Pulmonary Capacity in Lung Cancer Patients Prior to Lung Resection
— Comparison of the Unilateral Pulmonary Artery Occlusion Test with Expired Gas Analysis during Exercise Testing —

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Summary: We attempted to determine if expired gas analysis during exercise testing has equal value to the unilateral pulmonary artery occlusion test (UPAO). Sixty-four lung cancer patients were evaluated. We performed UPAO and measured mean pulmonary artery pressure ($P_{PA}$) and cardiac output (C.O.) 15 min later, and calculated total pulmonary vascular resistance (TPVR). Expired gas analysis during exercise testing was performed, and the maximum oxygen consumption per unit body surface area ($V_{O2\text{max}}/m^2$) and the anaerobic threshold (AT/m²) were calculated. The patients were divided into two groups according to the $P_{PA}$ as follows: Group $P_{PA}(L)$ and Group $P_{PA}(H)$, and the TPVR as follows: Group TPVR(L) and Group TPVR(H). Comparative studies of the mean values of $V_{O2\text{max}}/m^2$ and AT/m² were performed between the two groups. $V_{O2\text{max}}/m^2$ was significantly higher in Group $P_{PA}(L)$ than in Group $P_{PA}(H)$. $V_{O2\text{max}}/m^2$ was significantly higher in Group TPVR(L) than in Group TPVR(H). TPVR and $V_{O2\text{max}}/m^2$ showed no significant correlation, but a weak negative quadratic correlation with the equation $y = 2276 - 246.6 \log x$ was found. This result led a minimal acceptable levels for lung resection of $V_{O2\text{max}}/m^2$ of 650 ml/min/m² corresponding to the TPVR levels of 700 dyne.sec.cm⁻²/m².

Key words: lung resection, expired gas analysis, exercise testing, unilateral pulmonary artery occlusion test, maximum oxygen consumption

Introduction

Many patients with lung cancer are elderly persons over 70 years of age. Surgery in these patients reduces pulmonary function. To evaluate preoperative pulmonary function, the unilateral pulmonary artery occlusion test (UPAO) (Carlens et al. 1951; Sloan et al. 1955) is often performed in addition to spirometry. However, UPAO is an invasive procedure that is difficult to perform on...
outpatients. In order to simultaneously evaluate pulmonary ventilation and circulation function, we conducted a study using expired gas analysis during exercise testing. This procedure is performed widely in exercise physiology as a method for evaluating exercise tolerance. Recently this procedure has been introduced in thoracic surgery as a comprehensive method for preoperative (Miyoshi et al. 1987; Gomibuchi et al. 1993; Nagamatsu et al. 1994) and postoperative (Nagamatsu et al. 1992, 1994) evaluation of remnant pulmonary capacity. The purpose of this study was to determine if expired gas analysis during exercise testing is of equal value to UPAO in assessing pulmonary capacity.

Patients and Methods

The study was conducted on 64 patients with lung cancer who had been admitted to our institute during the 5-year period between 1990 and 1994. The patients ranged in age from 42 to 81 years (average age 67.4±7.9 years), with a male: female ratio of 52:12. Surgical procedures performed were as follows: 13 pneumonectomies, 44 lobectomies, 2 exploratory thoracotomies, and the remaining 5 patients did not undergo surgery.

Method of the unilateral pulmonary artery occlusion test (UPAO)

The test was done within one week preoperation. A pulmonary artery occlusion/thermodilution catheter (Model: 93A-841 7.5F, Baxter Healthcare Corp., Irvine, CA) was inserted into each patient via the femoral vein, and the pulmonary artery to the affected lung was occluded. After 15 min of occlusion, the mean pulmonary artery pressure (P_{PA}) and cardiac output (C.O.) were measured. Cardiac index (C.I.) and total pulmonary vascular resistance (TPVR) were calculated.

Expired gas analysis during exercise testing

The test was done within one week preoperation. Expired gas analysis during exercise testing was performed. Maximum oxygen consumption (\(\dot{V}O_2\)max) (Kurihara and Fujimoto, 1984) and the anaerobic threshold (AT) were measured. AT was classified as the definition proposed by Wasseerman et al. (1973): the intensity of exercise or \(\dot{V}O_2\) level immediately prior to the occurrence of metabolic acidosis due to elevation of the arterial lactate level during an exercise workload of gradually increasing intensity.

Expired gas analysis was conducted using a SYSTEM 2900 Energy Measurement System (manufactured by SENSOR MEDKS, Yorba Linda, CA), and the graded workload was performed using a bicycle ergomater. The exercise workload was initiated at a level of 30 watts with an increase in 10 watts increments every 2 min. At the level 60 watts level, the workload was increased by 20 watts increments to the level of target Borg rating (Borg, 1970) of 16. Expired gas analysis was performed every 20 sec, and at the maximum value \(\dot{V}O_2\)max was measured and AT was determined by the V-slope method (Bearver et al.1986). All values were divided by body surface area (\(\dot{V}O_2\)max/m² and AT/m²).
Comparison of results between the unilateral pulmonary artery occlusion test and expired gas analysis during exercise testing

In UPAO, 30 mmHg (Nakata and Nitta, 1975) in $P_{PA}$ is tolerance limit for lung resection. Patients were divided into two groups according to the $P_{PA}$ as follows: Group $P_{PA}(L)$ (n=55), $P_{PA}<30$ mmHg, and Group $P_{PA}(H)$ (n=9), $P_{PA} \geq 30$ mmHg. Comparative studies of the mean values of $V_{o2}\text{max}/m^2$ and $AT/m^2$ were performed between the two groups. In UPAO, a TPVR of 700 dyne.sec.cm$^{-5}$/m$^2$ is the tolerance limit for lung resection. Patients were divided into two groups according to TPVR as follows: Group TPVR(L) (n=49), TPVR$<700$ dyne.sec.cm$^{-5}$/m$^2$, and Group TPVR(H) (n=14), TPVR $\geq 700$ dyne.sec.cm$^{-5}$/m$^2$. Comparative studies of the mean values of $V_{o2}\text{max}/m^2$ and $AT/m^2$ were performed between the two groups.

Statistical analysis was performed by using the Students t test, Mann Whitney test and the Pearson and Spearman methods, with a significant difference defined as $p<0.05$. Data are expressed as mean values±standard deviation (S.D.).

**Results**

Comparison of $V_{o2}\text{max}/m^2$ and $AT/m^2$ with respect to $P_{PA}$ (Table 1)

$V_{o2}\text{max}/m^2$ in Group $P_{PA}(L)$ was significantly higher than in Group $P_{PA}(H)$. $AT/m^2$ in Group $P_{PA}(L)$ was significantly higher than in Group $P_{PA}(H)$ by the t test alone.

Comparison of $V_{o2}\text{max}/m^2$ and $AT/m^2$ with respect to TPVR (Table 2)

$V_{o2}\text{max}/m^2$ in Group TPVR(L) was significantly higher than in Group TPVR(H). $AT$ in Group TPVR(L) was significantly higher than in Group TPVR(H) by the t test alone.

In order to determine the minimal acceptable levels for lung resection of $V_{o2}\text{max}/m^2$, the correlation of TPVR and $V_{o2}\text{max}/m^2$ was analyzed (Fig. 1). TPVR

**TABLE 1.**

<table>
<thead>
<tr>
<th>Group</th>
<th>$n$</th>
<th>$V_{o2}\text{max}/m^2$ (ml/min/m$^2$)</th>
<th>$AT/m^2$ (ml/min/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{PA}(L)$</td>
<td>55</td>
<td>753±171***</td>
<td>405±76***</td>
</tr>
<tr>
<td>$P_{PA}(H)$</td>
<td>9</td>
<td>599±165**</td>
<td>327±97</td>
</tr>
</tbody>
</table>

*$V_{o2}\text{max}$: Maximum oxygen consumption; $AT$: anaerobic threshold; $P_{PA}$: mean pulmonary artery pressure; $P_{PA}(L)=P_{PA}<30$ mmHg; $P_{PA}(H)=P_{PA} \geq 30$ mmHg

**TABLE 2.**

<table>
<thead>
<tr>
<th>Group</th>
<th>$n$</th>
<th>$V_{o2}\text{max}/m^2$ (ml/min/m$^2$)</th>
<th>$AT/m^2$ (ml/min/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPVR (L)</td>
<td>49</td>
<td>763±167**</td>
<td>406±78***</td>
</tr>
<tr>
<td>TPVR (H)</td>
<td>14</td>
<td>620±173**</td>
<td>351±88</td>
</tr>
</tbody>
</table>

*$V_{o2}\text{max}$: Maximum oxygen consumption; $AT$: anaerobic threshold; TPVR: total pulmonary vascular resistance; TPVR (L)=TPVR$<700$ dyne.sec.cm$^{-5}$/m$^2$; TPVR (H)=TPVR$\geq 700$ dyne.sec.cm$^{-5}$/m$^2$

**TPVR(L) vs TPVR(H) t test: $p=0.026$, Mann Whitney test: $p=0.012$

**TPVR(L) vs TPVR(H) t test: $p=0.047$, Mann Whitney test: $p=0.172**$

In order to determine the minimal acceptable levels for lung resection of $V_{o2}\text{max}/m^2$, the correlation of TPVR and $V_{o2}\text{max}/m^2$ was analyzed (Fig. 1). TPVR
and $\bar{V}_{o_2,\text{max}}/m^2$ showed no significant correlation but a weak negative quadratic correlation by the equation $y=2276-246.6 \log x$ was found. This result led to a minimal acceptable levels for lung resection of $\bar{V}_{o_2,\text{max}}/m^2$ of 650 ml/min/m$^2$ corresponding to the TPVR levels of 700 dyne.sec.cm$^{-5}$/m$^2$.

**Fig. 1.** Relationship between TPVR and $\bar{V}_{o_2,\text{max}}/m^2$. TPVR and $\bar{V}_{o_2,\text{max}}/m^2$ showed no significant correlation (Pearson's correlation coefficient $r=-0.4520$, $p=0.0002$, Spearman's correlation coefficient $r=-0.4192$, $p=0.0006$), but a weak negative quadratic correlation by the equation $y=2276-246.6 \log x$ was found. This result led to a minimal acceptable levels for lung resection of $\bar{V}_{o_2,\text{max}}/m^2$ of 650 ml/min/m$^2$ corresponding to the TPVR levels of 700 dyne.sec.cm$^{-5}$/m$^2$.

**Discussion**

UPAO was proposed by Carlens et al. (1951) and Sloan et al. (1955) as a measurement of pulmonary capacity before lung resection. In Japan, this criteria was modified by Nakata and Nitta (1975) to determine the tolerance limit of lung resection. The tolerance limit using this criteria was defined as a TPVR of less than 700 dyne.sec.cm$^{-5}$/m$^2$ with a $P_{PA}$ value of less than 30 mmHg. By using the modified criteria, we have obtained favorable results for determining whether surgery is indicated. However, this method requires the performance of an invasive test. Therefore, UPAO is not an appropriate routine preoperative test for all patients. Therefore, expired gas analysis during exercise testing was evaluated as potential noninvasive cardiopulmonary test.

UPAO is strictly a load test. Expired gas analysis during exercise testing can be used to simultaneously evaluate pulmonary ventilation and circulation. In this study, we investigated whether expired gas analysis during exercise testing has equal reliability to UPAO.

Two variables, $AT/m^2$ and $\bar{V}_{o_2,\text{max}}/m^2$, were studied by expired gas analysis during exercise testing. $\bar{V}_{o_2,\text{max}}/m^2$ showed a lower level of significance than $AT/m^2$. Therefore, $\bar{V}_{o_2,\text{max}}/m^2$ is more useful than $AT/m^2$ because $\bar{V}_{o_2,\text{max}}/m^2$ can be measured at a higher exercise load. We employed the V-slope method to measure AT in this study. The V-slope method is not well established, and there is a possibility of considerable measurement error. This potential measurement error also may have contributed to the results of this study.

There were no significant correlations between $\bar{V}_{o_2,\text{max}}/m^2$ and TPVR. There were some patients with low $\bar{V}_{o_2,\text{max}}/m^2$ values despite sufficient car-
diopulmonary function. In these patients, sufficient exercise load may not have been applied. Future studies will require a definition of individual exercise load.

Expired gas analysis during exercise testing is a test capable of simultaneously measuring functional reserve capacity of pulmonary ventilation and circulation. This method has nearly equal value to UPAO.

References


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