One-lung or two-lung ventilation during transthoracic oesophagectomy?

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The purpose of this study was to determine the safety of one-lung ventilation (OLV) during transthoracic oesophagectomy. Changes in circulatory and respiratory variables during and after operation were compared in patients receiving OLV or conventional two-lung ventilation (TLV). Thirty patients undergoing transthoracic oesophagectomy were randomly divided into either the OLV or the TLV group. During thoracotomy, FiO_2 was kept to 1.0. The PaO_2 in the OLV group decreased from the prethoracotomy value of 467 ± 84 mmHg to 227 ± 162 mmHg during OLV. This decrease was greater than the decrease from 484 ± 79 mmHg to 380 ± 119 mmHg in the TLV group ($P < 0.05$). The shunt ratio increased in the OLV group from $20 \pm 7\%$ to $35 \pm 13\%$ during OLV which was greater than the increase in the TLV group ($26 \pm 7\%$ from $17 \pm 8\%$) ($P < 0.05$). Other variables and the incidence of the complications, however, were little different between the two groups during and after OLV and up to POD 3. It is concluded that OLV is as safe as TLV during oesophagectomy.

Cette étude vise à évaluer la sécurité de la ventilation unipulmonaire (OLV) pendant l'oesophagectomie transthoracique. Les modifications aux variables circulatoires et respiratoire pendant et après l'intervention sont comparées chez des patients en OLV ou sous ventilation conventionnelle bipulmonaire (TLV). Trente patients subissant une oesophagectomie transthoracique sont répartis au hasard entre les groupes OLV et TLV. Pendant la thoracotomie, la FiO_2 est maintenue à 1.0. Dans le groupe OLV, la PaO_2 baisse pendant l'OLV de la valeur préthoracotomie de 467 ± 84 mmHg à 227 ± 162 mmHg. Cette baisse est plus importante que la baisse de 484 ± 79 mmHg à 380

± 119 mmHg qui survient dans le groupe TLV ($P < 0.05$). La fraction de shunt augmente dans le groupe OLV de $20 \pm 7\%$ à $35 \pm 13\%$ pendant l'OLV, ce qui constitue une augmentation plus importante que l'augmentation constatée dans le groupe TLV (de $17 \pm 8\%$ à $26 \pm 7\%$) ($P < 0.05$). Cependant, les autres variables et l'incidence des complications ne diffèrent pas entre les deux groupes pendant et après OLV jusqu'au troisième jour postopératoire. Pendant l'oesophagectomie, la marge de sécurité est la même entre OLV et TLV.

One-lung ventilation (OLV) during thoracotomy for oesophagectomy was first reported by Scherer,¹ followed by several authors.²⁻⁴ The purpose is to achieve good surgical exposure and to allow aggressive lymphadenectomy around the upper mediastinum. It is not known whether the collapsed lung during OLV affects cardiopulmonary variables and postoperative pulmonary complications or whether compression of the lung and heart to achieve good surgical conditions during conventional two-lung ventilation (TLV) affect cardiopulmonary function. Therefore, we evaluated the safety of OLV compared with TLV, examining the circulatory and respiratory changes during and after transthoracic oesophagectomy.

Methods

Thirty patients with carcinoma of the thoracic oesophagus were prospectively randomized into two groups to receive either left OLV or conventional TLV group during transthoracic oesophagectomy. All tracheas were intubated with a Carlens' endobronchial double lumen tube.⁵ In 15 patients, the lungs were ventilated by left OLV immediately after opening the chest whilst in the other 15, TLV was maintained. Hexothane ($< 1.0\%$ inspired) and neuroleptanalgesia with epidural anaesthesia were used during thoracotomy. The lungs were ventilated as follows: FiO_2 1.0, tidal volume $10 \text{ ml} \cdot \text{kg}^{-1}$, and average respiratory rate of 16 bpm, adjusted to maintain $PaCO_2$ of 35–45 mmHg. In the TLV group, hyperinflation was freely applied. Before closing the chest, the lungs were expanded to a maximum inspiratory pressure of 30 cm H_2O in both groups.

Key words

ANAESTHESIA: thoracic;

EQUIPMENT: tubes, endobronchial.

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Measurements and calculations

A 7F Swan-Ganz catheter (American Edwards Laboratories, Irvine, Calif.) was inserted into the pulmonary artery via the right external jugular vein at the beginning of anaesthesia. A left radial artery was cannulated with a 23G cannula tube for determination of mean arterial blood pressure (mBP) and blood gas analysis using acid-base analyzer (Radiometer, ABL30). These catheters were connected to a pressure transducer (Nihon Kohden, TP-300T) and the pressure wave form was displayed on the multi-chart recorder (Nihon Kohden, RM-6000).

Measured variables included heart rate (HR), central venous pressure (CVP), mBP, mean pulmonary arterial pressure (mPAP), and pulmonary capillary wedge pressure (PCWP).

The arterial catheter was used to sample blood for blood gas analysis. The pulmonary artery catheter allowed sampling of mixed venous blood gas for analysis as well as measurement of cardiac output (CO) by triplicate thermal dilution using a cardiac output computer (American Edward, 9520).

From these primary measurements, the following physiological secondary variables were derived using standard formulas: cardiac index (CI), stroke volume index (SVI), systemic vascular resistance (SVR), pulmonary vascular resistance (PVR), left ventricular stroke work index (LVSWI), right ventricular stroke work index (RVSWI).

The alveolar oxygen tension was estimated by applying the standard alveolar air equation and the oxygen contents of arterial, mixed venous, and capillary blood were calculated using the following formula:⁶

$$O_2 = 1.34 \times Hb \times SO_2 + 0.0031 \times PO_2$$

Then, physiological shunt was calculated.

After 15 min under stable condition, baseline measurements were obtained as control (preoperative) and repeated at 15, 30, 60, 90 min after the chest was open (intraoperative), and at the first, second, and third postoperative days (POD).

Chest x-ray

Chest x-ray appearances of the two groups were examined on POD 1, 2, 3, 5, 7, 10, 14, 20, 30. Abnormal appearances were classified into four types: (1) a patchy pattern with scattered small nodules and reticular shadow less than 10 mm, (2) an infiltrative pattern with clearly defined nodules more than 10 mm in size, (3) a widely disseminated pattern like atelectasis, and (4) a vascular pattern with high density hilar vascular shadows. The location of these shadows was divided into four regions: lateral upper and lower regions with referring the height of the right interlobar fissure (hairline). The duration and location of abnormal shadows were investigated.

TABLE I Patient characteristics

	TLV (n = 15)	OLV (n = 15)
Age (yr)	62.1 ± 8.8	64.0 ± 5.1
Sex (M/F)	14/1	14/1
Tumour location		
- Upper/Middle/Lower stage ⁷	2/7/6	3/9/3
- 0/I/II/III/IV curability ⁷	2/0/1/2/10	4/0/1/3/7
- III/II/I/0	5/0/4/6	7/0/3/5
Spirometry		
- VC (ml)	3810 ± 882	3552 ± 660
- %VC	115 ± 21	111 ± 14
- %FEV _{1.0}	74.5 ± 6.4	71.1 ± 11.6
Op. time (min)	387 ± 60	408 ± 43
Blood loss (ml)	1068 ± 705	976 ± 460
Duration of open chest (min)	139 ± 28	137 ± 27
Duration of OLV (min)	-	101 ± 17

Mean ± SD. P: NS.

Postoperative complications

Pulmonary complications were defined by the following criteria: abnormal shadow on the chest x-ray as pneumonia, atelectasis, and oedema, hypoxia (PaO₂ < 100 mmHg with FiO₂ 0.4 over 12 hr), and/or prolonged ventilation for > five days. Moderate pneumothorax and pleural effusion were excluded.

Analytic method

Results are expressed as mean (M) ± SD. The ANOVA test was used to test for significant level of differences among groups and Chi-square test for patient characteristics and rates of postoperative complications. Probability values of *P* < 0.05 were considered to be statistically significant.

Results

Characteristics of the 30 patients are shown in Table I. Mean age, sex ratio, tumour location, stage, assessment of curability,⁷ and preoperative spirometry of both groups were not different. Blood loss during operation, 1068 ± 705 ml in the TLV group, was not different from that, 976 ± 460 ml, in the OLV group. The duration of open chest was 139 ± 28 min in the TLV group and 137 ± 29 min in the OLV group and the duration of OLV was 101 ± 17 min (range 70–120 min).

In 29 patients the oesophagus was substituted with the greater curvature of the stomach retrosternally and in one (TLV group) with the right hemi-colon in the antethoracic route.

In one patient OLV was unsatisfactory because of an inconvenient position of endotracheal tube. Reintubation with a conventional single-lumen nasotracheal tube required 18 ± 6 min.

TABLE II Postoperative complications

	TLV	OLV
Pulmonary	5 (33.3%)	4 (26.7%)
- Pneumonia	2 (aspiration)	1
- Pulmonary oedema		1
- Atelectasis	1	
- Bronchial erosion	1	
- Pyothorax	1	2
Anastomotic leak	1 (6.7%)	2 (13.3%)
Intraabdominal abscess		2 (13.3%)
DIC	1 (6.7%)	

DIC: disseminated intravascular coagulopathy. *P*: NS.

Postoperative complications

Five patients (33.3%) in the TLV group and four (26.7%) in the OLV group developed pulmonary complications. In the TLV group, two had aspiration pneumonia due to recurrent nerve paralysis on POD 13 and 18, one developed atelectasis due to sputum retention on POD 2, one had bronchial erosion on PDO 4 due to aggressive lymphadenectomy and one had a pyothorax. In the OLV group one patient developed pneumonia associated with mediastinitis from cervical anastomotic leakage on POD 5, one had pulmonary oedema due to cardiac failure on POD 3, and two developed pyothorax. Other non-pulmonary complications consisted of one anastomotic leakage in the TLV group and two in the OLV group, two intraabdominal abscess in the OLV group, and one disseminated intravascular coagulation (DIC) in the TLV group (Table II).

Circulatory variables

Circulatory changes are shown in Table III. There was no difference between the OLV and TLV groups up to POD 3. Compared with preoperative values the HR increased on POD 2 and POD 3 in both groups ($P < 0.05$), and CVP and SVR in the OLV group decreased after surgery ($P < 0.05$).

Respiratory variables

Respiratory changes are shown in Table IV. The PaO_2 in the OLV group decreased from the prethoracotomy value of 467 ± 84 mmHg to 227 ± 162 mmHg during OLV and this decrease was greater than the decrease to 380 ± 119 mmHg from 484 ± 79 mmHg in the TLV group ($P < 0.05$). The decrease of PaO_2 continued during 90 min by OLV. However, PaO_2 returned to prethoracotomy values after OLV was stopped. No difference was found between the two groups in the postoperative period (Figure 1). In the OLV group, seven patients (46.7%) had $\text{PaO}_2 < 100$ mmHg and in one hyperinflation was applied at 30 and 60 min after the beginning of OLV be-

cause of PaO_2 of 63.7 mmHg. The $\dot{Q}_s/\dot{Q}_t$ increased in the OLV group from $20 \pm 7\%$ to $35 \pm 13\%$ during OLV which was greater than the increase in the TLV group ($26 \pm 7\%$ from $17 \pm 8\%$) ($P < 0.05$). However, the $\dot{Q}_s/\dot{Q}_t$ returned to prethoracotomy value in the postoperative period and no difference was found between both groups (Figure 2). The A-aDO_2 and the RI increased more during OLV than TLV ($P < 0.05$). The A-aDO_2 decreased after surgery in both groups. In summary, in the OLV group PaO_2 , $\dot{Q}_s/\dot{Q}_t$, A-aDO_2 , and RI changed transiently during OLV but returned to prethoracotomy values after closing the chest.

Chest x-ray

Abnormal shadows were seen in 40% of patients on POD 2 and POD 3 in the TLV group and in 33% from POD 3 to POD 10 in the OLV group (P : NS) (Figure 3). Of the 25 lesions in the TLV group eleven were patchy (44%), eight had a vascular pattern (32%), four infiltration (16%) and two had a disseminated pattern (8%). In 19 lesions of the OLV group, seven were patchy with infiltration (36.8%), four vascular (21.1%) and one had a disseminated pattern (5.3%). Abnormal shadows were located in the right lower region in 66.7% on POD 2 and POD 3 in the TLV group and 60.0% on POD 5 and POD 7 in the OLV group. Shadows occurred in left lower region in 22.2% of TLV and 16.7% of OLV. Lesions were infrequent in bilateral upper regions. The patchy and vascular abnormal shadows were obvious between POD 2 and POD 7 in the right lower region in both groups.

Discussion

The indications for one-lung ventilation (OLV) can be divided into absolute and relative indications.⁸ In the latter, OLV during oesophageal resection is to obtain a better surgical exposure but has a low priority. On the other hand, Scherer¹ reported OLV in oesophageal surgery in 1984, which was followed by several other reports.^{2-4,9} The purpose of OLV is to achieve good surgical exposure, to allow aggressive lymphadenectomy around the upper mediastinum, and to allow thoracoscopic mobilization of the oesophagus. Therefore, OLV during oesophageal surgery has become a frequent method of choice.

During OLV, transient increases of $\dot{Q}_s/\dot{Q}_t$ and decreases of PaO_2 are well known but these changes returned immediately after OLV was stopped.^{2,10} This is confirmed by our results. Scherer¹ and Sugihara² reported that CI did not change during and immediately after OLV and the increase of mPAP and SVR during OLV were signs of hypoxic pulmonary vasoconstriction in the unventilated lung but these variables returned to the previous value after OLV was stopped. During OLV, hypoxia may be a severe problem. In this study, seven

TABLE III Circulatory variables

During thoracotomy									
	Group	Preop.	15'	30'	60'	90'	1 POD	2 POD	3 POD
HR (bpm)	TLV	72 ± 12	77 ± 14	82 ± 18	79 ± 17	83 ± 14	94 ± 14§	94 ± 12§	103 ± 15§
	OLV	75 ± 12	85 ± 14	85 ± 12	86 ± 14	83 ± 23	93 ± 23§	97 ± 13§	87 ± 16*†
mPB (mmHg)	TLV	83 ± 19	76 ± 19	81 ± 16	82 ± 15	82 ± 13	93 ± 23	89 ± 19	89 ± 19
	OLV	95 ± 15	82 ± 13	88 ± 17	89 ± 14	91 ± 22	88 ± 16	88 ± 23	81 ± 9†
mPAP (mmHg)	TLV	15 ± 5	17 ± 7	19 ± 7	15 ± 5	16 ± 7	17 ± 4	16 ± 5	14 ± 5
	OLV	19 ± 7	20 ± 6	19 ± 8	20 ± 7*	20 ± 9	18 ± 4	17 ± 4	16 ± 4
PWP (mmHg)	TLV	9 ± 4	10 ± 5	11 ± 7	9 ± 5	8 ± 6	8 ± 4	7 ± 3	5 ± 6
	OLV	12 ± 7	12 ± 5	13 ± 6	11 ± 6	10 ± 7	9 ± 3†	6 ± 4†	7 ± 3†
CVP (cmH ₂ O)	TLV	7.6 ± 3.7	8.9 ± 3.5	9.9 ± 3.1	9.9 ± 3.7	9.5 ± 2.2	8.3 ± 6.4	4.9 ± 3.4	5.0 ± 2.9
	OLV	9.9 ± 4.6	15.4 ± 5.0*	16.3 ± 4.7*	13.3 ± 5.9	11.3 ± 4.4	7.2 ± 2.7†	6.7 ± 3.2†	6.9 ± 2.3
CI (L · min ⁻¹ · m ⁻²)	TLV	2.99 ± 0.74	3.32 ± 1.16	3.35 ± 1.32	3.14 ± 1.15	3.26 ± 1.15	3.68 ± 1.01	3.96 ± 0.93	3.88 ± 0.92
	OLV	3.13 ± 0.56	3.19 ± 0.51	2.97 ± 0.66	2.87 ± 0.53	3.02 ± 1.11	3.79 ± 0.73	4.07 ± 0.58	4.14 ± 1.12†
SVI (ml · beat ⁻¹ · m ⁻²)	TLV	39.9 ± 10.7	41.0 ± 8.2	38.5 ± 8.7	37.5 ± 8.9	37.7 ± 11.3	37.5 ± 11.4	41.1 ± 10.3	36.5 ± 7.7
	OLV	42.0 ± 7.3	38.1 ± 7.8	35.8 ± 9.5	33.9 ± 7.3	37.3 ± 11.6	42.6 ± 11.3	43.0 ± 9.6	48.2 ± 12.8*
SVR (dynes · sec · cm ⁻⁵)	TLV	2181 ± 619	1798 ± 642	1912 ± 615	2156 ± 802	1980 ± 525	1971 ± 653	1741 ± 320†	1874 ± 529
	OLV	2221 ± 521	1704 ± 412	2006 ± 614	2197 ± 717	2311 ± 834	1708 ± 305†	1613 ± 458†	1507 ± 337*†
PVR (dynes · sec · cm ⁻⁵)	TLV	160 ± 89	207 ± 97	206 ± 128	156 ± 142	206 ± 128	247 ± 81†	207 ± 54	216 ± 78
	OLV	189 ± 99	195 ± 111	160 ± 130	259 ± 128*	266 ± 154	220 ± 85	213 ± 54	169 ± 60
LVSWI (g · m · m ⁻²)	TLV	38.8 ± 14.8	36.9 ± 17.4	36.7 ± 14.0	33.9 ± 16.0	37.5 ± 15.4	42.2 ± 20.7	45.6 ± 17.9	42.0 ± 15.9
	OLV	46.7 ± 10.5	36.5 ± 11.2	36.6 ± 12.3	35.6 ± 9.8	40.7 ± 14.0	46.9 ± 18.7	48.1 ± 17.1	49.0 ± 17.0
RVSWI (g · m · m ⁻²)	TLV	4.31 ± 3.65	5.09 ± 4.99	4.67 ± 3.97	2.74 ± 3.59	3.53 ± 4.31	4.23 ± 2.39	5.71 ± 2.40	4.64 ± 1.69
	OLV	5.66 ± 4.82	2.35 ± 3.26	1.52 ± 4.42*	3.32 ± 3.86	5.32 ± 6.75	6.51 ± 3.64	5.98 ± 3.17	6.06 ± 3.09

M ± SD. *P < 0.05, †P < 0.01 TLV vs OLV. ‡P < 0.05, §P < 0.01 vs preop.

TABLE IV Respiratory variables

During thoracotomy												
	Group	Preop.	90'				1 POD		2 POD		3 POD	
			15'	30'	60'	90'						
PaO ₂ (mmHg)	TLV	484 ± 79	380 ± 119	367 ± 115	382 ± 117	382 ± 133	112 ± 23	104 ± 26	102 ± 24			
	OLV	467 ± 84	227 ± 162*	192 ± 129*	191 ± 99*	199 ± 123*	102 ± 23	92 ± 24	88 ± 15			
PaCO ₂ (mmHg)	TLV	37 ± 7	37 ± 8	40 ± 10	40 ± 9	43 ± 8	36 ± 3	37 ± 3	37 ± 3			
	OLV	34 ± 5	40 ± 9	40 ± 9	42 ± 10	45 ± 13	37 ± 5	36 ± 4	36 ± 4			
Qs/Qt (%)	TLV	17.3 ± 7.8	26.6 ± 10.6	26.0 ± 7.3†	22.6 ± 8.5	23.1 ± 8.8	11.4 ± 4.0	14.8 ± 6.3	13.0 ± 7.0			
	OLV	19.7 ± 6.8	35.2 ± 14.2†	35.0 ± 12.6*†	34.3 ± 9.1†§	34.4 ± 10.1†§	15.7 ± 8.8	17.4 ± 10.0	16.1 ± 5.3			
A-aDO ₂ (mmHg)	TLV	192 ± 81	295 ± 119§	306 ± 115§	291 ± 117§	319 ± 171†	98 ± 41†	103 ± 59	73 ± 56§			
	OLV	242 ± 85	447 ± 161†§	481 ± 128†§	480 ± 98†§	468 ± 124*§	109 ± 50§	113 ± 59†	95 ± 45§			
RI	TLV	0.44 ± 0.26	1.08 ± 1.15	1.22 ± 1.46	0.97 ± 0.75	1.09 ± 1.11	0.93 ± 0.47†	1.01 ± 0.57†	0.85 ± 0.56			
	OLV	0.70 ± 0.44	3.57 ± 3.48*	3.75 ± 3.12†	3.03 ± 2.15†	2.91 ± 2.15†	1.09 ± 0.63	1.29 ± 0.72	1.21 ± 0.41			

M ± SD. *P < 0.05, †P < 0.01 TLV vs OLV. ‡P < 0.05, §P < 0.01 vs preop.

FIGURE 1 Changes of PaO₂. Mean $\pm$ SD. * $P < 0.05$. ** $P < 0.01$.

FIGURE 2 Changes of Qs/Qt. Mean $\pm$ SD. * $P < 0.05$. ** $P < 0.01$.

of 15 patients in the OLV group had transient PaO₂ values < 100 mmHg within 30 min after OLV was started and one of the seven needed hyperinflation. Thus, careful observation of PaO₂ is recommended within 30 min after the start of OLV.¹¹

In the postoperative period, it has not been determined if the collapsed lung during OLV affects cardiopulmonary variables and pulmonary complications. Therefore, we prospectively evaluated the safety of OLV compared with two-lung ventilation (TLV) in a randomized fashion. First, cardiopulmonary variables were not different between the one-lung and two-lung ventilation (TLV) groups up to POD 3. Second, A-aDO₂ increased in the postoperative period in both groups, but there was no difference between the two groups. Third, the rates of postoperative pulmonary complications and abnormal chest x-ray shadows were not different between the two groups. Sugihara² reported that the rate of pulmonary complication after oesophagectomy using OLV was 12.5% and that was less than the 14.1% seen with non-OLV.

FIGURE 3 The frequency of abnormal chest x-ray findings. Each fine bar represents the duration of abnormal finding of each patient.

He considered that this was associated with decreased compression to the heart and lung by the surgical instruments and with decreased stimulation of the inspired gas to the bronchial mucosa of the non-ventilated lung during OLV. Imamura⁴ reported that during OLV in patients undergoing oesophagectomy for oesophageal cancer with pulmonary dysfunction, high-frequency jet ventilation contributed to a decrease of postoperative pulmonary complications and the survival curve of these patients was not different from that of other patients. For these reasons, it appears that OLV during oesophageal surgery does not affect postoperative cardiopulmonary changes and pulmonary complications compared with TLV.

Thus, it is concluded that OLV during oesophagectomy is as safe as TLV regarding the incidence of cardiopulmonary variables and pulmonary complications.

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