学 位 論 文

# Y-shaped catheter improves carbon dioxide clearance during apnoeic oxygenation in tracheal surgery

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機能構築医学専攻

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# Y-shaped Catheter Improves Carbon Dioxide Clearance During Apneic Oxygenation in Tracheal Surgery

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Word count: 4426

## Visual Abstract

Key question
Does Y-shaped catheter improve the clearance of carbon dioxide in apneic oxygenation?
Key findings
Y-shaped catheter repressed $CO_2$ accumulation with 30-min tracheal resection-reconstruction apneic oxygenation surgery.
Take-home message
Apneic oxygenation with Y-shaped catheter may be a valid alternative ventilation method in tracheal surgery.


## Abstract

Objectives: Apneic oxygenation is a ventilation method in tracheal surgery, but has the disadvantage of causing progressive hypercapnia. The aim of this experimental study was to evaluate the efficacy of a Y-shaped catheter for the prevention of accumulation of carbon dioxide in tracheal surgery.

Methods: Surgery for tracheal resection and reconstruction was performed in 10 beagles under general anesthesia. Before transecting the trachea, the dogs were hyperventilated for 10 minutes with pure oxygen. After the airway was opened, ventilation was maintained with a small catheter for apneic oxygenation for 30 minutes until the end of the tracheal reconstruction. Y-shaped catheters were used in 5 dogs and straight catheters were used in 5 dogs for oxygen insufflation. Hemodynamic values and blood gas values were evaluated and compared between the two groups.

Results: The mean elevation in the carbon dioxide partial pressure value per minute from 5 minutes after the start of the procedure to the end of apneic oxygenation was 1.34 mmHg (95% confidence interval 1.00–1.68) in the Y-shaped catheter group and 2.03 mmHg (95% confidence interval 1.54–2.53) in the straight catheter group ($p < 0.018$). The total carbon dioxide partial pressure elevation value was 59.5 mmHg in the Y-shaped catheter group and 89.0 mmHg in the straight catheter group ($p < 0.006$). There were no significant differences in hemodynamic values between the two groups.

Conclusions: Apneic oxygenation using a Y-shaped catheter represses the accumulation of carbon dioxide compared with a straight catheter, in canine tracheal resection-reconstruction surgery.



Keywords: tracheal surgery, apneic oxygenation, catheter, carbon dioxide clearance

## Introduction

In tracheal surgery, respiratory management under an open airway is an essential factor for achieving airway reconstruction (1). The cross-field ventilation method of intubating the endotracheal tube into the distal trachea is a simple method that can provide adequate oxygenation and carbon dioxide ($CO_2$) clearance by intermittent positive pressure ventilation, and is the most frequently used method (2). However, this method requires a frequent apnea phase by removing the endotracheal tube for airway suturing, and the size of the tube may be an obstacle to surgery (3, 4). Therefore, apneic oxygenation (AO), which maintains oxygenation by recruiting intrapulmonary oxygen stores and continuous oxygen insufflation from a small catheter in the distal trachea, could be an alternative method (5) (6). The AO method is convenient because it requires only a small amount of equipment in the surgical field and the operation is not interrupted for tube manipulation. However, the apnea causes hypercapnia and subsequent acidosis, and these are the primary concerns during airway reconstruction (7).

To address these concerns, we developed a new Y-shaped catheter with tips that can be located in the right and left stem bronchi. The location of the catheter tip is one of the proven factors associated with $CO_2$ accumulation (8) (9). $CO_2$ clearance is improved when the tip is located at the periphery of the airway.

The purpose of this experimental study was to evaluate the accumulation of $CO_2$ during tracheal AO surgery using a new Y-shaped catheter and to examine the possibilities of its clinical application.

## Materials and Methods

### Terminology

The term preoxygenation is used for hyperventilation with pure oxygen to wash out the lung nitrogen before the apneic phase of AO. The term apneic oxygenation is used for the apneic period with oxygen insufflation to the airway. The term postoxygenation is used for the hyperventilation intended for oxygenation and removal of $CO_2$ after the AO period.

### Animals

The Animal Care and Use Committee for Kagawa University approved the protocol of this study. The Narc beagle dogs (both sexes, 1–2 years old, weighing 9–11 kg) were obtained from Kitayama Shizuoka Laboratory Animal Center (Shizuoka, Japan). The dogs were fasted for 12 hours before the experiment with free access to water.

Catheters for Apneic Oxygenation

A total of ten beagle dogs, five in Group 1 and five in Group 2, were randomly allocated and used in this study. A Y-shaped catheter was used in Group 1, and a straight catheter with no branch was used in Group 2. The Y-shaped catheter is branched into two, and the distance from the branch to the tip is 2 cm, so as not to become wedged in the lobar bronchus, with each branch having an angle of 45°. Both catheters were made of silicone, had an outer diameter of 4 mm, and an inner diameter of 3 mm. These catheters were manufactured by Iwasaki Co., Ltd, Osaka, JAPAN (Fig. 1).

Anesthesia and Monitoring

The dogs were anesthetized with ketamine 10 mg/kg, xylazine 5 mg/kg, and atropine sulfate 0.05 mg/kg, intramuscularly. Ten minutes later, each dog was placed in a supine position on a table. An 18-gauge catheter was inserted into the external jugular vein, and infusion was maintained with normal saline at the rate of 5 ml/kg/h.

Anesthesia was maintained by continuous infusion of propofol at a rate of 20 mg/kg/h. For neuromuscular blockade, rocuronium was first injected at 5 mg/kg; an additional 2 mg/kg was administered according to neuromuscular function as evaluated by train-of-four stimulation using an acceleromyography test on a hind limb. Each animal was intubated with an 8-mm endotracheal tube, and mechanical ventilation was applied. The ventilator was set in a volume-controlled mode to deliver a tidal volume of 20 ml/kg at a rate of 15 breaths per min in 100% pure oxygen (fraction of inspired oxygen = 1.0), with an inspiratory: expiratory ratio of 1:1, and a positive end-expiratory pressure of 5 cm $H_2O$. A 20-gauge arterial catheter was inserted into the femoral artery for invasive arterial blood monitoring and blood sampling. A triple-lumen thermodilution catheter (Swan-Ganz 7 French, Instrumentation Laboratory) was advanced via the external jugular vein for measurements of pulmonary

147 artery pressure and cardiac output. A pulse oximeter was placed on the tongue.

148

149 Trachea Resection- Reconstruction with Apneic Oxygenation

150 After local anesthesia with 2% lidocaine 30 mg/kg, the dog was longitudinally incised in the neck. The
151 neck muscles were separated, and the cervical trachea was exposed. Release of the lower anterior surface
152 of trachea was made for mobility of the trachea. Preoxygenation was started before opening the airway,
153 and the ventilator was set at 30 breaths/min for 10 min, and the other settings were not changed. After
154 preoxygenation, the endotracheal tube was pulled back just below the vocal cord, and the cervical
155 trachea was resected to 2 cm in length (4 tracheal rings) from 5 cm below the cricoid cartilage. The
156 silicone catheter was immediately inserted across the surgical field into the distal trachea, the position
157 of the tip was confirmed by bronchoscope, and then fixed with 3-0 polypropylene sutures (Vicryl,
158 Ethicon, USA) onto the tracheal wall (Fig. 2). In Group 1, the catheter tips were placed in both stem
159 bronchi. In Group 2, the catheter tip was placed 1 cm above the carina. AO was started by insufflation
160 of 100% pure oxygen through the silicone catheter at a flow rate of 1.0 L/kg/min, and maintained during
161 the tracheal reconstruction, for which 3-0 polypropylene sutures and 3-0 polydioxanone sutures (PDSII,
162 Ethicon, USA) were used. The tracheal membrane wall was reconstructed using a running suture and
163 the tracheal cartilage wall by interrupted sutures. Regardless of the time required for the tracheal
164 reconstruction, AO was applied to all dogs for 30 minutes. The silicone catheter was removed after the
165 AO period, and the endotracheal tube located below the vocal cord was advanced into the distal trachea
166 beyond the anastomotic portion. Postoxygenation was then started by hyperventilation for 10 minutes
167 with the same ventilator setting as for preoxygenation. The remaining surgery and cartilage wall
168 anastomosis of the trachea was completed. After no air leakage from anastomosis was confirmed, the
169 surgical incision was then closed by layers. After completion of the operation, anesthesia was
170 discontinued. The dogs were mechanically ventilated until signs of spontaneous ventilation were
171 apparent and were then extubated appropriately. Cefmetazole sodium 25 mg/kg was administered
172 intramuscularly daily until postoperative day 7.

173

174 Data Collection

Heart rate (HR), mean arterial blood pressure (MAP), and oxygen saturation were continuously monitored and recorded at the following ten time points (as shown in Fig. 3): before the operation (Baseline); after preoxygenation (Pre-Oxy); every 5 minutes during AO (T5, 5 min after start of AO to T30, 30 min after start of AO); after postoxygenation (Post-Oxy); and after surgery was completed (Post-Op). Arterial blood samples were collected at the same ten time points, and a blood gas analysis was performed using an ABL 800 FLEX blood gas machine (Radiometer, Medical ApS, Copenhagen, Denmark). In addition, arterial pH (pHa), oxygen partial pressure ($PaO_2$), $CO_2$ partial pressure ($PaCO_2$), base excess (BE), and bicarbonate salt ($HCO_3$) were measured. Cardiac output (CO) was measured using a thermal dilution method at baseline, at 25 min after the start of AO (T25), and Post-Op. Mean pulmonary artery pressure was measured at the same time points as CO. The dogs' appetites and activity were observed for one month after surgery.

### Statistics

Mean and standard deviations (SD) of the values were calculated using a 95% confidence interval (CI). Blood gas values and hemodynamic variables were compared between Group 1 and Group 2, and the statistical significance was calculated. Statistical analysis was performed with SPSS 20.0 (IBM Japan, Tokyo, Japan). Changes were established by Student's unpaired t-test for paired data and repeated measures model was used for comparison of continuous changes during the AO period. Significance was taken to be $p < 0.05$. Primary comparison was defined as $PaCO_2$ elevation value in AO period.

## Results

All ten dogs completed the experimental procedure and were analyzed. The blood gas values at each time point are shown in Table 1. The mean time required for tracheal reconstruction in the AO phase for Group 1 and Group 2 was 27 min (range 25-30 min) and 23.8 min (range 16-30 min), respectively, with no significant difference between the two groups. $PaO_2$ was maintained at a high level throughout the experimental procedure and was recorded at over 500 mmHg for Group 1 and 450 mmHg for Group 2, even during the AO period. A significant difference was confirmed only at T5. The maximum increase in $PaCO_2$ was reached immediately after starting AO and showed a time-dependent increase during the

AO period. Values rapidly returned to normal with hyperventilation after completion of the AO. The mean $PaCO_2$ elevation value at T5 was 5.22 mmHg/min for Group 1 and 7.63/min mmHg for Group 2; there was no significant difference between the two groups. However, a significant difference was observed at all time points from T5 to the end of AO, except for T20 (Fig. 4). $PaCO_2$ increased by an average of 1.34 mmHg (95% CI 1.00–1.68) every minute from T5 to the end of AO in Group 1, and 2.03 mmHg (95% CI 1.54–2.53) in Group 2; the difference was significant ($p < 0.018$). The values for pHa, BE, and $HCO_3$ also showed a time-dependence similar to that of $PCO_2$ over the AO period, and rapidly returned to normal values with hyperventilation. There were no significant differences in these three values between the two groups.

The hemodynamic values at each time point are shown in Table 2. Although there was no change in HR during the AO period, MAP decreased in a time-dependent manner. CO increased during AO and remained elevated even after post-oxygenation. No changes in PAP were observed. There were no significant differences in hemodynamic values between the two groups.

Appetite and activity were well maintained in all dogs, and neurological abnormalities were not observed throughout the month after surgery.

## Discussion

The major method for open airway management in tracheal surgery is cross-field ventilation, although frequent apnea and obstruction by the endotracheal tube creates difficulties. Use of a small catheter for ventilation is superior in terms of optimizing the surgical field, but oxygenation and $CO_2$ retention are still issues. Since oxygen consumption during anesthesia is 200 to 250 ml/min, use of total nitrogen washout and replacement of the functional residual capacity of 2500 to 3000 ml with pure oxygen results in a sufficient oxygen supply for 10 to 12 minutes. This is despite the total apnea. Moreover, when insufflating oxygen into the airway through a small catheter, the patient can "breathe" despite ongoing total apnea and can survive apneic periods of up to 50 minutes (10). The method for oxygenation maintenance under apneic conditions with only a small catheter and airflow was first reported in 1949 (5). McClish et al. later reported high-flow oxygen (40 to 60 L/min) administration through the catheter as a ventilation method under open airway that does not obstruct surgical exposure, and in which the

231 operation is not interrupted by manipulation of the endotracheal tube (11). Thereafter, use of low flow-
232 rate oxygen (10 L/min) was considered adequate for oxygenation with a low risk of barotrauma (6).
233 Several subsequent reports of tracheal surgery performed with similar AO methods confirmed it as an
234 alternative method of cross-field ventilation (4, 12). Ripoli et al. reported the use of an EZ-blocker
235 (AnaesthetIQ, Rotterdam, The Netherlands) in tracheal surgery, which is a Y-shaped distal end double-
236 lumen catheter for bronchial blocking (13, 14). The maximum rate of oxygen insufflation was 4 L/min
237 in each branch due to structural problems, and the effects of $CO_2$ were not reported, but the concept is
238 similar to our catheter (13, 14).
239 To the best of our knowledge, this is the first report of tracheal surgery using the AO method performed
240 in a large animal model. As AO during tracheal surgery can lead to deviations of the catheter from
241 surgical manipulation and debris in the peripheral trachea, the results of this study are expected to be
242 close to clinical results.
243 During AO, $PaO_2$ was maintained at 400 mmHg or more for 30 minutes in each dog. Sufficient
244 oxygenation was maintained for a long period, as in previous clinical reports (4, 12).
245 $CO_2$ accumulation was markedly low in the Y-shaped catheter group. The rise in $CO_2$ levels under apnea
246 is initially caused by differences between the venous and arterial blood (15) and is subsequently caused
247 by the production of $CO_2$ in the tissues. Typically, $PaCO_2$ may increase by 10 to 13 mmHg/min in the
248 first minute and thereafter 3 to 4 mmHg/min (16).
249 Additionally, in this experiment, mean $CO_2$ increased 32.4 mmHg in the first 5 minutes, which was
250 higher than the subsequent mean increase of 8.4 mmHg per 5 minutes. This $CO_2$ accumulation
251 mechanism is considered to account for the lack of a significant difference in the $PaCO_2$ increase value
252 during the first 5 minutes (15).
253 In Group 1, from T5 to T30, the increase in $CO_2$ was two-thirds of the increase observed in Group 2.
254 Application of continuous oxygen flow during AO reduced the $CO_2$ concentration in the alveoli with a
255 pressure gradient and diffusion gas balance caused by pure oxygen convection (17) (18). The further the
256 tip of the catheter is inserted into the peripheral airway, the more the injected gas can reach the periphery
257 of the lungs. It is particularly important to locate the tips more distally than the carina (9, 19). It is
258 hypothesized that the $CO_2$ concentration in the alveoli was lowered by our Y-shaped catheter, which

allows the tip of the catheter to be positioned more distally than the carina.

In previous clinical reports of tracheal surgery, within 15 minutes of the start of AO, mean $PaCO_2$ was 73.2 mmHg in 31 patients (20), and at 60 minutes, the mean $PaCO_2$ was 105 mmHg in 18 patients (12). Although there is no clinically acceptable landmark for hypercapnia, several reports have demonstrated that progressive $CO_2$ retention causes severe hypercapnia and acidemia that may provoke hypotension (21) and arrhythmia because it influences myocardial contractility and sympathetic activity (22, 23). Hypercapnia also increases mean pulmonary artery pressure and pulmonary vascular resistance (24). In our experiments, we observed acidemia and hypotension following hypercapnia in both groups. In order to better maintain the physiological state, it is necessary to suppress $PaCO_2$ accumulation more effectively.

The Y-shaped catheter could be easily placed in the target position because of the adequate length, thickness, and branching angle we designed. By advancing the catheter into the peripheral trachea and confirming that the bifurcated portion of the catheter was coincident with the carina, it was possible to place the tips of the catheter in each of the left and right main bronchi. Regarding surgery, since the thickness of the straight portion of the Y-shaped catheter is equal to the thickness of the straight catheter, there was no difference between the two catheters in terms of compromising surgical exposure during tracheal reconstruction. We did not need to reposition the catheter during the operation, and the catheter could be removed easily compared with the straight catheter.

An advantage of this silicone catheter for clinical applications is that it can be adjusted to the maximum length such that the catheter tip does not become wedged in the lobar bronchus, according to the length of the main bronchus as determined in the preoperative image examination as CT. There is a possibility that this Y-shaped catheter can provide the maximum AO effect in each patient.

Our study has several limitations. The silicone catheter we developed is soft and kinks easily during surgery. Softness is necessary to insert the Y-shaped catheter, but there is a possibility that it can interfere with oxygen administration. Additionally, since the thickness of the trachea and bronchi are different between adult patients and dogs, the pressure formed in the airway and alveoli with oxygen administration will vary even when the oxygen dosage is the same. Therefore, there is a possibility that the superiority of the Y-shaped catheter observed in this experiment may not be thoroughly translated

to human adults. In this experiment, body temperature was not managed during surgery, so hypothermia may have affected respiratory parameters and hemodynamic parameters. Since anesthetic agents such as propofol affect cardiovascular parameters, there is a possibility that its influence on hemodynamic changes of the Y-shaped catheter could not be clearly evaluated. Based on previous papers and our experience of tracheal surgery, we decided on the AO period as 30 minutes. Further study would be needed to confirm the application of long-term AO in complex surgeries such as carinal reconstruction. In conclusion, the results of this study indicate that use of a new Y-shaped catheter for AO with continuous oxygen flow represses the accumulation of $CO_2$ compared to the straight no-branch catheter that is conventionally used. In the Y-shaped catheter, the accumulation of $CO_2$ was repressed to about two-thirds, with a total of 30 minutes of tracheal resection-reconstruction AO surgery. Although this procedure does not completely eliminate the retention of $CO_2$, its accumulation can be suppressed by using a Y-shaped catheter in AO. There is a possibility that it may be a valid alternative in tracheal surgery without losing the advantages of AO, such as uninterrupted airway suturing, maintenance of adequate gas exchange, and optimal surgical exposure. Further study would be needed to confirm its application of long-term AO in complex surgery such as carinal reconstruction.

Funding

This work was supported by JSPS KAKENHI Grant Number 15K10261.

Acknowledgements

We acknowledge the technical assistance from the staff at the Vivarium, University of Kagawa.

Conflicts of Interest: none declared

310 Figures

311

312 Figure 1. Equipment for continuous flow during apneic oxygenation. Silicone Y- shaped and straight

313 (no branching) catheters.

314

315 Figure 2. The small catheter for apneic oxygenation inserted into the transected trachea.

316

317 Figure 3. Schematic diagram of the ten time points.

318 Pre-Oxy = preoxygenation; time points are every 5 minutes during AO (T5 at 5 minutes after start of

319 AO up to T30, 30 minutes after start of AO); Post-Oxy = postoxygenation; Post-Op = after surgery.

320

321 Figure 4. Increase in values for partial pressure of carbon dioxide during apneic oxygenation. Data are

322 expressed as mean ± standard error. The straight line represents Group 1 (Y-shaped catheter), and the

323 broken line represents Group 2 (straight catheter). Asterisk indicates the statistical significance

324 between the two groups. $*p < 0.05$.

325 Pre-Oxy = pre-oxygenation; time points are every 5 minutes during AO (T5 at 5 minutes after start of

326 AO up to T30, 30 minutes after start of AO); Post-Oxy = post-oxygenation; Post-Op = after surgery.

327

328 Table 1 Blood gas values

| | | BL | Pre-Oxy | Apneic Oxygenation period (total 30 min) | | | | | | Post-Oxy | Post-Op |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | T5 | T10 | T15 | T20 | T25 | T30 | | |
| PaO2 (mmHg) | Group 1 | 579± 36 | 533± 39 | 539± 24* | 553± 37 | 536± 28 | 518± 51 | 557± 48 | 513± 31 | 556± 57 | 597± 25 |
| | Group 2 | 508± 111 | 512± 57 | 472± 23* | 511± 40 | 497± 26 | 489± 43 | 483± 63 | 460± 48 | 538± 38 | 513± 113 |
| PaCO2 (mmHg) | Group 1 | 41±6. 1 | 35±9. 7 | 60±5. 1 | 67±5. 6* | 76±4. 3* | 83±5. 3 | 87±8. 5* | 93±6. 6* | 37±4. 3 | 36±2. 3 |
| | Group 2 | 45±1 6 | 30±3. 6 | 70±5. 0 | 84±9. 2* | 90±1 1* | 98±1 5 | 105± 12* | 117± 14* | 41±3. 6 | 35±5. 1 |
| pHa | Group 1 | 7.31± 0.06 | 7.30± 0.10 | 7.17± 0.02 | 7.13± 0.00 | 7.07± 0.01 | 7.04± 0.02 | 7.02± 0.02 | 6.97± 0.04 | 7.26± 0.05 | 7.29± 0.02 |
| | Group 2 | 7.33± 0.16 | 7.41± 0.06 | 7.15± 0.06 | 7.08± 0.06 | 7.04± 0.05 | 7.01± 0.06 | 6.98± 0.06 | 6.94± 0.09 | 7.27± 0.07 | 7.31± 0.08 |
| HCO3 (mEq/L) | Group 1 | 19.7± 0.5 | 17.9± 1.6 | 20.8± 1.8 | 21.0± 1.7 | 21.1± 1.7 | 21.3± 1.4 | 21.3± 1.7 | 21.0± 1.2 | 16.7± 1.7 | 16.9± 1.8 |
| | Group 2 | 22.1± 3.5 | 18.7± 3.8 | 23.2± 2.5 | 23.8± 2.4 | 23.4± 2.3 | 23.4± 2.1 | 23.3± 2.4 | 23.5± 2.6 | 18.5± 3.3 | 16.7± 1.3 |
| BEa | Group 1 | - 5.8±1 .1 | - 6.6±2 .0 | - 9.0±1 .7 | - 10.1± 1.4 | - 11.4± 1.6 | - 13.0± 0.3 | - 12.8± 1.7 | - 13.9± 2.0 | - 9.1±2 .0 | - 8.5±2 .0 |
| | Group 2 | - 3.7±6 .0 | - 4.3±4 .4 | - 7.8±3 .4 | - 9.4±3 .4 | - 10.7± 2.7 | - 11.6± 2.8 | - 12.5± 3.3 | - 13.5± 4.7 | - 7.7±4 .2 | - 8.4±2 .8 |

329

330 Group 1 = Y-shaped catheter, Group 2 = straight catheter

331 Data are expressed as mean ± standard deviation. Asterisk indicates a statistical significance between

332 the two groups. *$p < 0.05$.

333 BL = baseline; $PaO_2$ = partial pressure of oxygen in arterial blood; $PaCO_2$ = partial pressure of carbon

334 dioxide in arterial blood; pHa = PH in arterial blood; $HCO_3$ = bicarbonate in arterial blood; BEa =

335 base excess in arterial blood; Pre-Oxy = pre-oxygenation; time points are every 5 minutes during AO

336 (T5 at 5 minutes after start of AO up to T30, 30 minutes after start of AO); Post-Oxy = post-

337 oxygenation; Post-Op = after surgery.

338

339

340 Table 2 Hemodynamic values

| | | | Pre-Oxy | Apneic Oxygenation period (total 30 min) | | | | | | Post-Oxy | Post-Op |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BL | | T5 | T10 | T15 | T20 | T25 | T30 | | |
| SpO2 (%) | Group 1 | 99.5± 0.6 | 98.8± 0.5 | 98.8± 1.0 | 98.5± 1.3 | 99.0± 0.8 | 98.8± 1.0 | 98.3± 1.3 | 98.5± 1.0 | 98.3± 1.0 | 99.3± 1.0 |
| | Group 2 | 99.0± 0.8 | 99.3± 0.5 | 97.3± 1.7 | 97.3± 1.7 | 97.3± 1.7 | 97.5± 1.3 | 98.3± 1.3 | 98.5± 1.0 | 97.8± 1.0 | 98.8± 1.0 |
| HR | Group 1 | 95±26 | 110± 28 | 96±9 | 98±10 | 96±11 | 94±12 | 93±11 | 91±11 | 100± 6 | 95±9 |
| | Group 2 | 103± 25 | 112± 22 | 98±20 | 100± 15 | 95±18 | 96±18 | 94±16 | 93±13 | 94±12 | 96±10 |
| MAP | Group 1 | 143± 23 | 143± 25 | 102± 9 | 95±17 | 89±24 | 80±16 | 75±17 | 77±17 | 132± 11 | 144± 11 |
| | Group 2 | 146± 35 | 130± 23 | 90±27 | 78±18 | 73±11 | 71±12 | 66±10 | 64±12 | 145± 17 | 125± 18 |
| mPAP | Group 1 | 17.0± 1.0 | | | | | | 13.6± 3.4 | | | 15.6± 4.7 |
| | Group 2 | 17.9± 8.4 | | | | | | 18 | | | 20 |
| CO | Group 1 | 1.2±0 .3 | | | | | | 1.6±0 .1 | | | 1.7±0 .3 |
| | Group 2 | 0.8±0 .2 | | | | | | 1.3±0 .6 | | | 1.1±0 .3 |

341

342 Group 1 = Y-shaped catheter, Group 2 = straight catheter

343 Data are expressed as mean ± standard deviation.

344 $SpO_2$ = arterial oxygen saturation; HR = heart rate; MAP = mean arterial pressure; mPAP = mean

345 pulmonary arterial pressure; CO = cardiac output; Pre-Oxy = pre-oxygenation; time points are every 5

346 minutes during AO (T5 at 5 minutes after start of AO up to T30, 30 minutes after start of AO); Post-

347 Oxy = post-oxygenation; Post-Op = after surgery.

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## References


[1]. Geffin B, Bland J, Grillo HC. Anesthetic management of tracheal resection and reconstruction. Anesth Analg 1969;48(5):884-90.

[2]. Grillo HC, Bendixen HH, Gephart T. Resection of the carina and lower trachea. Ann Surg 1963;158:889-93.

[3]. Pinsonneault C, Fortier J, Donati F. Tracheal resection and reconstruction. Can J Anaesth 1999;46(5 Pt 1): 439-55.

[4]. Wiedemann K, Mannle C. Anesthesia and gas exchange in tracheal surgery. Thorac Surg Clin 2014;24(1):13-25.

[5]. Draper WB, Whitehead RW, Spencer JN. Studies on diffusion respiration: alveolar gases and venous blood pH of dogs during diffusion respiration. Anesthesiology 1947; 8(5):524-33.

[6]. Go T, Altmayer M, Richter M, Macchiarini P. Decompressing manubriectomy under apneic oxygenation to release the median thoracic outlet compartment in Bechterew disease. J Thorac Cardiovasc Surg 2003;126(3):867-9.

[7]. Fraioli, RL, Sheffer LA, Steffenson JL. Pulmonary and cardiovascular effects of apneic oxygenation in man. Anesthesiology 1973;39(6):588-96.

[8]. Smith RB, Sjostrand UH. Apneic diffusion oxygenation and continuous flow apneic ventilation. A review. Acta Anaesthesiol Scand 1985;29(1):101-5.

[9]. Slutsky AS, Menon AS. Catheter position and blood gases during constant-flow ventilation. J Appl Physiol (1985) 1987;62(2):513-9.

[10]. Zander R, Mertzlufft F. Clinical use of oxygen stores: pre-oxygenation and apneic oxygenation. Adv Exp Med Biol 1992;317:413-20.

[11]. McClish A, Deslauriers J, Beaulieu M, Desrosiers R, Fugère L, Ginsberg RJ, et al. High-flow catheter ventilation during major tracheobronchial reconstruction. J Thorac Cardiovasc Surg 1985;89(4):508-12.

[12]. Jiménez MJ, Sadurní M, Tió M, Rovira, I., Fita, G., Martínez, E, et al. Apnoeic oxygenation in complex tracheal surgery: O-58. Eur J Anaesthesiol 2006;23:20.

[13]. Rispoli M, Rossella Nespoli M, De Simone MG, Maria Mattiacci D, Buono S, Corcione A. EZ-Blocker in tracheal surgery. J Cardiothorac Vasc Anesth 2015;29(6):e89-90.

[14]. Rispoli M, Nespoli MR, Mattiacci DM, Esposito M, Corcione A, Buono S. Intraoperative extracorporeal carbon dioxide removal during apneic oxygenation with an EZ-blocker in tracheal surgery. A A Case Rep 2016;6(11):358-61.

[15]. Mertzlufft FO, Brandt L, Stanton-Hicks M, Dick W. Arterial and mixed venous blood gas status during apnoea of intubation - proof of the Christiansen-Douglas-Haldane effect in vivo. Anaesth Intensive Care 1989;17(3):325-31.

[16]. Stock MC, Schisler JQ, McSweeney TD. The PaCO2 rate of rise in anesthetized patients with airway obstruction. J Clin Anesth 1989;1(5):328-32.

[17]. Chen FJ, Menon AS, Lichtenstein SV, Zamel N, Slutsky AS. Mechanisms of gas exchange with different gases during constant-flow ventilation. J Appl Physiol (1985) 1990;68(1):88-93.

[18]. Bunegin L, Bell GC, Gelineau J, Smith RB. Continuous-flow apneic ventilation with small endobronchial catheters. Acta Anaesthesiol Scand 1988;32(8):603-6.

[19]. Smith RB, Babinski M, Bunegin L, Gilbert J, Swartzman S, Dirting J. Continuous flow apneic ventilation. Acta Anaesthesiol Scand 1984;28(6):631-9.

[20]. Frumin MJ, Epstein RM, Cohen G. Apneic oxygenation in man. Anesthesiology 1959;20:789-98.

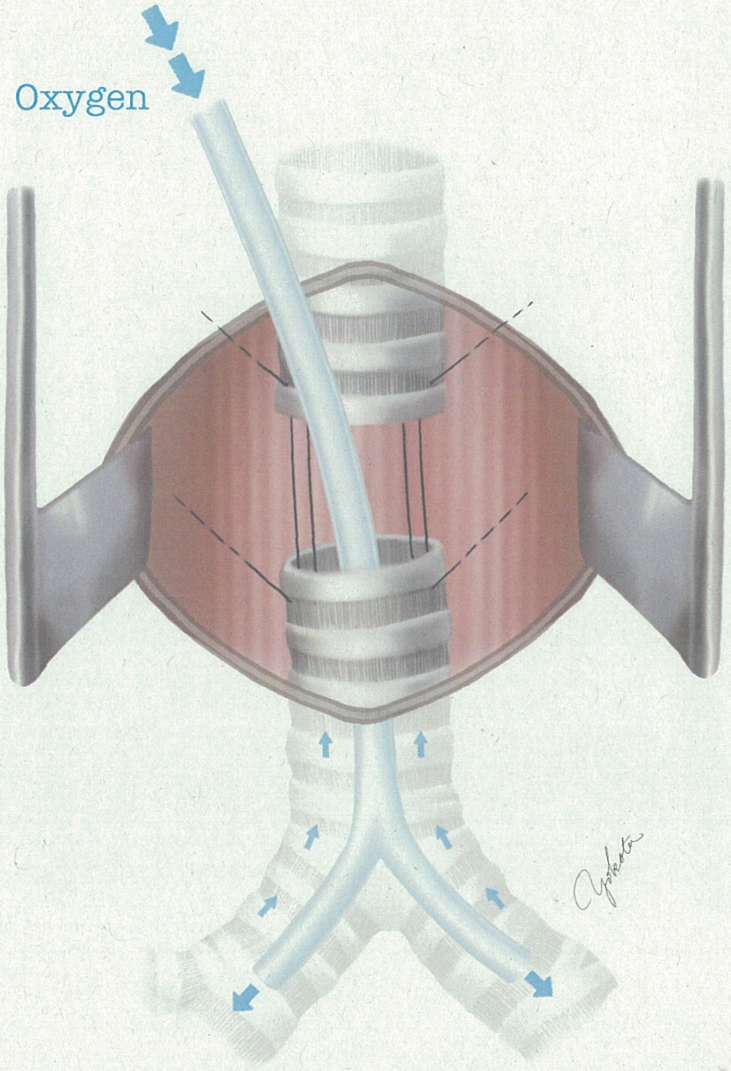
[21]. Kolettas, A.A., G.G. Tsaousi, V. Grosomanidis, Karakoulas KA, Thomareis O, Kotzampassi K, et al. Influence of apneic oxygenation on cardiorespiratory system homeostasis. J Anesth 2014;28(2):172-9.

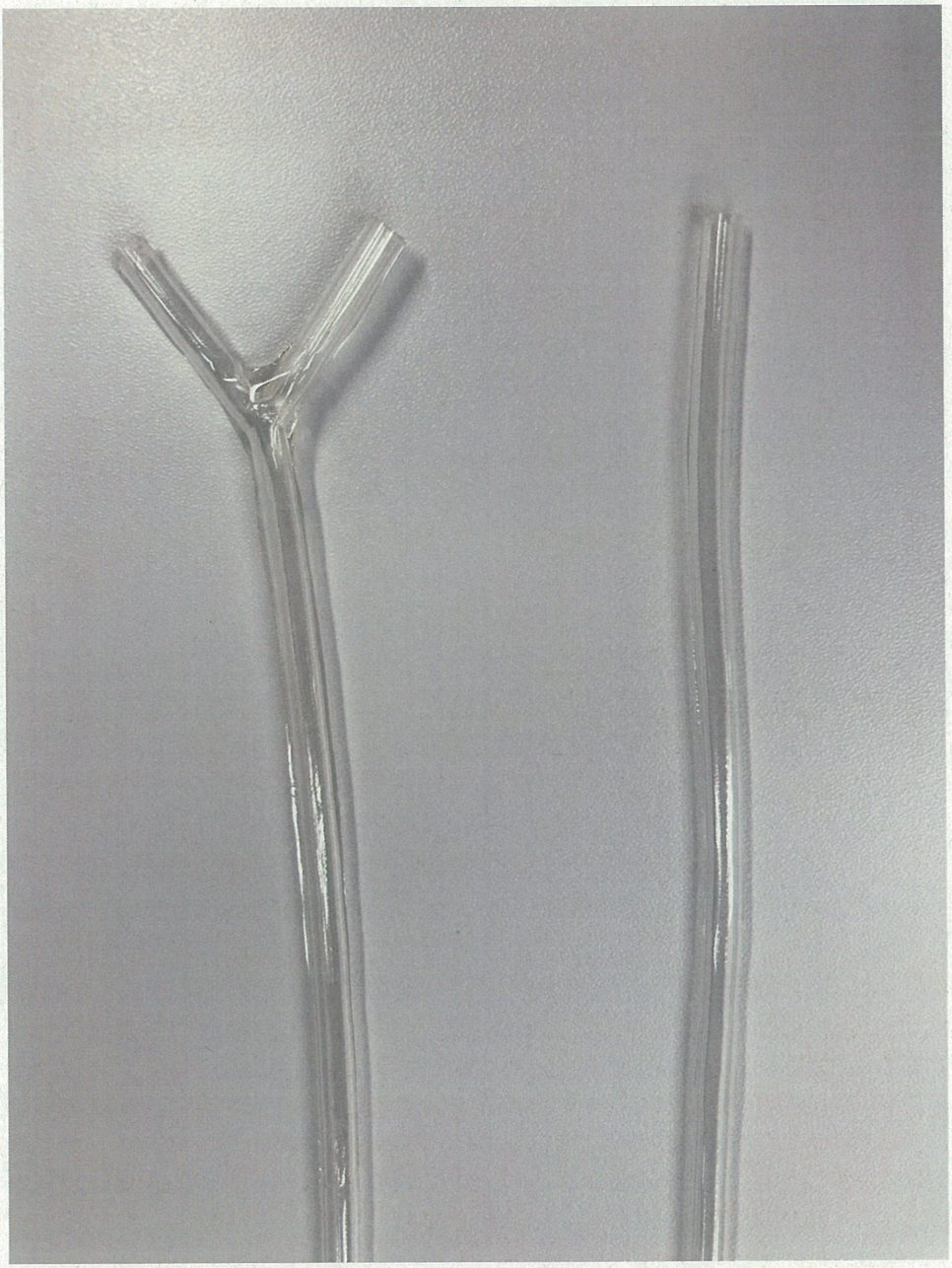
[22]. Weber T, Tschernich H, Sitzwohl C, Ullrich R, Germann P, Zimpfer M, et al. Tromethamine buffer modifies the depressant effect of permissive hypercapnia on myocardial contractility in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 2000;162(4):1361-5.

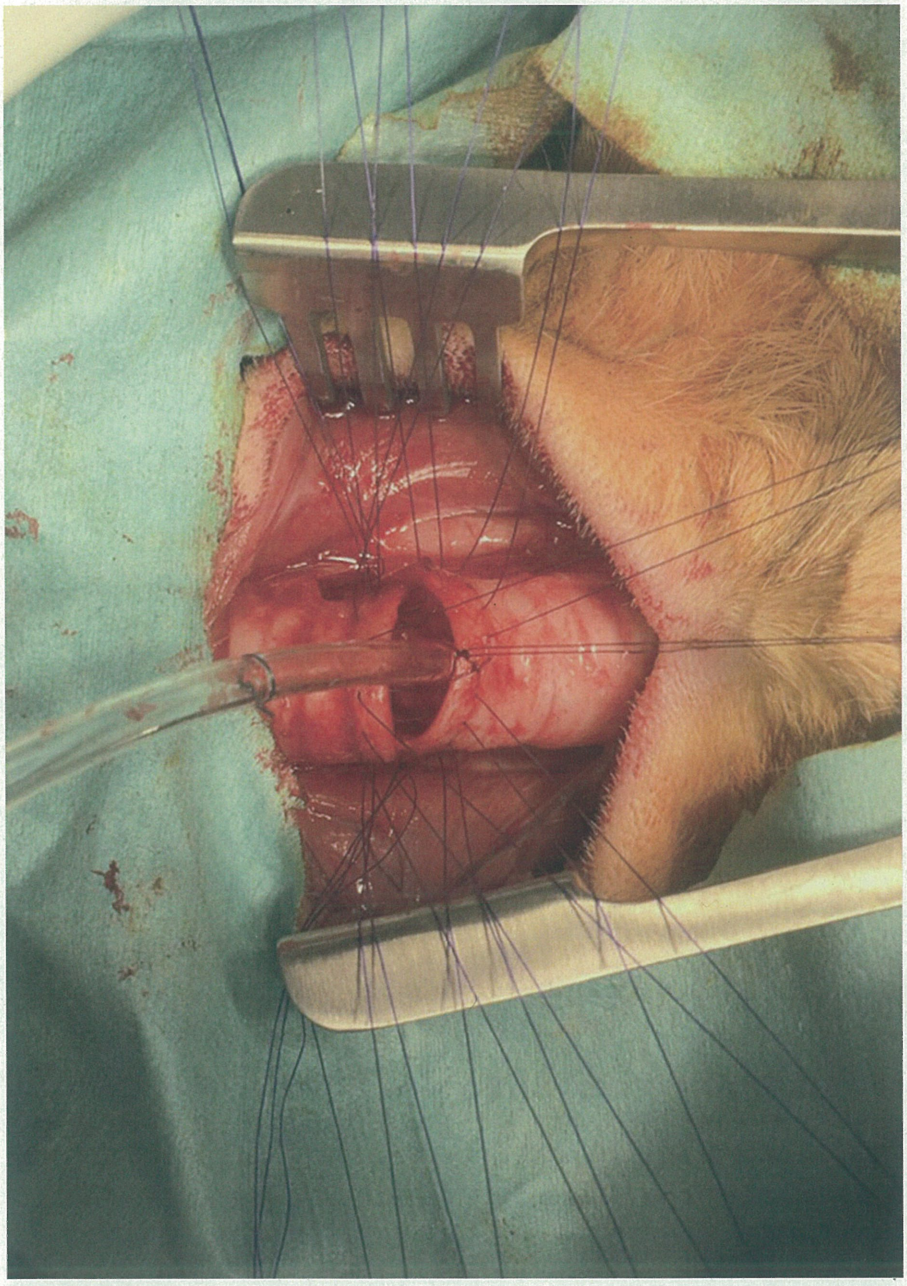
[23]. Thorens JB, Jolliet P, Ritz M, Chevrolet JC. Effects of rapid permissive hypercapnia on hemodynamics, gas exchange, and oxygen transport and consumption during mechanical

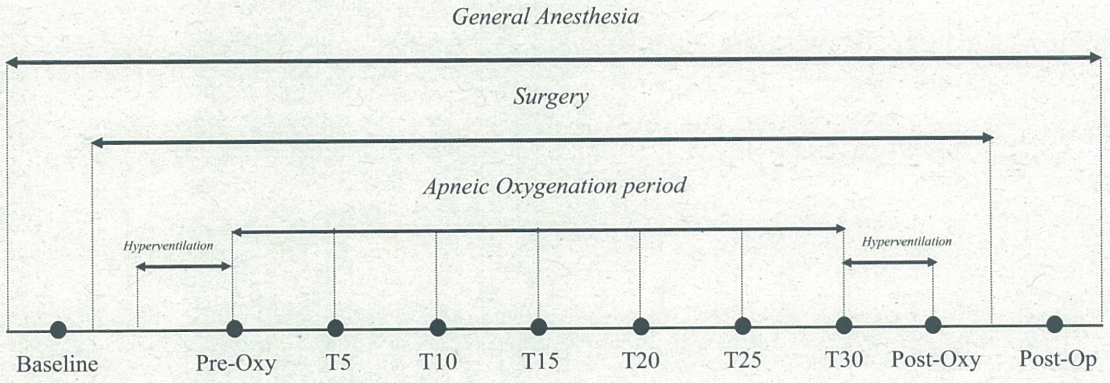
ventilation for the acute respiratory distress syndrome. Intensive Care Med 1996;22(3):182-91.

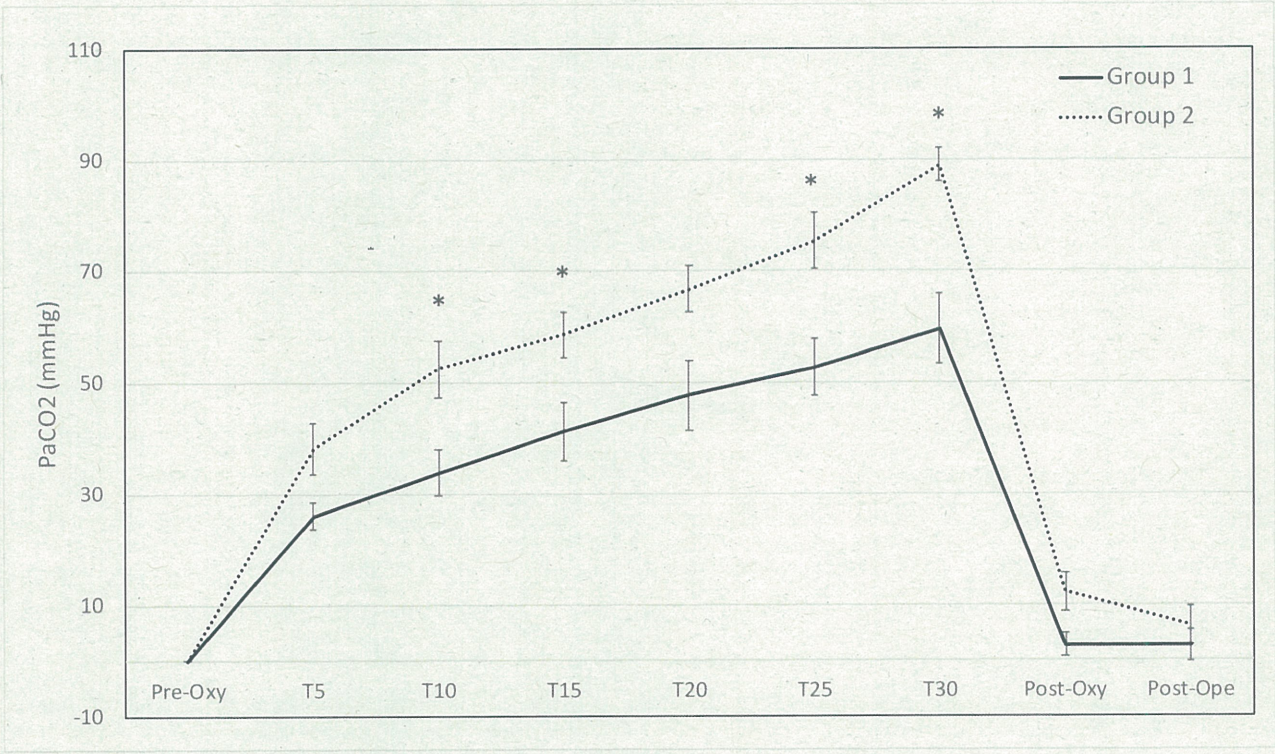
[24]. Kiely DG, Cargill RI, Lipworth BJ. Effects of Hypercapnia on Hemodynamic, Inotropic, Lusitropic, and Electrophysiologic Indices in Humans. CHEST 1996;109(5):1215–21.


Oxygen






General Anesthesia
Surgery
Apneic Oxygenation period
Hyperventilation
Hyperventilation
Baseline
Pre-Oxy
T5
T10
T15
T20
T25
T30
Post-Oxy
Post-Op


110
90
70
50
30
10
-10
PaCO2 (mmHg)
Group 1
Group 2
*
*
*
*
Pre-Oxy
T5
T10
T15
T20
T25
T30
Post-Oxy
Post-Ope