in case 8 (fig. 4). The bronchus was

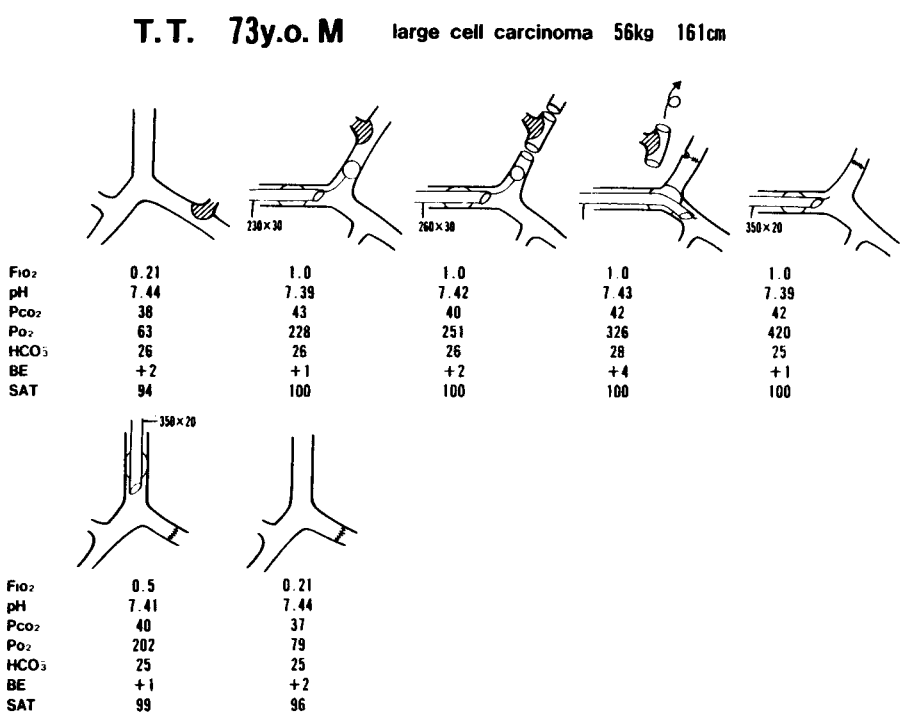


Fig. 5. The ventilation method for the case 11 (left upper sleeve lobectomy) and blood gas values.

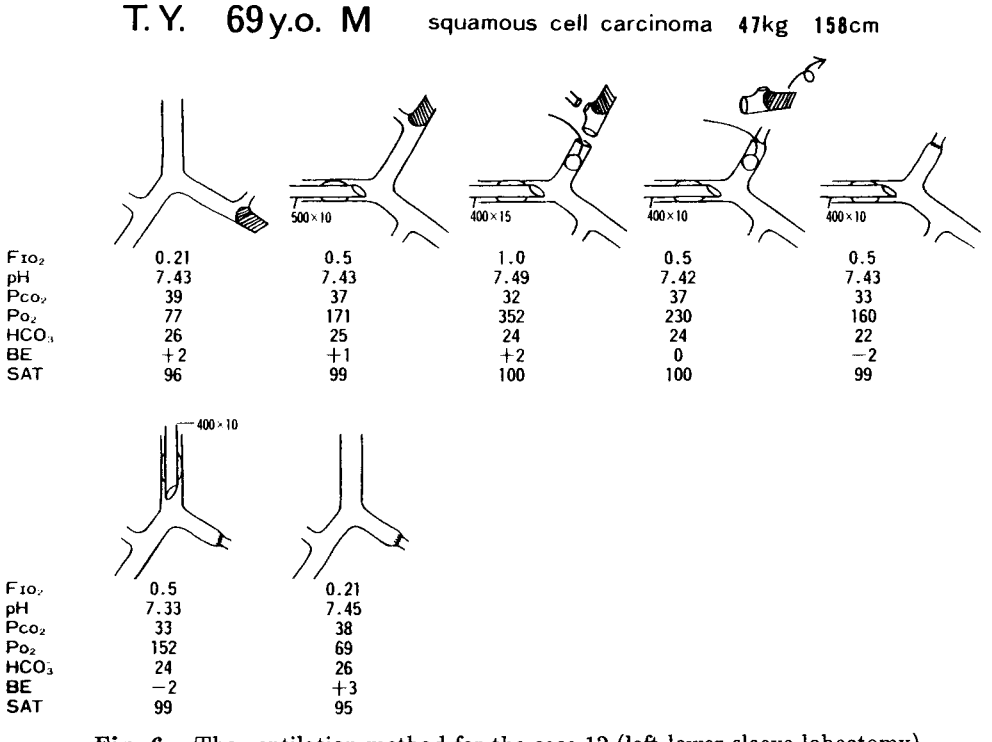


Fig. 6. The ventilation method for the case 12 (left lower sleeve lobectomy) and blood gas values.

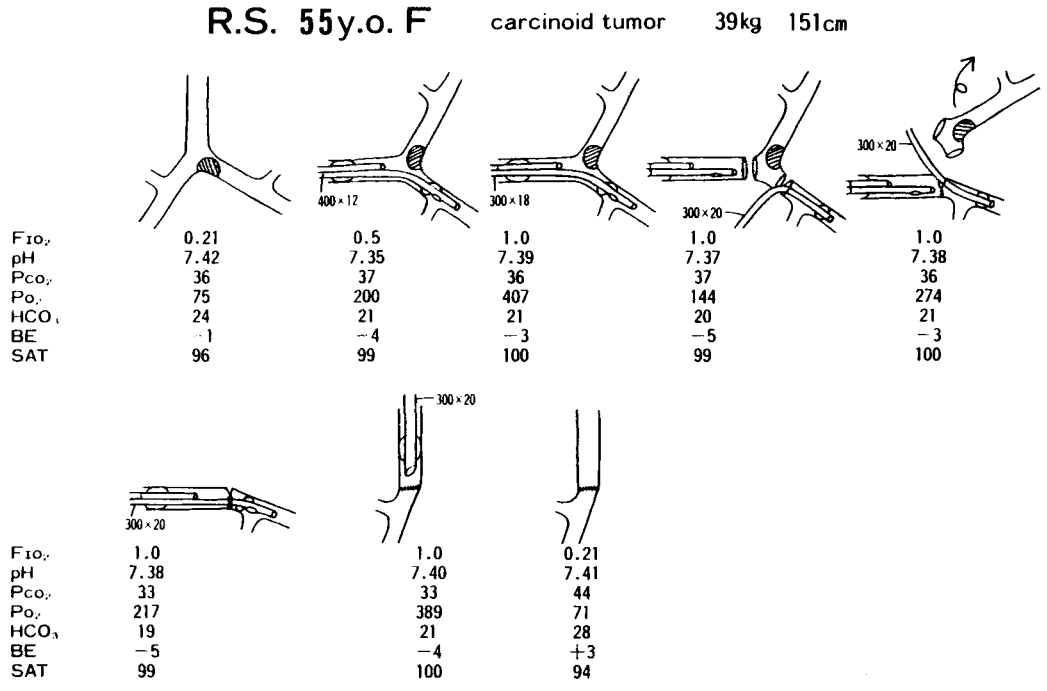


Fig. 7. The ventilation method for the case 13 (left sleeve pneumonectomy) and blood gas values.

reconstructed (anastomosis of right upper bronchus to right main bronchus) uneventfully under left OLV using a Broncho-cath tube (for left bronchus, 35 Fr).

4. Left upper sleeve lobectomy

In case 9, the bronchus was reconstructed (anastomosis of left lower bronchus to left main bronchus) uneventfully under left OLV using a Broncho-cath tube (for right bronchus, 35 Fr), using a single-lumen ETT with a bronchial blocker cuff (Univent^{TM}, Fuji systems co., Tokyo, I.D. 8.5 mm) in case 10. In case 11 (fig. 5), the reconstruction started initially under right OLV using a Univent tube (I.D. 8.5 mm). The cuff, blocking the left main bronchus, was ruptured inadvertently during surgical manipulation, making it impossible to maintain ventilation. To keep on ventilating the right lung, the Univent tube was advanced into the right main bronchus. Then the operation was continued.

5. Left lower sleeve lobectomy

It was decided to reconstruct the bronchus (anastomosis of left upper bronchus to left main bronchus) intraoperatively in case 12 (fig. 6). A Foley catheter (10 Fr) was inserted and used as a blocker of the left main bronchus. The reconstruction was performed uneventfully under right OLV.

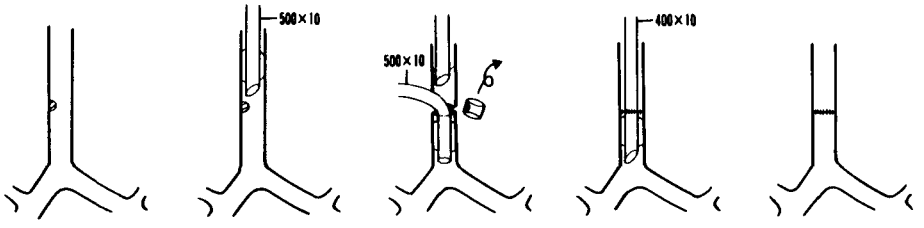
6. Left sleeve pneumonectomy

The operation started under TLV using a Broncho-cath tube (for right bronchus, 35 Fr) in case 13 (fig. 7). Prior to sectioning the right main bronchus, the tube was drawn back in the trachea. Immediately after the sectioning, a spiral tube (Rusch, 22 Fr) was inserted surgically into the truncus intermedius. The bonchus was reconstructed (anastomosis of right main bronchus to trachea) under right middle and lower lobe ventilation. The spiral tube was removed after the anastomosis was about 2/3 completed, and the Broncho-cath tube was advanced again into the right main bronchus under BFS guidance. The operation was continued under right OLV.

7. Reconstruction of cervical trachea

In case 14, a tracheotomy, distal to the tumor, was performed under local anesthesia,

A.M. 55y.o. F thyroid cancer (papillary adenocarcinoma) 83kg 154cm



F_{IO_2}	0.21	0.5	1.0	1.0	0.21
pH	7.43	7.45	7.50	7.33	7.45
P_{CO_2}	38	33	30	44	42
P_{O_2}	64	89	200	178	52
HCO_3	26	23	24	23	30
BE	+1	0	+2	−2	+6
SAT	95	97	100	99	89

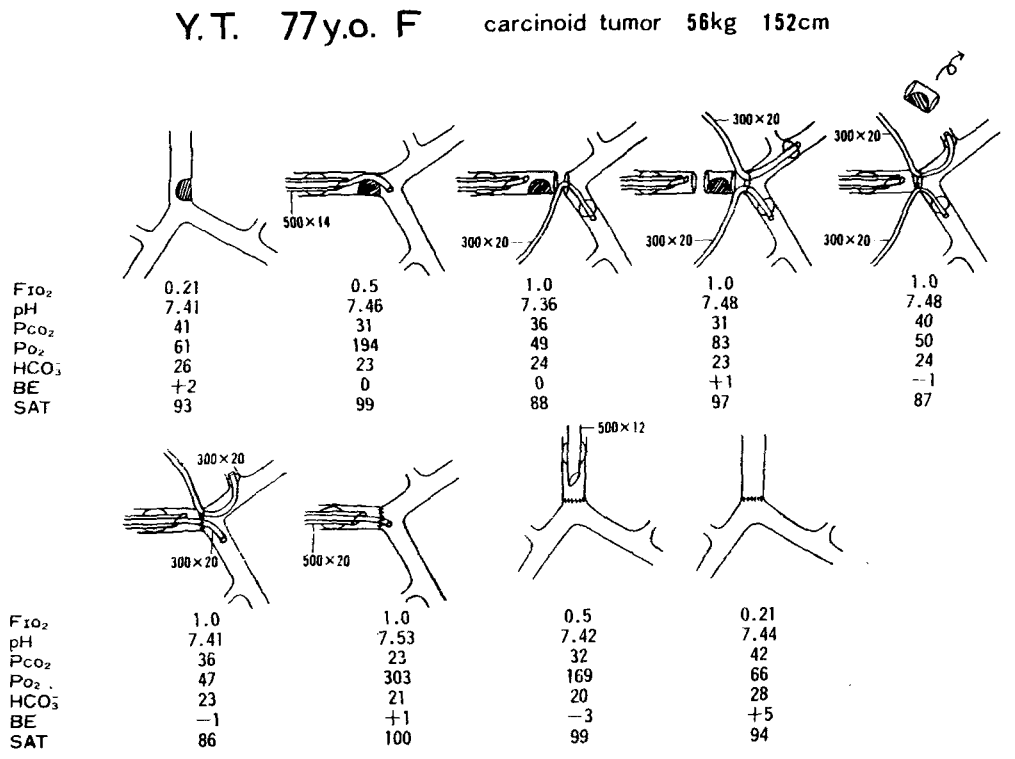
Fig. 8. The ventilation method for the case 15 (reconstruction of cervical trachea) and blood gas values.

then a spiral tube (I.D. 7.5 mm) was inserted through the tracheal fistula. Reconstruction of the trachea started under TLV. After the end-to-end anastomosis of trachea was about 2/3 completed, a second spiral tube (I.D. 7.5 mm) was inserted through a nostril into the trachea. Then the first tube, inserted via the tracheostomy, was removed and the second tube was advanced beyond the anastomotic site. The remaining operation was completed under TLV using the second tube.

Since the tumor invaded the trachea in case 15, a partial tracheal resection followed by an end-to-end reconstruction was done (fig. 8). An ETT (I.D. 7.5 mm) was drawn back proximal to the invaded site, and the trachea was sectioned distally from it. Immediately after the sectioning, a second tube (spiral, Rusch, 26 Fr) was inserted from the cut edge of the trachea. The trachea was partially resected and reconstructed under TLV using the second tube. The second tube was removed after the anastomosis was about 2/3 completed and the orally intubated ETT was advanced again beyond the anastomotic site. The remaining anastomosis was completed under TLV using the first tube.

8. Reconstruction of intrathoracic trachea

In case 16 (fig. 9), the patient complained of dyspnea due to tracheal stenosis caused by the tumor. At first, an oral awake endotracheal intubation was performed using a Portex™ ETT (Portex limited, Hythe, Kent, England, I.D. 9.0 mm). Then a second tube, a split half (endobronchial part) of a Portex twin-lumen tube™ (for left bronchus, I.D. 6.5 mm), was inserted through the first tube and was advanced under BFS guidance beyond the tumor to just above the carina. Right thoracotomy was performed under TLV using the second tube. Prior to the partial resection of the trachea invaded by the tumor, the second tube was drawn back to just above the tumor. Immediately after sectioning the trachea, a third tube (spiral, Rusch, 22 Fr) was inserted from the cut edge of the trachea into the left main bronchus to achieve left OLV. Blood gas analysis revealed hypoxemia, Pa_{O_2} was 49 mmHg and Pa_{CO_2} was 30 mmHg, which necessitated additional right lung ventilation. A fourth tube (spiral, Rusch, 22 Fr) was inserted into the truncus intermedius from the cut edge of the trachea to ventilate the right middle and lower lobes. This additional ventilation improved oxygenation and the Pa_{O_2} increased to 83 mmHg. The third tube was removed after the anastomosis of the trachea was about one half completed, then the second tube in the trachea was advanced again into the left main bronchus beyond the anastomotic site to continue ventilating the



F_{IO_2}	0.21	0.5	1.0	1.0	1.0
pH	7.41	7.46	7.36	7.48	7.48
P_{CO_2}	41	31	36	31	40
P_{O_2}	61	194	49	83	50
HCO_3	26	23	24	23	24
BE	+2	0	0	+1	−1
SAT	93	99	88	97	87

F_{IO_2}	1.0	1.0	0.5	0.21
pH	7.41	7.53	7.42	7.44
P_{CO_2}	36	23	32	42
P_{O_2}	47	303	169	66
HCO_3	23	21	20	28
BE	−1	+1	−3	+5
SAT	86	100	99	94

Fig. 9. The ventilation method for the case 16 (reconstruction of intrathoracic trachea) and blood gas values.

left lung. During the following manipulation, the fourth tube was inadvertently dislocated into the right upper bronchus, and the Pa_{O_2} decreased again to 47 mmHg. At this time, the tracheal anastomosis was about 3/4 completed, so the fourth tube was removed. The remaining anastomosis was completed under left OLV using the second tube. After the anastomosis was completed, the second tube was removed and the operation was completed under the TLV using the first tube.

9. Reconstruction of the carina

In case 17, a right thoracotomy was performed under TLV using a Broncho-cath tube (for left bronchus, 35 Fr), placed in the trachea (fig. 10). After the left main bronchus was sectioned, a second tube (spiral, Rusch, 22 Fr) was inserted into the left main bronchus for left OLV. Then, the right main bronchus was sectioned and a third tube (spiral, Rusch, 22 Fr) was inserted into the truncus intermedius for additional ventilation of the right middle and lower lobes. The lesion involving the carina was resected under the combination of left lung and right segmental ventilation, followed by anastomosis of the left main bronchus to the trachea. The second tube was removed after this anastomosis was about 2/3 completed. The first tube in the trachea was advanced into left main bronchus beyond the anastomotic site to maintain left lung ventilation, then the anastomosis was completed. The right main bronchus was anastomosed to the trachea using the end-to-side technique. After this anastomosis was about 2/3 completed, the third tube was removed and, in turn, a 12 gauge intravenous catheter was inserted into the truncus intermedius in the operating field for high-frequency jet ventilation (HFJV) of the right lung. The remaining anastomosis was completed under the isolated lung ventilation with HFJV for the right lung and intermittent positive pressure ventilation for the left lung.

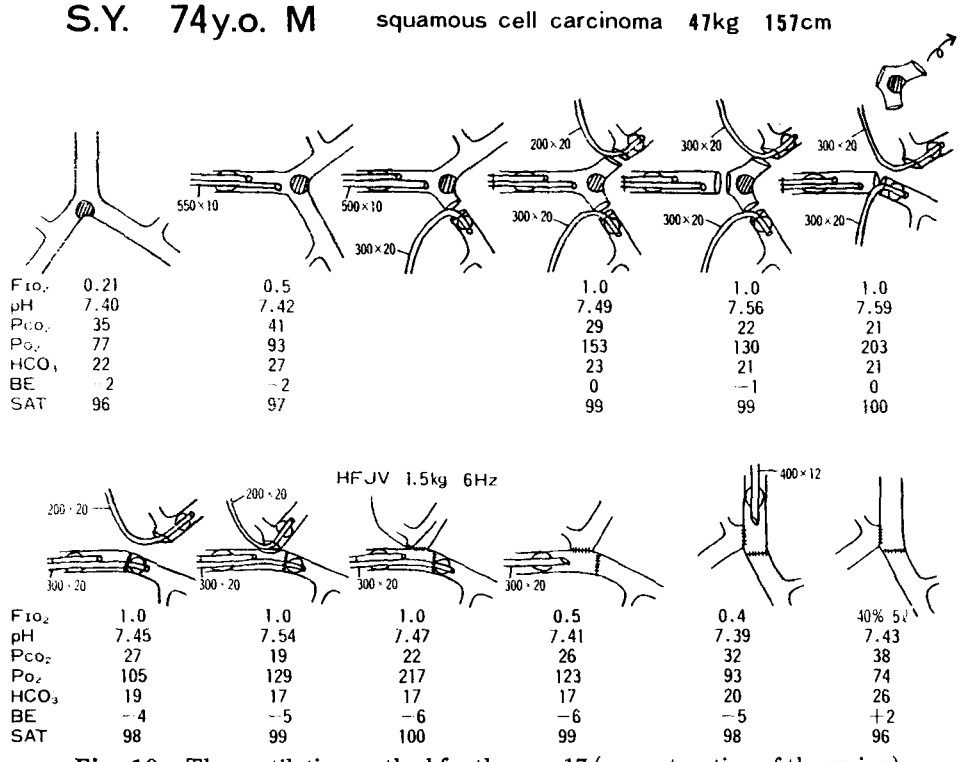


Fig. 10. The ventilation method for the case 17 (reconstruction of the carina) and blood gas values.

Discussion

One-lung ventilation (OLV) is usually done in the lateral position. In the lateral position, does not only OLV produce large right-to-left shunt in the non-dependent lung, but also the distribution of the pulmonary blood flow shift to the dependent lung from the non-dependent one. The mediastinal contents are shifted downward by gravity. Furthermore, general anesthesia and use of muscle relaxants shift the diaphragm and abdominal viscera cephalad. Since the expansion of the dependent lung is significantly restricted in such situation, the functional residual capacity is reduced, resulting in deteriorated oxygenation[1,2]. Thus, adequate ventilation of the dependent lung is essential during OLV. Benumof[2] recommended the following approaches during OLV;

1. Maintain two lung ventilation (TLV) as long as possible
2. Begin OLV with a tidal volume of 8–12 ml·kg^{-1}
3. Adjust the respiratory rate so that Pa_{CO_2} = 40 mmHg
4. Use high F_{IO_2}
5. Frequently or continuously monitor arterial Pa_{O_2} and Pa_{CO_2}.

We set the ventilator conditions agreeing with his recommendations. With this, the Pa_{CO_2} was maintained at approximately 40 mmHg in all cases, while as expected, hypoxemia (Pa_{O_2} below 80 mmHg) occurred in three cases. In case 1, the duration of OLV was short enough to make it unnecessary to intervent to improve oxygenation. In cases 5 and 16, an additional tube was inserted into the truncus intermedius through the sectioned bronchus, making it possible to perform additional middle and lower lobe ventilation. With this, the duration of OLV was shortened in both cases as recommended by Benumof.

A Broncho-cath^{TM} double lumen endotracheal tube (ETT) (for left bronchus) was

used for left OLV. Ordinary ETTs could also be used for the same purpose, being advanced into the left main bronchus under bronchofiberscopic (BFS) guidance, as in cases 5 and 7.

There were three ways to achieve right OLV. The first way was to use a Broncho-cath ETT for the right bronchus. However, it was difficult to set the side hole of a Broncho-cath tube exactly in front of the upper bronchial orifice. Moreover, it was necessary to fix the tube precisely and to check frequently whether it was correctly positioned, using bronchofiberscopy. The second way was to use a Univent tube which blocks the orifice of the left main bronchus with a mobile cuff. In contrast to a Broncho-cath ETT, this tube had advantages such as being inserted easily and having no risk of obstructing the orifice of the right upper bronchus, since the tube itself was placed in the trachea. The disadvantage was that surgical manipulation might accidentally injure the cuff and inadequate ventilation might occur as in case 11. In that case, the tube was advanced into the right main bronchus and right OLV could be continued. The third way was to use an ordinary ETT and a balloon catheter. A balloon catheter placed in the left main bronchus through its cut edge could be used to block the orifice of the left main bronchus. Although this method was easy to perform at any time, there were two possible disadvantages. One was that the balloon with large diameter or the catheter lying in the operating field might disturb the surgical procedures. The other was that, since bleeding blood flowed into the right (dependent) lung until the left main bronchus was completely blocked by the balloon, frequent endobronchial suctioning was necessary.

The reason why the ventilation of the right middle and lower lobe only did not cause hypoxemia in case 13 was apparently that the blood flow of the left lung had been abolished by the pneumonectomy.

No ventilation problems occurred during the reconstruction of the cervical trachea, since the ETT was placed in the distal portion of the surgical manipulation.

The ventilation methods were complicated in the reconstruction of intrathoracic trachea, especially when the lesion included the carina. In cases 16 and 17, two tubes were placed separately in both main bronchi and TLV was applied. We used HFJV for right lung ventilation with an intravenous catheter in case 17, because it took time to complete the anastomosis of the right main bronchus to the trachea.

We could use commonly available ETTs, because all of our patients were adults. Such ETTs cannot always be used in neonate for congenital tracheobronchial stenosis. The use of HFJV and an extracorporeal membrane oxygenator (ECMO) was reported[3]. Even in adults, when the reconstruction of the pulmonary vasculature or the vena cava are also needed, the use of extra-corporeal circulation (ECC) should be considered.

Diverse operative methods were reported for the reconstruction of TBT[4,5]. Anesthesiologists should not only select an appropriate ventilation method suitable for the operative mode, but they should also be familiar with the various ventilation methods and techniques.

(Received May 1, 1989, accepted for publication Jun. 20, 1989)

References

1. Nunn JF: Respiratory aspects of anesthesia, Applied Respiratory Physiology. 3rd ed. Edited by Nunn JF, London, Butterworths, 1987, pp. 350–378
2. Benumof JL: Physiology of the open chest and one-lung ventilation, Thoracic Anesthesia. Edited by Kaplan JA, New Yorl, Churchill Livingstone, 1983, pp. 287–316
3. Hayashi K, Ishida H, Kamagata S, Sanhonmatsu T, Nagashima M, Sugafuji S, Satsumahayashi K, Kijimoto T, Suzuki G: A case of tracheal plasty with ECMO in congenital tracheal stenosis. Jpn J Pediatr Surg 23:349, 1987
4. Nakamoto K, Maeda M, Nanjo S, Nakamura K: Theoretically possible modes of tracheobronchial plasty. Jpn Thorac Surg 40:12–17, 1987
5. Maeda M: Tracheobronchoplasty. Jpn Thorac Surg 40:1105–1120, 1987