Video-assisted thoracoscopic surgery does not deteriorate postoperative pulmonary gas exchange in spontaneous pneumothorax patients

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Received 12 October 1998; received in revised form 8 March 1999; accepted 7 April 1999

Abstract

Objectives: Video-assisted thoracoscopic surgery (VATS) is generally recognized as a less invasive method than thoracotomy. However, the influence of VATS on postoperative pulmonary gas exchange has yet to be evaluated. Methods: Thirty eight patients with spontaneous pneumothorax were randomized into bullectomy by VATS (n = 20) or axillary thoracotomy (n = 18). Gas exchange was assessed by using hot wire mass spectrometer, and blood gas analysis preoperatively and postoperatively at 1, 3, 6, 12, 24, and 48 h and on days 4 and 6. Postoperative pain control was managed by continuous epidural morphine injection and administration of diclofenac sodium orally or suppository. Postoperative atelectasis was assessed by daily chest roentgenograms. Results: VATS patients had continuously higher PaO₂ than axillary thoracotomy at 12, 48 h and day 4 postoperatively (P < 0.05). Alveolar-arterial oxygen tension gradient in VATS patients was significantly less than that in patients with axillary thoracotomy from the 6th h throughout to the 4th day postoperatively (P < 0.01). Use of postoperative analgesics and the incidence of peripheral atelectasis were more frequent in patients with axillary thoracotomy. Conclusions: Bullectomy via VATS was less deleterious to pulmonary gas exchange. Axillary thoracotomy caused worsening of gas exchange postoperatively due to incisional pain, chest wall deformity, and peripheral atelectasis. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Pulmonary gas exchange; Thoracotomy; Video-assisted thoracoscopic surgery; Atelectasis; Spontaneous pneumothorax

1. Introduction

Pulmonary complications, such as atelectasis, pneumonia, pulmonary edema and ventilatory insufficiency, are the leading causes of postoperative morbidity after thoracic surgery [1]. Older age, obesity, low serum protein and cardiopulmonary disease are risk factors for postoperative complications, even after minor surgery. It has been reported that minor operations such as a simple thoracotomy have adverse effects on chest wall motion and pulmonary function, represented by total lung capacity (TLC) and functional residual capacity (FRC) [2,3].

To minimize thoracic surgical trauma, video-assisted thoracoscopic surgery (VATS) has been introduced as an alternative to thoracotomy for the treatment of certain thoracic diseases. This less invasive surgical technique is gaining popularity because of a low incidence of complications and an excellent safety profile [4,5]. It is also associated with lesser postoperative pain, and a shorter hospital stay [5,6]. The effect of VATS on postoperative physiologic parameters, however, has not been well studied. Investigation of postoperative pulmonary physiology is important for the understanding of the effects, complications and influence of VATS on lung function and chest wall motion.

Recently, constant monitoring of pulmonary gas exchange has become possible by hot wire mass spectrometer [7]. This non-invasive method allows for detailed and accurate study of the breathing pattern, oxygen consumption (VO₂), and CO₂ production (VCO₂). Furthermore, gas exchange, represented by the alveolar-arterial oxygen tension gradient (AaΔO₂), can be measured by combining the above measurements with arterial blood gas analysis.

The purpose of the current study is to investigate the influence of bullectomy with axillary thoracotomy or VATS on postoperative gas exchange measured by hot wire mass spectrometer. Furthermore, we intend to study
the effects of postoperative complications on gas exchange parameters.

2. Materials and methods

2.1. Patients

The study protocol was approved by the institutional review board of Sakura National Hospital. The nature, purpose, and potential risks of the study were carefully explained to all patients before obtaining their informed consent to participate. None of the participants had preoperative cardiac or respiratory functional abnormalities evident by either ECG or spirometry. A total of 322 measurements of pulmonary gas exchange were performed in 38 patients with unilateral spontaneous pneumothorax from April, 1992 through March, 1995. None of the patients had diffuse emphysematous lungs or giant bullae, but all had limited blebs or bullae confirmed by chest computed tomography (CT) with 10 mm slice thickness. Patients were randomized into the axillary thoracotomy (thoracotomy group) or VATS group. At the time of diagnosis of pneumothorax, a chest tube drainage was placed. Bullae or blebs were confirmed by chest radiographs and CT. The operation was usually scheduled within 10 days after tube drainage. In the event of continuous air leakage, the patient was excluded from randomization (n = 5). This was done to avoid the impact of tube drainage on pulmonary gas exchange. All of the 38 remaining patients that entered randomization were in excellent condition with full inspiratory expansion of their lungs at the time of operation. Of these, 18 had bullectomy through axillary thoracotomy, and 20 through VATS.

2.2. Anesthesia

Anesthesia was performed by one anesthesiologist (Y.M.). Since general anesthesia alters postoperative breathing pattern [8,9], an attempt was made to keep anesthetic procedures uniform and to achieve the same level of consciousness at the end of surgery in all patients. The patients were premedicated with 0.5 mg of atropine sulfate, 25 mg of hydroxyzine hydrochloride and 10 mg of diazepam intramuscularly 45 min prior to the operation. For management of postoperative analgesia, epidural catheterization into the interspace between the fourth and fifth thoracic vertebra was performed before induction of general anesthesia. General anesthesia was induced with an intravenous injection of 6 mg/kg of thiopental and intubation was facilitated by 1 mg/kg of suxamethonium chloride. A double-lumen endotracheal tube was used in all patients for uniformity of respiratory support. Positioning of the double-lumen endotracheal tube was verified by fiberoptic bronchoscope. Anesthesia was maintained with nitrous oxide/oxygen (2:1) and 1–2% isoflurane. Pancuronium bromide (0.08 mg/kg) was used to maintain relaxation. Patients were subsequently placed in either the right or left lateral decubitus position. One lung ventilation was started at the time of skin incision. Intraoperatively, blood loss was replaced with crystalloid solutions. No blood transfusion was needed.

Upon completion of each surgical procedure, the patient was returned to the supine position. Reversal of muscle paralysis was achieved with 2.5 mg of neostigmine and 1 mg of atropine sulfate intravenously. We attempted to prevent atelectasis by manual hyperinflation (recruitment maneuver) [10]. After confirming the consciousness of each patient by hand grasp and nod, sufficiency of lung inflation was assessed by chest radiograph. Thereafter, the patient was extubated in the operating room and transferred to the intensive care unit (ICU). Each patient was attempted to be fully conscious on admission to the ICU.

2.3. Surgery

Surgery was performed on all patients by the same thoracic surgeon (Y.S.). In the thoracotomy group, thoracotomy was performed by a 7 cm vertical axillary skin incision at the fourth intercostal space without rib resection. Serratus anterior muscle was divided over a longitudinal span of 10 cm, and the fourth intercostal muscles were incised over a span of 15 cm. The fourth intercostal space was opened 6 cm in width by a retractor. Bullectomy was carried out with autosutures (Proxymate TLC55, Ethicon, Tokyo, Japan) with resection of a small amount of adjacent parenchyma. Upon completion, the incision was closed by four interrupted sutures. A 20 Fr intercostal suction drainage tube was placed through the fifth intercostal space, and the tip of the drainage was positioned toward the apex. In the VATS group, three trocar tubes were inserted through the fifth intercostal space at the mid-axillary line, the fourth intercostal space at the posterior-axillary line, and the third intercostal space at the mid-clavicular line. Bullectomy was also carried out with an endoscopic stapling device (Endopath ELC35, Ethicon) with resection of a small amount of adjacent parenchyma. A 20 Fr intercostal suction drainage tube was placed through the port at the fifth intercostal space in the same manner. Deccorticatio was not performed on any patient. There was no crossover from VATS to open thoracotomy throughout the trial.

2.4. Postoperative care

In both groups, postsurgical pain was controlled by a continuous epidural injection of 0.008 mg/kg per h of morphine hydrochloride for the first 3 days only. Adequacy of analgesia was assessed by questioning the patient at the time of each gas measurement. If analgesia was inadequate, 50 mg of diclofenac sodium was given as a suppository before, or as tablet after the diet was resumed. No epidural bolus injection was given after surgery.
Table 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Thoracotomy</th>
<th>VATS</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M/F)</td>
<td>11/7</td>
<td>14/6</td>
<td>NS</td>
</tr>
<tr>
<td>Age (years)</td>
<td>30.2 ± 12.6</td>
<td>34.4 ± 8.5</td>
<td>NS</td>
</tr>
</tbody>
</table>

**Preoperative value**

<table>
<thead>
<tr>
<th>BGA (room air)</th>
<th>Thoracotomy</th>
<th>VATS</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO2 (mm Hg)</td>
<td>87.5 ± 8.6</td>
<td>88.5 ± 13.9</td>
<td>NS</td>
</tr>
<tr>
<td>PaCO2 (mm Hg)</td>
<td>39.7 ± 3.2</td>
<td>43.7 ± 2.9</td>
<td>NS</td>
</tr>
<tr>
<td>FVC (l)</td>
<td>3.40 ± 1.23</td>
<td>3.74 ± 1.26</td>
<td>NS</td>
</tr>
<tr>
<td>FEV1.0 (l/s)</td>
<td>3.18 ± 1.14</td>
<td>3.39 ± 1.10</td>
<td>NS</td>
</tr>
<tr>
<td>Operation time (min)</td>
<td>60.3 ± 10.2</td>
<td>88.4 ± 21.5</td>
<td>NS</td>
</tr>
<tr>
<td>Blood loss (ml)</td>
<td>10.9 ± 6.0</td>
<td>8.0 ± 2.5</td>
<td>NS</td>
</tr>
<tr>
<td>Postoperative drainage (days)</td>
<td>1.9 ± 1.2</td>
<td>2.2 ± 1.6</td>
<td>NS</td>
</tr>
<tr>
<td>Water balance during operation (ml)</td>
<td>698 ± 402</td>
<td>950 ± 377</td>
<td>NS</td>
</tr>
<tr>
<td>Water balance during the first 3 days (ml/day)</td>
<td>987 ± 450</td>
<td>720 ± 366</td>
<td>NS</td>
</tr>
</tbody>
</table>

2.5. Protocol and measurements

A total of nine serial tests of gas exchange and arterial blood gas analysis were performed preoperatively and at 1, 3, 6, 12, 24, 48 h, and 4 and 6 days postoperatively (day of operation = day 0). Data were not obtained from patients in the VATS group at day 6, because all the patients were discharged by the 5th postoperative day. Preoperative measurement was undertaken under the condition of full lung expansion and no tube drainage. Oxygen consumption (\( \dot{V}O_2 \)), carbon dioxide production (\( \dot{V}CO_2 \)), tidal volume (\( VT \)), respiratory rate (RR), minute volume (\( VE \)) and fractional concentration of inspiratory oxygen (\( FIO_2 \)) were measured by continuous hot wire mass spectrometer with a breath-by-breath basis analysis (RM-300, Minato Medical Science). The instrument was calibrated before each study with a standardized, certified gas mixture (15.02% \( O_2 \), 4.91% \( CO_2 \)). Preoperative and postoperative measurements on days 4 and 6 were performed before breakfast. The patients were supine, comfortable, pain-free and alert in an air-conditioned environment. After a 15-min rest period to allow for stabilization of ventilatory data (steady-state condition), a 15-min test was performed. No patient received any supplemental oxygen during the test. Using the metabolic monitor, \( VO_2 \), \( VCO_2 \) and respiratory quotients (RQ) were measured continuously and the average values of measurements were printed at 15-min intervals. Arterial blood samples were obtained from the radial artery by puncture. Arterial blood gas tension, concentration, saturation and pH were measured with a blood gas analyzer (278 Blood Gas Analyzer, CIBA-Corning, Tokyo, Japan). If asleep at the time of measurement, the patient was woken up, and the adequacy of analgesia was assessed.

From the directly-measured parameters, the following indices were calculated:

\[
\text{RQ} = \frac{\dot{V}CO_2}{\dot{V}O_2}
\]

\[
V_D/V_T = 1 - \frac{V_A}{V_E} = \frac{(P_E \dot{CO}_2 - P_I \dot{CO}_2)}{(P_a \dot{CO}_2 - P_I \dot{CO}_2)}
\]

\[
AaDO_2 = 713 \times F_I O_2 - (PaCO_2/RQ) - PaO_2
\]

where RQ is the respiratory quotient, \( P_I \dot{CO}_2 \), inspiratory pressure for \( CO_2 \); \( P_a \dot{CO}_2 \), inspiratory pressure for \( CO_2 \); \( F_I O_2 \), fractional concentration of inspiratory oxygen; \( V_D/V_T \), dead space-to-tidal volume ratio; \( AaDO_2 \), alveolar-arterial oxygen tension gradient.

Chest roentgenogram was done to assess presence of atelectasis or other pulmonary abnormalities at the end of operation, and on days 1, 2, 4 and 6 postoperatively. The presence of atelectasis was expressed by a four-point score as previously reported by other investigators [12]: 0, no atelectasis; 1, plate-like atelectasis; 2, segmental atelectasis; and 3, lobar atelectasis.

2.6. Data analysis

Data were expressed as mean ± SD. All data were analyzed by SAS statistical software program package Version 6.10 (SAS Institute, Cary, NC).

Variations between patient demographics of two groups were tested with an unpaired t-test or the Mann–Whitney test for continuous variables and the \( \chi^2 \) test or Fisher’s Exact Test for categorical variables. The multiple comparison of paired t-tests for the difference from baseline on different occasions in each treatment group was calculated by the Dunnett method [13,14]. Multiple comparisons of the t-test difference between the treatment groups for each time measurement was adjusted by the re-sampling based method [15]. This method was without replacement sampling in order to avoid the mis-specification of the correlated structure across treatment groups. Concerning the software, we used PROC MULTTEST of SAS/STAT for the above analysis. Differences were considered statistically significant when the \( P \) value was less than 0.05.

3. Results

The clinical patient characteristics are shown in Table 1. None of the demographic differences between the thoracotomy and VATS groups were statistically significant. No patient had any apparent postoperative complication, except atelectasis. Three patients (17%) in the thoracotomy group and no patient in the VATS group requested diclofenac sodium during epidural analgesia. Thirteen patients (72%)
in the thoracotomy group and eight patients (40%) in the VATS group were administered diclofenac sodium three times a day after discontinuation of epidural analgesia ($P\approx 0.046$). All patients in both groups had sufficient analgesia for postoperative pain at each time of measurement of pulmonary gas exchange.

The average duration of preoperative tube drainage was 6.5 ± 1.7 days in the thoracotomy group and 6.9 ± 1.4 days in the VATS group ($P\approx 0.49$). The duration of postoperative tube drainage was 1.9 ± 1.8 days in the thoracotomy group and 2.2 ± 1.6 days in the VATS group ($P\approx 0.43$).

### 3.1. Blood gas analysis

$\text{PaO}_2$ in the thoracotomy and VATS groups did not differ significantly through the measurements. $\text{PaO}_2$ in the thoracotomy group was significantly lower than that in the VATS group at 12, 48 h and day 4 postoperatively ($*P < 0.05$, **$P < 0.01$). Thoracotomy, bullectomy via axillary thoracotomy; VATS, bullectomy via video-assisted thoracoscopic surgery.

### 3.2. Ventilation pattern

The respiratory rate (RR) of each patient increased immediately after surgery. This was more prominent in the thoracotomy group at 6 h ($P = 0.04$). The tidal volume ($V_T$) decreased in subjects of both groups on the 1st day after surgery, and recovered on the 2nd day. The difference was not statistically significant at each time point. Minute volume ($V_E$) at the 3rd and 6th postoperative h in the thoracotomy group was significantly higher than those in the VATS group ($P = 0.01, 0.01$, respectively) (Fig. 3).

$V_D/V_T$ increased immediately after the operation and gradually recovered to the preoperative value with a similar pattern in both groups (Fig. 4).

### 3.3. Gas exchange

Since $\dot{V}O_2$ and $\dot{V}CO_2$ levels were stable during the tests, RQ remained constant and there was no difference between the two groups at any time point (data not shown).

While $\text{AaDO}_2$ in the thoracotomy group tended to increase after 6 h (statistically not significant), $\text{AaDO}_2$ measurements in the VATS group stayed at their preoperative value throughout the study. Therefore, $\text{AaDO}_2$ in the thoracotomy group was significantly higher than the VATS group ($**P < 0.01$).

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that in the thoracotomy group, despite a longer operating time in the VATS group. This finding may suggest that one lung ventilation may not be deleterious to gas exchange during a relatively short operation.

The impairment of lung function is accompanied by a reduction in total lung capacity (TLC), vital capacity (VC), residual volume (RV) and functional residual capacity (FRC) [3]. Reduction in lung volume reaches a nadir at 4 days [2], and in some cases can persist for weeks to months [17]. This may be because thoracotomy induces pathophysiologic changes. These include mechanical lung damage by surgical manipulation, paralysis of the cough reflex, atelectasis, deformity of rib cage, intrapulmonary exudates, pleural effusion and postoperative pain. The most important factor for the influence on postoperative pulmonary function is postoperative pain [5, 18]. Hypoxemia induced by postoperative pain is thought to be due to smaller tidal volumes to avoid significant pain [19]. In this study, the tidal volume was similar between the two groups at each time point, and all the patients continuously received sufficient analgesia. Although the effect of postoperative pain cannot be neglected, other factors, such as physiological alterations of the rib cage or thoracic muscles, may still have existed. Indeed, Furrer et al. [20] reported that decrease in pulmonary function was slightly more pronounced after thoracotomy than after thoracoscopy during the early postoperative period, even with similar pain relief. Radberg et al. [21] reported that far fewer restrictions of shoulder movements in thoracoscopy patients were identified compared to thoracotomy patients without any difference in pain sensation. Hazelrigg et al. [22] reported that patients undergoing muscle-sparing thoracotomies had lesser postoperative pain than standard thoracotomies with similar pulmonary function parameters. Gebhard et al. [23] reported that patients with pneumothorax treated by open thoracotomy had higher concentrations of inflammatory mediators, such as C-reactive protein, prostacyclin and thromboxane A₂, than those who underwent VATS. They suggested that VATS, compared to open thoracotomy, minimized inflammatory damage to the chest wall. These reports suggest that even with sufficient analgesia, thoracotomy may adversely affect postoperative pulmonary function. The incision of the serratus anterior muscle and the intercostal muscles for exposure of chest and suturing of the fourth and fifth ribs for closure of thoracic cavity may cause restrictive dysfunction of the rib cage motion in the thoracotomy group.

In this study, no patient had pulmonary dysfunction with inadequate PaO₂ level at any time. The subjects of this study were relatively young with a median age of 30.2 ± 12.6 years in the thoracotomy and 34.4 ± 8.5 years in the VATS group. However, attenuation of postoperative oxygenation in older patients is more prominent than younger patients [24]. Therefore, we believe that even minor thoracotomy imposes the risk of adversely affecting pulmonary function and oxygenation in older patients.

We speculate that intensity of postoperative pain and deformity of the rib cage in thoracotomy patients reduces...
the expansion of thoracic cavity, which in turn induces peripheral atelectasis. The lesser amount of required analgesia and less frequent postoperative atelectasis in the VATS group is in support of our hypothesis. Similar results were reported by Tschernko et al. [18]. Our VATS group patients also showed better PaO2 and lower AaDO2, which can be because of lesser pain, restriction of rib cage and atelectasis.

There was no disadvantage of VATS regarding gas exchange.

Peripheral atelectasis tended to appear more at day 1 than the day of surgery, and to disappear by day 4. Rothen et al. reported that although manual hyperinflation (recruitment maneuver) decreased pulmonary shunt for up to 40 min after general surgery, atelectasis can reappear at a later time [10,25]. This was because lung collapse could recur upon return to conventional ventilation after hyperinflation. This phenomenon might affect the change of PaO2 and AaDO2 in the thoracotomy group. From the 1st through the 6th h, both values kept their preoperative value. Thereafter, they started to decline gradually until day 4 (statistically not significant). The degree of gas exchange was parallel to radiographic appearances.

In conclusion, even minimal thoracotomy can cause an impairment of gas exchange in the immediate postoperative period because of pain, restriction of chest wall motion and peripheral atelectasis. Thoracoscopic surgery was less deleterious to gas exchange compared to open thoracotomy.

Acknowledgements

The authors would like to thank Naoki Ishizuka (Division of Biostatistics, Tokyo University, Tokyo, Japan) and Eri Sekine (Quintiles Asia Inc., Tokyo, Japan) for statistical consultation. We also acknowledge Mehrdad Behnia (Division of Pulmonary and Critical Care Medicine, Indiana University, Indianapolis, Indiana) for his review of the manuscript.

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