Breathing Pattern and Arterial Blood Gases During Nd-YAG Laser Photoablation of Endobronchial Lesions Under General Anesthesia*

**Use of Negative Pressure Ventilation: A Preliminary Study**

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*Study objective:* To evaluate the efficacy of negative pressure ventilation (NPV) in avoiding or reducing apneas and related hypoxemia and respiratory acidosis during laser therapy (LT) of endobronchial lesions.

**Design:** A prospective, controlled, randomized study.

**Setting:** An operating theater of a respiratory endoscopy and laser therapy unit.

**Population and intervention:** Twenty-seven consecutive patients referred to LT were entered into the study. Fourteen patients were randomly assigned to LT under general anesthesia and spontaneous assisted ventilation (control group) whereas in 13 cases, NPV by a poncho-wrap ventilator (NPV group) was added to the procedure.

**Measurements and results:** The prevalence and the duration of apnea/hypopnea periods assessed by respiratory inductive plethysmography during LT were significantly reduced under NPV, compared to the control group. As compared to baseline, during LT, all control patients developed mild to severe hypercapnia (PaCO₂ ranging from 55 to 76 mm Hg) and respiratory acidosis (pH from 7.33 to 7.19), whereas only three patients undergoing NPV (23%) developed hypercapnia (PaCO₂ from 52 to 68 mm Hg) and related acidosis (pH from 7.29 to 7.21). Optimal oxygenation was achieved in all of the patients; nevertheless, patients under NPV needed a lower mean oxygen supply; five of them (38%) could be treated at a fraction of inspired oxygen of 0.21 for the whole procedure.

**Conclusion:** NPV may be useful in reducing apneas during laser therapy under general anesthesia, thus reducing hypercapnia, related acidosis, and need of oxygen supplementation.

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**Key words:** high-frequency jet ventilation; interventional bronchoscopy; noninvasive mechanical ventilation; spontaneous assisted ventilation

**Abbreviations:** ABG=arterial blood gases; AHD=apnea/hypopnea duration; AHe=apnea/hypopnea event; AHI=apnea/hypopnea index; ASA=American Society of Anesthesiologists; Fio₂=inspiratory oxygen fraction; HR=heart rate; LT=laser therapy; NPV=negative pressure ventilation; %pred=percent predicted; RIP=respiratory inductance plethysmography; SaO₂=arterial oxygen saturation; Ve=minute ventilation; Vt=tidal volume

Laser therapy (LT) has proved to be a very suitable procedure to treat endobronchial lesions, even in patients at very severe stages of diseases. Although the risk of general anesthesia is considered to be low, hypoxemia, hypercapnia, and acidosis secondary to apneas or reduction in ventilation are presumed to be the major causes of intraoperative and postoperative complications. These conditions have been observed under both general and topical anesthesia by arterial blood gases (ABG) measurement or by pulse oximetry evaluation of arterial oxygen saturation (SaO₂). A transient increase in PaCO₂ and related respiratory acidosis have been described in up to 87% and a reduction in PaO₂ in up to 93% of cases, the type of anesthesia not affecting the duration of the endoscopic proce-
dure. Cardiovascular complications were reported to be <1% in large surgical series and attributed to general anesthetics or hypoxia, while in recent reports, the incidence of cardiac complications was up to 28%. Safely providing adequate oxygenation during laser photoablation via a rigid bronchoscope can be a difficult task. Due to combustion hazard, the recommended inspiratory oxygen fraction (FiO₂) is below 0.5. Intermittent oxygen supplementation with pulse oximetry guidance has been proposed as an effective technique for maintaining adequate oxygenation. Several techniques of ventilation have also been proposed for this purpose: conventional mechanical ventilation through the bronchoscope, conventional or manual jet ventilation, and spontaneous assisted manual ventilation.

Negative pressure ventilation (NPV) by a poncho-wrap has been shown to be able to increase minute ventilation (Ve) in normal as well as in COPD patients. NPV by means of iron lung, poncho-wrap, or cuirass ventilators has been successfully used in the treatment of acute respiratory failure due to neuromuscular disease, secondary to Pneumocystis carinii pneumonia and due to COPD, and in weaning from prolonged mechanical ventilation.

We hypothesized that application of NPV by means of a poncho-wrap ventilator would improve ventilation during LT, thus avoiding or reducing apneas and related periods of hypoxemia and respiratory acidosis. A randomized prospective controlled study was conducted on 27 consecutive patients undergoing LT for obstructive lesions of the large airways. The aim was to evaluate the effects of the addition of NPV to the procedure commonly used in our institution (general anesthesia and spontaneous assisted manual ventilation) on blood gases, prevalence and duration of apnea episodes, need of oxygen supplementation, and length and complications of LT. If the results of this preliminary study are encouraging, the technique might be further evaluated in patients with higher anesthetic risk and in conditions requiring a deeper level of anesthesia.

Materials and Methods

Study Population

Twenty-seven consecutive patients underwent LT by means of rigid bronchoscopy because of tracheal or bronchial lesions. Demographic, anthropometric, associated conditions, diagnoses of endobronchial lesions, and the anesthetic risk of patients as assessed by means of the American Society of Anesthesiologists (ASA) risk classification are shown in Table 1. Most patients showed significant symptoms of airway obstruction. In 8 of 27 patients (30%), LT was performed for cure of benign tumors or postintubation tracheal stenosis. In 19 patients (70%), LT was used as a palliative therapy for endoluminal tracheal or bronchial tumors.

All of the patients gave their informed consent to participate in the study that was approved by the Research Ethics Committee of our institution.

Procedure

Under continuous monitoring of arterial BP and ECG, all procedures were performed by the same expert operator (S.C.) through a rigid bronchoscope using a Nd-YAG laser (Multilaser 2500A Tecnomed; Vaulx-en-Velin, France). Each laser pulse was limited to a maximum energy of 20 to 30 W with longer exposure times (4 to 5 s) for photoablation or up to 60 W with shorter exposure (0.7 to 1.2 s) for resection. Full details of the procedure were described previously. Following 3 min of preoxygenation by mask breathing spontaneously with an FiO₂ of 1.0, anesthesia was induced by IV administration of fentanyl (3 μg/kg body weight), droperidol (0.07 mg/kg), propofol (2 mg/kg), and succinylcholine (1.5 mg/kg). After a 3-min manual ventilation through a bag (Ambu Bag; Ambu; Copenhagen, Denmark), 5% lidocaine (4 mL) was injected onto the vocal cords by direct laryngoscopy. After intubation with the rigid bronchoscope, patients were ventilated manually using high-flow oxygen through an anesthesia balloon attached via flexible tubing to the ventilation port of the bronchoscope. A security valve prevented excess pressure of 30 cm H₂O during the periods of assisted ventilation. Anesthesia was maintained by continuous infusion of propofol (7 to 10 mg/kg/h). Infusion was increased or reduced, and fentanyl boluses (range, 25 to 100 μg) were administered as needed, depending on the patient’s heart rate (HR), cough, and body movements and on the procedure as well. Once the effects of succinylcholine waned, the patients breathed spontaneously and oxygenation was assured by continuous 10 L/min oxygen flow through the anesthesia balloon. To reduce the risk of combustion during LT, oxygen flow was maintained at the lowest possible level to keep 95% > SaO₂ > 93%.

| Table 1—Anthropometric, Demographic, Clinical Characteristics, and Pathologic Condition Requiring LT in Studied Patients |
|---------------------------------|-----------------|-----------------|
| No. of patients                 | 13              | 14              |
| Gender, M/F                     | 9/4             | 9/5             |
| Age, yr, mean±SD (range)        | 59±17           | 69±4            |
| Weight, kg, mean±SD             | 64±8            | 67±10           |
| Patients with IBW>120%, No. (%) | 3 (23)          | 2 (14)          |
| Smokers, No. (%)                | 3 (23)          | 4 (28)          |
| COPD, No. (%)                   | 2 (15)          | 2 (14)          |
| FEV₁ (%pred)                    | 59 (10)         | 57 (8)          |
| FVC (%pred)                     | 68 (4)          | 62 (4)          |
| FEV₁/FVC                        | 71 (9)          | 61 (6)          |
| ASA II, No. (%)                 | 7 (53)          | 8 (57)          |
| ASA III, No. (%)                | 6 (46)          | 6 (43)          |
| Malignant tumor, No. (%)        | 8 (61)          | 8 (57)          |
| Carcinoids, No. (%)             | 1 (8)           | 2 (14)          |
| Benign tumor, No. (%)           | 1 (8)           | 1 (7)           |
| Tracheal stenosis, No. (%)      | 3 (23)          | 3 (21)          |

*IBW=ideal body weight; %pred=percent of predicted value.
In case of prolonged apnea assessed clinically, and/or oxyhemoglobin desaturation ($\text{SaO}_2 < 88\%$), maximal oxygen supplementation was given, and ventilation was assisted manually until optimal saturation returned. At the end of the operation, patients were extubated when spontaneous ventilation had returned and awakening was imminent. Oxygen was administered by a nasal cannula and patients were moved to the recovery room.

Thirteen of 27 patients were randomly selected and underwent the described procedure wearing a poncho-wrap connected to NPV (Emerson Negative Pressure Ventilator 33 C2; Emerson; Cambridge, Mass). Figure 1 shows the poncho-wrap, which consists of a vest that fits over a rigid grid encircling the patient’s rib cage and abdomen and is arched posteriorly by a backplate. After intubation with the rigid bronchoscope, the poncho-wrap was strictly sealed at the neck, arms, and legs, and NPV was started. The ventilator setting was as follows: intermittent external negative pressure ranging from 18 to 35 cm H$_2$O at a frequency slightly higher than the patient’s own respiratory rate when awake, with an inspiratory time to expiratory time ratio ranging 1/1 to 1/2. Peak negative pressure, respiratory rate, and inspiratory time to expiratory time ratio could be changed according to ABG values and SaO$_2$ monitoring.

The other 14 control patients underwent the same procedure without NPV.

![Figure 1. Poncho-wrap device used in this study.](image-url)
Measurement

Lung Function Tests: Dynamic lung volumes and flow-volume loops were assessed by a portable spirometer (Pony class 1 Type B; COSMED; Roma, Italy); both digital readout and paper tracings were obtained. The highest values of FVC and FEV₁ (fixed) were observed in three tests were considered and expressed as percent of the predicted values (%prd).

Arterial Blood Gases: At baseline, ABGs were assessed by means of an analyzer (ABL 300 Radiometer; Copenhagen, Denmark) on blood samples drawn from the radial artery while patients breathed room air in the supine position before anesthesia. Thirty minutes after anesthesia induction (and 10 min after the last manual ventilation), ABG values were evaluated while patients were breathing with an FiO₂ keeping SaO₂ > 95% (see “Procedure” and “Results” section).

During the procedure the following parameters were monitored continuously.

Oxygen Saturation: SaO₂ was monitored by means of a pulse oximeter (Propac Q; Drägerwerk; Lubeck, Germany).

Apnea Assessment: Time course of respiratory rate, tidal volume (VT), VE, number of apnea/hypopnea events (AHe) per patient, apnea/hypopnea index (AHI), and apnea/hypopnea duration (AHD) were assessed by means of evaluation of thoracic and abdominal movements using respiratory inductance plethysmography (RIP) (Respirac Plus; Ambulatory Monitoring; Ardley, NY). Quantitative diagnostic calibration was done calibrating the sum of rib cage and abdominal signals against the signal of VT by the flow transducer with the patients in supine position before anesthesia. Previous studies report the use of RIP under NPV. Apnea was defined as 10-s absence of thoracoabdominal movements. Hypopnea was defined as a 45% reduction in VT in comparison to baseline VT. Although AHI generally is given as episodes per hour, as is shown in Figure 2, since some of the procedure lasted less than an hour, in Table 2, AHI was defined as the number of apneas and/or hypopneas per minute of recording. AHD was defined as the percentage of recording time spent with an apnea and/or hypopnea > 10 s. All parameters were stored and analyzed by means of dedicated computer software (Respitrends; Ambulatory Monitoring). Results of AHI, AHD, and HR are reported as mean values for the time of recording as given by the program. Due to the variability related to the presence of AHe, mean values of respiratory rate, VT, and VE during recording were not considered for further analysis. The accuracy and significance of scoring AHe from calibrated RIP has been reported.

![INPV vs CONTROL](image_url)

**Figure 2.** Time course of cardiorespiratory indexes during LT as assessed by RIP for a patient representative of NPV group (left panel) and control group (right panel). From top to bottom: respiratory rate, breaths/min; VT, m³; VE, L/min; AHI, event/h; AHD, % time; HR, beats/min. Bolded lines on the top of single parameter trends represent device alarms indicating values exceeding alarm threshold of the RIP.
Table 2—Apnea Events and HR Change Induced by LT

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<th>NPV Patients</th>
<th>Control Subjects</th>
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<tbody>
<tr>
<td></td>
<td>Baseline†</td>
<td>Treatment</td>
</tr>
<tr>
<td>AHe, No.*</td>
<td>—</td>
<td>10±6</td>
</tr>
<tr>
<td>AHI, event/min</td>
<td>0.22±0.11</td>
<td></td>
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<tr>
<td>AHD, % time</td>
<td>14±102‡</td>
<td></td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>109±10</td>
<td>86±11</td>
</tr>
</tbody>
</table>

* AHe refers to number of events per patient.
† p<0.01; difference between NPV and controls during treatment.
‡ p<0.001; difference between treatment of NPV group and control group.
§ No patient showed any event during baseline measurements.

Recording: Other parameters recorded included the following:
total duration of the procedure, total number of manual ventilatory assistance procedures performed, minimum oxygen flow (in L/min) able to maintain 98%>SaO2>93%, intraoperative complications, and type and dosage of drugs employed.

Statistics

Differences between groups and within phases (baseline vs procedure) were computed by analysis of variance. Statistical significance of differences between variables assessed at one phase was determined by unpaired t test. A p value <0.05 was considered significant. Differences in frequency were assessed using χ² comparison of means.

RESULTS

As shown in Table 1, there were no significant differences between the two groups as for demographic, anthropometric, and spirometric data, diagnoses of endobronchial lesions, and the anesthetic risk. The duration of the surgical procedure was similar in the two groups (46±12 min vs 49±21 min for NPV group and control group, respectively); the additional time to arrange for NPV ranged from 3 to 6 min per patient.

Mean values of number of AHe per patient, AHI, AHD, and HR in the two groups during the period of observation are shown in Table 2. Tracings of breathing pattern of two patients representative of the two groups are shown in Figure 2. At baseline, no AHe were observed in either group. LT did induce periods of AHe in both groups, but AHI and AHD were significantly lower in patients undergoing NPV. In the NPV group, six patients (46%) showed <10 AHe, five (38%) showed 10 to 15 AHe, and only two (16%) showed >15 AHe. On the contrary, in the control group, only 1 patient (7%) showed <10 AHe, 3 (21%) showed 15 to 30 AHe, whereas 10 (72%) showed >30 AHe. Mean HR during the procedure was significantly lower in the NPV group.

Mean values of ABG and oxygen supplementation needed to maintain SaO2 >93%, at baseline and during the procedure, are shown in Table 3. Compared to control subjects, patients undergoing NPV showed lower mean levels of PaCO2 and higher pH. During LT, all 14 control patients developed a mild to severe hypercapnia (values of PaCO2 ranging from 55 to 76 mm Hg) and respiratory acidosis (pH from 7.33 to 7.19), whereas only 3 (23%) patients undergoing NPV developed hypercapnia (PaCO2 during the procedure ranging from 52 to 68 mm Hg) and acidosis (pH from 7.29 to 7.21). Optimal oxygenation was achieved in both groups of patients, although those undergoing NPV needed a lower amount of supplemental oxygen; five of them (38%) could be treated with an FIO2 of 0.21 for the whole procedure; the others needed an oxygen flow lower than 10 L/min, in contrast to all control patients who needed an oxygen flow higher than 10 L/min. Patients in the NPV group needed also a lower mean number of manual ventilations (0.5±0.8 vs 3±3 in NPV and control groups, respectively; p=0.02); in the NPV group, 8 of 13 (61%) patients needed no ventilations, 3 (23%) needed only one ventilation, and 2 (16%) needed two ventilations. In the control group, only two (14%) patients required no ventila-

Table 3—ABGs and Oxygen Supply During LT

<table>
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<th>NPV Patients</th>
<th>Control Subjects</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Treatment</td>
</tr>
<tr>
<td>pH</td>
<td>7.41±0.02</td>
<td>7.36±0.08*</td>
</tr>
<tr>
<td>PaCO2, mm Hg</td>
<td>39±4</td>
<td>47±10†</td>
</tr>
<tr>
<td>PaO2, mm Hg</td>
<td>76±13</td>
<td>94±26†</td>
</tr>
<tr>
<td>O2 supply, L/min</td>
<td>0</td>
<td>2.5±3.0</td>
</tr>
<tr>
<td>SaO2, %</td>
<td>93±7</td>
<td>96±2</td>
</tr>
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</table>

* p<0.01; differences between baseline and treatment.
† p<0.05; differences between baseline and treatment.
‡ p<0.001; differences between baseline and treatment.
§ p<0.005; differences between NPV patients and control subjects.
¶ p<0.001; differences between NPV patients and control subjects.
tions, four (28%) needed at least five manual ventilations during the procedure, up to a maximum of eight in one patient. No intraoperative or perioperative complications were observed in either group; no patient of either group needed reintubation at the end of procedure.

**DISCUSSION**

Several studies describe techniques of ventilation and anesthesia during LT or bronchoscopy: conventional mechanical ventilation through the bronchoscope, and spontaneous assisted ventilation. Most of these studies are uncontrolled or retrospective; no study is randomized. To the best of our knowledge, ours is the first prospective randomized controlled study to report the breathing pattern of patients undergoing LT under general anesthesia and spontaneous ventilation. We also believe that this is the first study to show that the addition of NPV to general anesthesia and manual ventilation results in the reduction of apneas, thus reducing hypercapnia, acidosis, and the need for oxygen supplementation.

Many different factors have been claimed to cause hypoxemia, hypercapnia, and related respiratory acidosis during LT. Airway obstruction by the bronchoscope, prolonged suctioning, low FIO2 (to prevent laser combustion), and respiratory depression resulting from anesthetic, hypnotic, or sedative agents have been advocated as causes of these respiratory responses. Anthropometric, demographic, and clinical conditions were similar in the two groups of our study. In particular, ASA status II and III were similarly distributed between the two groups, indicating that this factor did not influence the different results.

The prevalence of hypoxemia, hypercapnia, and related respiratory acidosis in control patients of our study is in agreement with other reports in the literature. In the study by McCaughan et al, ABG assessed immediately after the endoscopic procedure revealed significant increases in PaCO2 in 87% and reduction in PaO2 in 93% of cases without differences between bronchoscopy and esophagoscopy, general and local anesthesia. In that study, hypoxemia was controlled by LT discontinuation and oxygen supplementation. Hanowell et al described 21 episodes of oxyhemoglobin desaturation among 87 interventions under controlled ventilation and muscle relaxation. Hunton and Oswal performed carbon dioxide laser surgery under general anesthesia in 33 patients. Blood gas analysis showed that PaCO2 increased from preanesthesia values up to levels ranging from 49.4 to 67.6 mm Hg. With a maximum FIO2 of 0.40, the PaO2 remained between 129 and 152 mm Hg. In the study by Perrin et al, hypoxemia occurred in 15.2% of patients undergoing IV anesthesia and spontaneous manually assisted ventilation and was attributed to the procedure itself. In agreement with this report, we did not observe any cardiac complications; nevertheless, a higher mean HR was observed in the control group. In the study by Hanowell et al, cardiac complications occurred in 27.6% of cases and were related to longer duration of general anesthesia and increasing age. Mean duration of the procedure in our control patients and in the study by Perrin et al was 49±21 min and 63±33 min, respectively. Duration of the procedure did not differ in our two groups, indicating that application of NPV does not affect it.

In patients submitted for bronchoscopy and laser surgery of major tracheobronchial obstructions, Vourch et al compared jet ventilation and high-frequency jet ventilation. They demonstrated adequate and similar gas exchanges either with high-frequency jet ventilation or manual jet ventilation in patients with tracheal stenosis. The average duration of their sessions was 30 to 75 min. In their series, a total mortality of 1.3% was ascribed in most part to cardiac arrest, attributable, according to these authors, to inadequate ventilation. Blomquist et al reported their experience in 13 patients using general anesthesia and jet ventilation with air. Oxygen saturation was maintained at a higher level than when patients were breathing 100% oxygen before anesthesia. Occasional reductions in SaO2 were due to airway obstruction and were easily corrected by a short interruption of the procedure. High-frequency jet ventilation was used under general anesthesia for endoscopy, including laser surgery by Giunta et al who found considerable variability in PaO2. This technique may involve potential risks in relation to the high pressure of the gas and the danger of barotrauma. As reported by Conacher et al, jet ventilation was used under general anesthesia in 20 patients undergoing carbon dioxide laser bronchoscopy. Severe hypoxemia (PaO2 <46 mm Hg) was observed in 11.4% of laser sessions, and hypoxemia was observed (PaCO2 >49 mm Hg) in 67% of sessions with related respiratory acidosis (pH <7.32) in 53% of sessions. In a retrospective study, Stanoopoulos et al reported the use of jet ventilation during laser bronchoscopy for malignant airway obstruction leading to respiratory failure. The laser procedure was associated with mild transient arterial oxygen desaturation in 2 of 17 (12%) patients.

In our study, hypoxemia was avoided in both groups; however, NPV allowed reduction in FIO2, thus reducing the risk of combustion. According to our records, alterations in ABG values were associ-
ated with hypoventilation periods as assessed by AHI and AHD determination. Hypoventilation-induced hypoxemia and hypercapnia require an increase in FIO2 and, if necessary, manually assisted ventilation. Leaks throughout the bronchoscope may reduce the effectiveness of manual ventilation and the need to increase FIO2 may be associated with combustion hazard.10 Addition of NPV to general anesthesia and manually assisted ventilation resulted in lower AHI and AHD with reduced prevalence of hypoxemia, hypercapnia, respiratory acidosis, and consequent reduction in oxygen supplementation and the need for manual assistance.

Although NPV by poncho-wrap ventilators appears to be a safe means to reduce the prevalence of hypoventilation during LT, the real usefulness of the association of NPV, general anesthesia, and manually assisted ventilation might be questioned considering the absence of relevant clinical complications in both groups. Nevertheless, compared to our prior method and that of others (general anesthesia and manually assisted spontaneous ventilation),1,2,5,3 the use of NPV looks promising because of the ability of reducing the FIO2, thus reducing the combustion hazard, and the potential ability to use higher doses of sedatives and myorelaxants without worsening apneas. Our unpublished preliminary data seem to confirm the role of NPV in allowing a higher degree of anesthesia. Further studies should confirm the usefulness of this approach also when fiberoptic flexible instruments are used.

Despite the fact that the duration of the procedure did not differ in the two groups, thus indicating that application of NPV was not time consuming, it may be argued that the presence of a poncho-wrap and a grid around the body of the patient may be of some concern, when direct access to the patient should be required (eg, need for cardiac massage, etc) (Fig 1). However, it takes no more than a few seconds to free the patients from the poncho-wrap and the grid.

No cardiovascular complications were observed in either group and arterial BP was stable during the whole procedure. The lack of hemodynamic effects of NPV by poncho-wrap has been demonstrated previously.33 Even if some patients have been reported to develop airway occlusion during NPV by poncho-wrap ventilators,34 this concern does not apply to our study in which patients were breathing through the bronchoscope.

In summary, this prospective, controlled, randomized study establishes the efficacy of NPV in reducing apneas during LT under general anesthesia, thus reducing hypercapnia, related acidosis, and the need of oxygen supplementation.

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