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# Use of Apneic Oxygenation for the Performance of Pan-endoscopy

**Burkard Rudlof, MD[1], and Winfried Hohenhorst, MD[2]**

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## Abstract

*Objective.* To evaluate the efficacy of apneic oxygenation for the performance of pan-endoscopy.

*Study Design.* Clinical retrospective study.

*Setting.* A university teaching hospital in Wuppertal, Germany.

*Subjects.* Forty-seven patients who underwent pan-endoscopy under apneic oxygenation during a period of 1 year.

*Methods.* After preoxygenation and induction of anesthesia, an 8 French catheter was introduced into the trachea for oxygen supply. Pan-endoscopy was carried out, as long as there were no signs of desaturation. The data were collected retrospectively from the anesthesia charts.

*Results.* Apnea was well tolerated up to 45 minutes in most of the patients. In 2 patients, the method was carried out incorrectly, and in 1 obese patient, it was not possible to get an acceptable oxygenation.

*Conclusion.* With appropriate monitoring, sufficient nitrogen elution, and proper patient selection, we believe that this technique is superior to jet ventilation and intubation for pan-endoscopy, allowing unimpeded operative visualization.

## Keywords

pan-endoscopy, aventilatoric mass flow, apnea, preoxygenation

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Pan-endoscopy is a challenge for the operating surgeon and the anesthetist. It is frequently difficult to achieve the combination of optimal oxygenation with ideal operating conditions. By applying apneic oxygenation, we have succeeded in achieving both: all that is required is a 2.6-mm-diameter tube to supply the necessary oxygen, which in practice does not obstruct the operating surgeon.

The performance of pan-endoscopies always requires making compromises. Ensuring oxygenation by means of an endotracheal tube deteriorates the visibility of the operating field, even if thin tubes are inserted. An alternative is high-flow jet ventilation by way of high- or low-frequency ventilation. The disadvantage of this technique is tissue vibration. Preoxygenation, to circumvent tissue vibrations, allows only brief periods (approximately 5 minutes) for the actual surgery. In the case of especially difficult anatomic conditions, this will result in considerably extended operation times.

Apneic oxygenation provides an alternative. During apnea, carbon dioxide elimination is almost stopped. The human body has the capacity to store more than 100 L of carbon dioxide.[1] During apneic anesthesia, this volume is reached only after approximately 500 minutes. However, in praxi, this procedure would reach its limits because of the increasing excessive acidity of the organism. Since the carbon dioxide is stored in tissue as bicarbonate, the mixed venous blood level of $CO_2$ adjusts itself to the arterial carbon dioxide content with a tendency to rise (5 mm Hg during the first minute, 3 mm Hg any further minute[2]). Because of the Haldane effect, the arterial partial pressure does even exceed the mixed venous partial pressure.[3] This phenomenon is called a $pCO_2$ reversal. The uptake of oxygen, however, continues uninterrupted as long as there is enough oxygen in the lungs due to the presence of a diffusion gradient. This soon causes negative pressure in the pulmonary alveolus because the volume of the oxygen absorbed cannot be replaced by carbon dioxide, as is the case during ventilation. This negative pressure generates a gas flow into the lungs, also called aventilatory mass flow (AVMF; **Figures 1** and **2**). The AVMF will approximately approach the range of the oxygen consumption.[4] Provided that at the start of apnea an extensive nitrogen elution has taken place ($FetO_2 > 0.9$), the introduction of oxygen into the lungs ensures the oxygenation over a long period of time. This procedure is called apneic oxygenation and has previously been described by Kettler and Sonntag[5] in 1971 during bronchoscopies with apnea times of up to 20 minutes. The resulting hypercapnia was tolerated without any sequelae during anesthesia.

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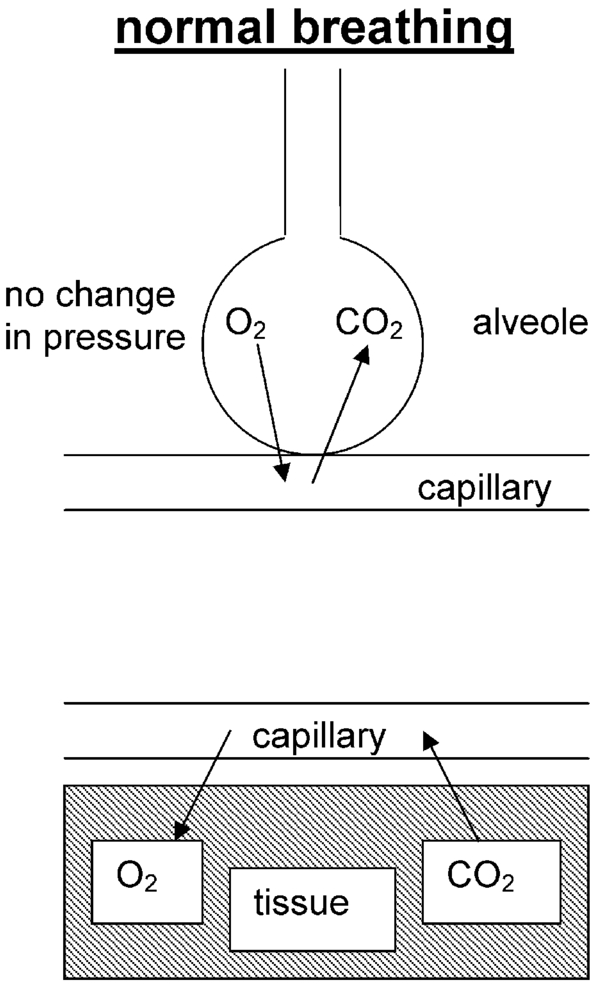


**Figure 1.** Assuming a respiratory quotient of 1, the same volume of $CO_2$ and $O_2$ is exchanged. There is no change of pressure in the alveole.

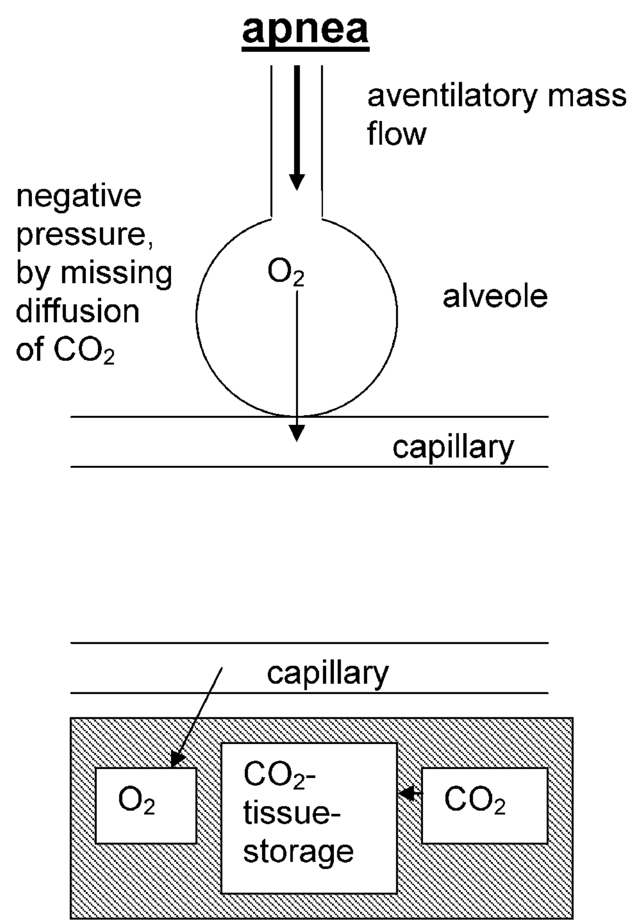


**Figure 2.** During apnea, only a minimum of $CO_2$ leaves the tissue because of the storage as $H_2CO_3$. If only $O_2$ diffuses into the blood, there is a negative pressure in the alveole. With open glottis, it results in a mass flow into the alveole, whose size is very near to the oxygen consumption.

We have successfully used this technique in our hospital to perform pan-endoscopies over the past 3 years. The description of our procedure and the retrospective evaluation of our data are the content of this article.

## Material and Methods

### Ethics Committee Approval

The ethics committee at St. Anna–Klinik, Wuppertal, Germany, approved this retrospective study.

### Case Material

All patients who had undergone an apneic oxygenation pan-endoscopy within a period of 1 year were analyzed. The following data were evaluated: American Society of Anesthesiologists (ASA) classification, age, weight, duration of apnea, $O_2$ saturation at the start and end of apnea, and any procedure termination due to a lack of oxygenation or circulation reactions.

The dependent variables were described by minimum, maximum, and median. The mean value and standard deviation were indicated (in case skewness ranged between $-1$ and $+1$).

### Techniques

All patients were monitored by electrocardiography (automated ST-segment measurement in V5), $psO_2$, noninvasive blood pressure, and neuromuscular tracing. After obtaining peripheral venous access and preoxygenation with 10 L of $O_2$/min for 3 minutes, anesthesia is administered using propofol, remifentanil, and mivacurium and maintained by continuous administration of propofol and remifentanil. When spontaneous ventilation stopped, a passive preoxygenation was carried out with a tight-fitting mask. To ensure a proper removal of nitrogen, an $FetO_2$ of $>0.9$ was aspired. After laryngoscopy, an 8 French catheter, with continuous oxygen flow of 0.5 L/min, was inserted up to the carina, and the patient was then ready for operation. The corresponding quality systems procedure stipulates that the operation is to be interrupted if the $psO_2$ falls below 90%, in case of significant ST-segment changes or if extreme circulation reactions occur.

**Table 1.** Patient data.

| | Age, y | Weight, kg | Height, cm |
|---|---|---|---|
| Median | 57 | 78 | 170 |
| Minimum | 34 | 44 | 156 |
| Maximum | 79 | 156 | 193 |
| Mean value | 58.7 | | 171.5 |
| Standard deviation | 0.54 | | 9.9 |

After the operation, the patient was normoventilated with a mask.

The anesthesia chart records the duration of apnea, the $psO_2$ at the end of apnea, the $petCO_2$ after ventilation, and, if applicable, the reasons for an interruption of the operation.

Anesthetic termination takes place if a train of four >80% was measured.

## Results

Anesthesia charts from 2009 were evaluated, recording 217 pan-endoscopies; 47 of these were performed as described above. Patients excluded were operated after preoxygenation in apnea without additional oxygen supply because of the expected short duration of the operation, in intubation narcosis using an existing tracheostoma or by means of orotracheal intubation as the operating field was not blocked by the tube or because laser and diathermy devices were used. None of the patients were excluded because of procedural reasons.

The average age was 59 (±11.7) years. All patients belong to the ASA risk class 2 and 3. Further demographic data are summarized in **Table 1**.

The average apnea time was 24.7 minutes (±8.7). During this period of time, the $psO_2$ dropped from 99% to 98%. In individual cases, it also came to a rise in $psO_2$ of 1%. The mean value of the final expiratory $CO_2$ partial pressure, measured after the first ventilation following apnea, increased by 1.6 mm Hg/min.

In the case of 3 patients, the procedure had to be stopped after 1, 5, and 12 minutes, respectively because of insufficient oxygenation.

There was no interruption of the procedure owing to patient circulation reactions. During painful operations, it was difficult to decide whether elevations of blood pressure were due to pain or suboptimal levels of anesthesia. An increase in the administration of anesthetics in comparison to conventionally performed pan-endoscopies could not be observed by any of the performing anesthesiologists.

ST-segment changes >2 mm in the V5 derivation did not occur.

Further data points are indicated in **Table 2**.

### *Failed Tests*

In the case of 3 patients, the procedure had to be terminated for reasons that will now be described.

### *Case 1*

This patient was obese (156 kg/172 cm), with extensively impaired gas exchange due to chronic obstructive pulmonary disease (COPD). The value of $psO_2$ measured during premedication on room air was 86%. Mask ventilation was difficult. It was not possible to obtain an $FetO_2$ of >0.9. At this point in time, $psO_2$ was 89%. To improve oxygenation and to provide for nitrogen elution, the anesthetist decided to intubate the patient. After 15 minutes of ventilation with an $FiO_2$ of 1.0 and a positive end-expiratory pressure of 20 cm $H_2O$, $psO_2$ increased to 93%. However, the $FetO_2$ did not exceed 0.7. The patient was then extubated, supplied with an oxygen catheter, and transferred to the operating theater. Prior to commencing surgery, the $psO_2$ decreased to 84%, necessitating reventilation. An attempted jet ventilation with different frequencies and flow patterns also failed, and the patient was reintubated. The operation was then carried out under suboptimal conditions because of the presence of the endotracheal tube. During the 60-minute operation, it was not possible to achieve an $FetO_2$ greater than 0.7 despite oxygen flow of 10 L $O_2$/min. Postoperatively, extubation was difficult, and he spent the night in the recovery ward before he was stable enough for transfer to the medical ward in the morning.

There are certainly multiple reasons for failure in this case, among them the lack of tolerance for apnea in obese people.[6]

### *Case 2*

Five minutes into apnea in a female patient with healthy cardiopulmonary function, the $psO_2$ decreased to less than 90%. By means of mask ventilation, the $psO_2$ could be raised quickly. A thorough nitrogen elution took place, and the 20-minute operation was carried out according to the

**Table 2.** Measured data during apnea.

| | Length of Apnea, min | $psO_2$ Start, % | $psO_2$ End, % | $petCO_2$ Start, mm Hg | $petCO_2$, End, mm Hg | $petCO_2$ Rise/Min, mm Hg |
|---|---|---|---|---|---|---|
| Median | 25 | 100 | 100 | 32 | 78 | 1.8 |
| Minimum | 1 | 93 | 84 | 28 | 40 | 0.7 |
| Maximum | 45 | 100 | 100 | 56 | 89 | 2.1 |
| Mean value | 24.7 | | | | 72.5 | |
| Standard deviation | 8.7 | | | | 14.1 | |

described procedure without any problem. In retrospect, it became apparent that with regard to preoxygenation, the anesthetist did not take into account the $FetO_2$ but was satisfied to achieve a $psO_2$ of 100%.

An optimal preoxygenation must involve a complete nitrogen elution from the body, especially from the lungs. Ideally, a $paO_2$ of 673 mm Hg (760 mm Hg [ambient pressure] – 47 mm Hg [water vapor pressure at 37°C] – 40 mm Hg [carbon dioxide partial pressure during normoventilation] = 673 mm Hg) ought to be achieved.[7,8] However, in cases in which the $paO_2$ is 150 mm Hg, the $psO_2$ is already at 100%,[8] making it unsuitable for use in monitoring preoxygenation. The duration of effective preoxygenation is specified to be at least 3 minutes with a fresh gas flow of 10 L $O_2$/min and a tight-fitting mask. Individually, however, considerable differences may occur that make monitoring by $FetO_2$ indispensable.

During incomplete preoxygenation, the AVMF consumes an oxygen-nitrogen-amalgamation instead of pure oxygen, which inevitably leads to a desaturation. Since the AVMF is within the range of the oxygen consumption, the oxygenation can be maintained only if pure oxygen is inserted.

### Case 3

In this cardiopulmonarily healthy patient with medication-controlled hypertension, initially normal $psO_2$ progressively declined after 12 minutes. Once again, mask ventilation provided a quick remedy, and the operation was completed within 10 minutes according to the described technique. All the same, during this period the $psO_2$ steadily declined to 94%. In retrospect, it became apparent that during the operation, the patient started to breathe spontaneously. Owing to the high flow velocity of the spontaneous respiration, nitrogen was inspirated from the ambient air and thus lowered the $FiO_2$. Since ventilation during anesthesia was probably insufficient and, in addition, was handicapped by inserted instruments, an obstruction of oxygenation by the AVMF occurred due to the nitrogen inflow. It is questionable whether it would have been possible to increase the oxygen flow to the extent that no nitrogen would have been inspired.

## Discussion

The method described was tested successfully on 44 patients. Optimal operating conditions were described by all surgeons.

Similar surveys show[6] that, apart from 3 patients, there was no adverse effect on oxygenation.

### Apnea Times

The length of apnea times was significant. The mean period of time was approximately 25 minutes. The maximum value was 45 minutes. That case involved a COPD patient with considerably impaired gas exchange. Preoperative psO2 was 93%. After complete nitrogen elution, the psO2 could be increased to only 94%, and after 45 minutes, it was still 93%. That shows that impaired gas exchange itself is no contraindication for this method.

In the literature,[3] a rise in $paCO_2$ of approximately 3 mmHg/min during apnea is assumed. The assumption that the patient at the beginning of apnea was normoventilated gives a calculated result in a $pCO_2$ of 175 mm Hg. Inserted into the Henderson-Hasselbach equation, pH at this time should have been 6.8. As there were neither ST-segment changes nor circulation reactions in the sense of a depression, we can assume that such acute changes of the acid-base balance are tolerated well. We have nevertheless modified our procedure to the effect that after the 20th minute, a blood gas analysis is taken every 10 minutes to avoid pH greater than 7.0.

### Characteristic of $petCO_2$

The rise of $petCO_2$ /min was surprisingly low. During a 3-minute-long investigation, Brandt et al[3] could demonstrate that after the first minute, a further linear rise of 3 mm Hg/min does occur. We recorded 1.8 mm Hg/min as a median value, which was much below the projected value. One reason for this discrepancy could have been due to the measurement technique, which was carried out via a mask, which allowed air leakage, thus carrying a considerable potential for error. Furthermore, it is likely that after the extensive apnea times with high alveolar oxygen concentrations, absorption atelectases may occur. It was observed that after applying mask respiration, partial dead space ventilation occurred after opening of the nonperfused atelectatic tissue. This led to a mix of gases both rich and poor in carbon dioxide. The final expiratory measurement was carried out without using an alveolar gas mixture, thus explaining the lower values. Despite these potential sources for error, the first ventilation was carried out with $CO_2$-free gas and thus results in considerable mixing. Therefore doubts are appropriate whether $petCO_2$ can be used for any conclusion of $paCO_2$ after apnea.

It is also conceivable that in the course of a longer-lasting apnea period, significant levels of carbon dioxide become stored in compartments with different velocities and that the rise in $paCO_2$ proceeds biphasically. The interpretation of the present results must therefore remain hypothetical. It must, however, be noted that the rise in $paCO_2$ did not lead to uncontrolled circulation reactions and to our surprise did obviously not influence the wakening behavior of patients. The patients make 2 or 3 deep breaths and awaken from anesthesia. We cannot see a difference to total intravenous anesthesia without apnea, but we did not measure the $paCO_2$ levels.

## Conclusion for the Clinical Practice

If performed correctly, apneic oxygenation can allow for extended operative times in the larynx. It was the opinion of all the surgeons involved in this study that operative visualization and working conditions were considerably better than either jet ventilation or intubation. It is easy and cheap to perform.

The following points were observed:

- This technique seems unsuitable in cases of extreme obesity and pulmonary-restricted patients.

- Prior to insertion of an oxygen catheter, a thorough preoxygenation under consideration of the $FetO_2$ has to be carried out.
- The $psO_2$ as a means of control of patients during apnea is indispensible.
- $PsO_2$, however, is unsuitable as a parameter for a successful preoxygenation.
- Spontaneous respiration leads to a nitrogen inflow and impedes the apneic oxygenation.
- The technique is unsuitable for patients suffering from elevated intracerebral pressure.
- The application of diathermy and laser is not possible because of the high oxygen concentration.

## Author Contributions

**Burkard Rudlof**, statistics, practical investigation, writing, literature research; **Winfried Hohenhorst**, practical investigation, writing, literature research.

## Disclosures

**Competing interests:** None.

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