Oxygenation and Ventilation during Cardiopulmonary Resuscitation Utilizing Continuous Oxygen Delivery via a Modified Pharyngeal-Tracheal Lumened Airway

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Use of continuous transtracheal oxygen delivery systems combined with rhythmic chest compressions can provide excellent oxygenation and ventilation during cardiopulmonary resuscitation. However, occasional displacement of the transtracheal catheter results in life-threatening pneumomediastinal complications. We investigated using the pharyngeal lumen of a pharyngeal-tracheal lumened airway (PtL) as an alternative delivery system for continuous oxygen flow in 21 large mongrel dogs. Excellent ventilation was possible in anesthetized, apneic, and paralyzed dogs in normal sinus rhythm from the "bellow's" effect of chest compressions. The hypercapnia and respiratory acidaemia resulting from 5 min of complete apnea in ten dogs during normal sinus rhythm was readily corrected (p<0.01). In an additional 11 dogs, external chest compressions were performed and oxygen was delivered continuously via the PtL during 20 min of ventricular fibrillation. During this period of cardiac arrest, pH declined (7.38±0.01 vs 7.19±0.02; p<0.01), but PaCO₂ (35±1 vs 38±3 mm Hg) and PaO₂ (67±2 vs 68±3 mm Hg) were not significantly different from prearrest values. Successful resuscitation was achieved in 8 of 11 (73 percent) animals, which is similar to the results in historical controls with endotracheal intubation. No pneumomediastinal complications were seen with use of the PtL. We conclude that using the pharyngeal lumen of the PtL for continuous delivery of oxygen combined with external chest compressions can provide a safe and effective mode of oxygenation and ventilation during cardiac arrest.

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Current therapy for cardiopulmonary collapse includes both artificial ventilation and circulation. Standards and guidelines for cardiopulmonary resuscitation and emergency cardiac care have been developed and promulgated by the American Heart Association and the American Red Cross. Current guidelines suggest that endotracheal intubation should be performed as soon as feasible during the treatment of cardiac arrest. Such therapy can enhance oxygenation while helping to decrease the possibility of aspiration. Endotracheal intubation, though preferable and generally successful, is not always achievable. Alternative methods of airway management and artificial ventilation that are less technically demanding than endotracheal intubation have been developed. Ventilatory face masks and bags, esophageal obturators, and esophageal-gastric tube airways are such alternatives. However, each has its own difficulties and limitations.

Recently, there has been a resurgence of interest in transtracheal oxygenation and ventilation as an additional alternative to emergency airway management. Continuous transtracheal oxygen administration has been shown to provide excellent oxygenation to apneic subjects, but its application has been limited because of the accumulation of carbon dioxide, which results in respiratory acidaemia. Sophisticated devices have been developed to interrupt the continuous flow of oxygen, thereby allowing better carbon dioxide elimination. Continuous transtracheal oxygenation devices also have been evaluated during active cardiopulmonary resuscitation, but their use is complicated by the need for equipment to interrupt flow for adequate ventilation.

Combining continuous transtracheal oxygen flow and standard external chest compressions for a simple system of both oxygenation and ventilation, without the need for a jet ventilator, has been tested recently in both an apneic and a cardiac arrest experimental model. Continuous transtracheal oxygen delivery through a percutaneously placed intravenous catheter combined with rhythmic chest compressions resulted in excellent ventilation and oxygenation in a canine cardiopulmonary resuscitation model. However, in a minority of animals the percutaneous catheter was displaced during the performance of cardiopulmonary resuscitation, resulting in life-threatening pneumo-
mediastinal complications. In an effort to use continuous oxygen delivery in conjunction with rhythmic chest compressions without the complications of the percutaneous transtracheal route, we examined the possibility of delivering continuous oxygen via the pharyngeal lumen of a pharyngeal-tracheal lumened airway (ReviveEasy [PtI airway]; Respirronics, Monroeville, Penn). This pharyngeal-tracheal lumened airway is seen in Figure 1. To establish the utility and safety of such a ventilatory system, we performed a two-part study. First, the pharyngeal-tracheal lumened airway combined with continuous oxygen flow was examined for its ability to both oxygenate and ventilate an anemic subject with an intact circulation. Second, we examined the system for its ability to oxygenate and ventilate during actual cardiac arrest while not disrupting the necessary hemodynamic support generated by cardiopulmonary resuscitation efforts. The effect of this alternative form of ventilation on survival following cardiac arrest was also evaluated.

**Methods**

All studies were conducted according to the principles of the American Physiological Society for the care and welfare of experimental animals. Twenty-one large mongrel dogs were studied during this two-phase experimental protocol.

**Phase 1**

Ten mongrel dogs (24 ± 1 kg) were anesthetized with intravenous (IV) pentobarbital (15 mg/kg). Maintenance anesthesia was provided with additional doses of pentobarbital (4 mg/kg IV) every hour as needed. Each animal was endotracheally intubated and placed on a Harvard ventilator. Pancuronium (0.1 mg/kg IV) was administered to produce complete muscular paralysis resulting in an anemic, but intact, circulatory mode (normal sinus rhythm). The ventilator settings for both rate and tidal volume were adjusted to produce a pH range of 7.35 to 7.45 and a PaCO₂ of 35 to 45 mm Hg. All animals were ventilated with 21 percent oxygen, rather than supplemental oxygen concentrations, to better mimic the clinical situation of most cardiac arrests. Electrocardiographic monitoring of each animal was done throughout the experiment.

During anesthesia, surgical cutdowns were performed for the placement of vascular sheaths in the right and left carotid arteries and right and left external jugular veins. Two 5F micromanometer-tipped catheters (Millar Instruments, Houston) were zeroed, calibrated at 37°C in normal saline solution, and inserted through the arterial and venous vascular sheaths. These micromanometers were advanced to the ascending aorta and right atrium for pressure monitoring during the experiment. Proper position was confirmed by the presence of characteristic pressure waveforms and by fluoroscopy, when needed. Arterial blood gas samples were obtained via the left carotid vascular sheath and processed with an automated blood gas analyzer (model IL 1301, Instrumentation Laboratory, Lexington, Mass).

The endotracheal tube was then removed, and the pharyngeal-tracheal lumened airway was inserted in a clinically realistic manner (blindly, without illumination assistance). The position of the airway was determined so that the oxygen source could be appropriately inserted (via the tracheal airway if in the trachea or via the pharyngeal airway with the occluding distal balloon inflated if in the pharynx). A 5-min period of complete apnea was allowed, after which an arterial blood gas sample was drawn. Oxygenation was then begun with 10-L/min continuous flow. Standard oxygen-connecting tubing was used to join the oxygen source and a smaller-caliber tubing, which was passed down the pharyngeal lumen of the airway. In no case was the trachea directly intubated during "blind" insertion; the smaller-caliber oxygen tubing was inserted down the pharyngeal lumen of the airway in each instance. External chest compressions at a rate of 80 to 100/min were begun after the 5 min of apnea, even while the animal was in normal sinus rhythm, to provide the "bellows" effect for adequate ventilation and pH control. All chest compressions were performed manually with a 50 percent duty cycle. Hemodynamic data, including aortic and right atrial pressures, were monitored continuously and recorded every 5 min. Ventilation with this continuous flow of oxygen and accompanying chest compressions were administered for 30 min. Arterial blood gas values were monitored every 2.5 min. After the last arterial blood gas sample had been obtained (at 30 min), the experiment was terminated, and the animal was killed with an intravenous injection (Euthanol).

The first four animals were used in a pilot study to determine the effect of inflation of the proximal posterior oropharyngeal balloon on optimal delivery of continuous oxygen as well as exhalation of carbon dioxide. Following this pilot work, six animals were studied during complete apnea but while remaining in normal sinus rhythm with an intact circulation.

**Phase 2**

Eleven mongrel dogs (weighing 23 ± 1 kg) were prepared as in phase 1 with the exception that pancuronium was not used. Instead of an anemic, perfusing model, a cardiac arrest model was employed. Ventricular fibrillation was induced by rapid right ventricular pacing at 800 beats per minute with use of a 5F pacing wire introduced through the left jugular vein. Arterial blood gas determinations and pressure tracings of the aorta and right atrium were obtained as in phase 1. After 3 min of no chest compressions, oxygenation, or ventilation, the animals received continuous oxygen flow, 10 L/min, through the pharyngeal lumen of the pharyngeal-tracheal lumened airway, combined with chest compressions at 80 to 100/min. Arterial blood gas samples were collected every 2.5 min throughout the resuscitation period. At 15 min of cardiac arrest, 1 mg of epinephrine was given intravenously. After 20 min of cardiac arrest, defibrillation was attempted with a maximum of three defibrillation shocks (300 J). Successfully defibrillated animals were then endotracheally intubated, ventilated per standard positive-pressure techniques, and monitored for an additional 60 min for continued hemodynamic stability.

**Statistical Analysis**

All results were expressed as the mean and standard error of the mean. The pilot studies were analyzed using unpaired, two-tailed, Student t testing to compare pH, PaCO₂, and PaO₂ with and without inflations of the posterior pharynx balloon. Differences over time in pH, PaCO₂, and PaO₂ during both phases 1 and 2 were examined with analysis of variance for unpaired data testing with the addition of Bonferroni's correction for multiple comparisons. Coronary perfusion pressures during phase 2 were compared between resuscitated and nonresuscitated animals using unpaired, two-tailed, Student t testing. Fisher's exact test was used to compare resuscitation success with continuous oxygenation and ventilation to that in a historical control group treated with endotracheal intubation...
Table 1 — Effect of the Posterior Oropharyngeal Balloon on Oxygenation and Ventilation*

<table>
<thead>
<tr>
<th>Variable</th>
<th>10 min</th>
<th>20 min</th>
<th>30 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH Inflated</td>
<td>7.10 ± 0.01</td>
<td>6.94 ± 0.03</td>
<td>6.95 ± 0.06</td>
</tr>
<tr>
<td>Deflated</td>
<td>7.30 ± 0.02</td>
<td>7.34 ± 0.02</td>
<td>7.33 ± 0.03</td>
</tr>
<tr>
<td>p value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PaCO₂, mm Hg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflated</td>
<td>73 ± 2</td>
<td>94 ± 3</td>
<td>87 ± 8</td>
</tr>
<tr>
<td>Deflated</td>
<td>38 ± 2</td>
<td>35 ± 1</td>
<td>37 ± 3</td>
</tr>
<tr>
<td>p value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PaO₂, mm Hg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflated</td>
<td>247 ± 29</td>
<td>250 ± 86</td>
<td>305 ± 90</td>
</tr>
<tr>
<td>Deflated</td>
<td>250 ± 55</td>
<td>147 ± 41</td>
<td>119 ± 17</td>
</tr>
<tr>
<td>p value</td>
<td>&gt;0.9</td>
<td>&gt;0.3</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

*Probability values represent level of significance of difference between value for inflated balloon and value for deflated balloon; probability value of less than 0.05 was considered significant.

Table 2 — Oxygenation and Ventilation with 10-L/min Continuous Oxygen Flow via the Pharyngeal Lumen in an Apneic, Intact Circulatory Model

<table>
<thead>
<tr>
<th>Time Period</th>
<th>pH</th>
<th>PaCO₂ mm Hg</th>
<th>PaO₂ mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.36 ± 0.01</td>
<td>37 ± 1</td>
<td>77 ± 4</td>
</tr>
<tr>
<td>5.0 min (apnea)</td>
<td>7.26 ± 0.02</td>
<td>57 ± 2</td>
<td>13 ± 1</td>
</tr>
<tr>
<td>7.5 min</td>
<td>7.26 ± 0.02</td>
<td>46 ± 3</td>
<td>247 ± 69</td>
</tr>
<tr>
<td>10.0 min</td>
<td>7.30 ± 0.02</td>
<td>38 ± 2</td>
<td>250 ± 50</td>
</tr>
<tr>
<td>12.5 min</td>
<td>7.32 ± 0.02</td>
<td>36 ± 2</td>
<td>160 ± 27</td>
</tr>
<tr>
<td>15.0 min</td>
<td>7.32 ± 0.02</td>
<td>37 ± 3</td>
<td>180 ± 45</td>
</tr>
<tr>
<td>17.5 min</td>
<td>7.33 ± 0.02</td>
<td>37 ± 2</td>
<td>171 ± 44</td>
</tr>
<tr>
<td>20.0 min</td>
<td>7.34 ± 0.02</td>
<td>35 ± 1</td>
<td>147 ± 38</td>
</tr>
<tr>
<td>22.5 min</td>
<td>7.33 ± 0.03</td>
<td>36 ± 3</td>
<td>135 ± 32</td>
</tr>
<tr>
<td>25.0 min</td>
<td>7.34 ± 0.03</td>
<td>36 ± 4</td>
<td>126 ± 23</td>
</tr>
<tr>
<td>27.5 min</td>
<td>7.34 ± 0.03</td>
<td>37 ± 3</td>
<td>134 ± 22</td>
</tr>
<tr>
<td>30.0 min</td>
<td>7.33 ± 0.03</td>
<td>37 ± 3</td>
<td>119 ± 16</td>
</tr>
</tbody>
</table>

Results

Phase 1

The effect of inflation of the standard proximal posterior oropharyngeal balloon markedly decreased effective exhalation of carbon dioxide, resulting in rapidly declining levels of pH. Table 1 shows the increasing hypercapnia resulting over 20 min with the posterior oropharyngeal balloon inflated. Oxygenation was somewhat better with the posterior oropharyngeal balloon inflated; however, even with the balloon deflated, the absolute PaO₂ always exceeded 100 mm Hg.

The pharyngeal-tracheal airway was therefore altered to remove the standard proximal posterior oropharyngeal balloon to ensure an adequate exhala-
tion airway. Once this alteration was completed, the airway was tested for its ability to deliver continuous oxygen flow and to provide adequate ventilation when combined with chest compressions in an apneic but intact circulatory model. During the 5 min of complete apnea with normal circulation (normal sinus rhythm) PaCO$_2$ rose from a baseline of 37±1 to 57±2 mm Hg (p<0.01), resulting in a decline in pH from 7.36±0.01 to 7.26±0.02 (p<0.01). Oxygenation during this apneic period also fell significantly from a baseline on room air of 77±4 to 13±1 mm Hg (p<0.01). Institution of continuous oxygen delivery and concurrent chest compressions resulted in rapid resolution of the hypercapnia and hypoxia. Table 2 shows these data over time. No differences in baseline arterial blood pH and PaCO$_2$ were seen between baseline values and those after 30 min of apnea during normal sinus rhythm treated with continuous oxygen flow through the modified pharyngeal-tracheal lumened airway combined with external chest compressions (Fig 2). The mean value for PaO$_2$ after 30 min was significantly higher than baseline with use of this continuous oxygen delivery system (Fig 2).

**Phase 2**

Continuous oxygen delivery utilizing the pharyngeal lumen of the modified pharyngeal-tracheal lumened airway coupled with external chest compressions provided adequate ventilation and oxygenation during 20 min of cardiac arrest. Mean arterial blood pH fell from a baseline of 7.38±0.01 to 7.19±0.02 (p<0.001) over the 20 min of cardiac arrest and resuscitation efforts, but PaCO$_2$ did not change significantly. Figure 3 shows the pH and PaCO$_2$ data from the prearrest period, 10 min into cardiac arrest, and after 20 min of cardiac arrest. Table 3 contains the data for the entire phase 2 experimental period. The ability of this system to oxygenate during actual resuscitation efforts for cardiac arrest is also shown in Figure 3. Oxygenation was significantly better at 10 min with this continuous flow system than it was at baseline on room air; by 20 min, though not as high as at 10 min, it was equivalent to the prearrest oxygenation.

This system of continuous oxygen delivery and chest compressions did not adversely affect the generation of aortic, right atrial, and myocardial perfusion pressures so critical to successful resuscitation (Table...
Table 3—Oxygenation and Ventilation with 10 L/min
Continuous Oxygen Flow via the Pharyngeal Lumen in a
Ventricular-Fibrillation Cardiac Arrest Model

<table>
<thead>
<tr>
<th>Time Period</th>
<th>pH</th>
<th>PaCO₂ mm Hg</th>
<th>PaO₂ mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.38 ± 0.01</td>
<td>35 ± 1</td>
<td>67 ± 2</td>
</tr>
<tr>
<td>3.0 min (untreated)</td>
<td>7.39 ± 0.01</td>
<td>33 ± 1</td>
<td>69 ± 2</td>
</tr>
<tr>
<td>5.0 min</td>
<td>7.33 ± 0.03</td>
<td>38 ± 3</td>
<td>115 ± 22</td>
</tr>
<tr>
<td>7.5 min</td>
<td>7.27 ± 0.03</td>
<td>42 ± 3</td>
<td>113 ± 19</td>
</tr>
<tr>
<td>10.0 min</td>
<td>7.25 ± 0.02</td>
<td>41 ± 3</td>
<td>94 ± 12</td>
</tr>
<tr>
<td>12.5 min</td>
<td>7.24 ± 0.02</td>
<td>39 ± 3</td>
<td>77 ± 9</td>
</tr>
<tr>
<td>15.0 min</td>
<td>7.24 ± 0.02</td>
<td>36 ± 3</td>
<td>82 ± 6</td>
</tr>
<tr>
<td>17.5 min</td>
<td>7.22 ± 0.02</td>
<td>37 ± 2</td>
<td>76 ± 7</td>
</tr>
<tr>
<td>20.0 min</td>
<td>7.19 ± 0.02</td>
<td>40 ± 3</td>
<td>67 ± 4</td>
</tr>
</tbody>
</table>

4). The mean myocardial perfusion pressure generated during the resuscitation effort was 24 ± 3 mm Hg. Figure 4 demonstrates the consistency of the myocardial perfusion pressure throughout the period of resuscitation.

Eight of 11 animals were successfully resuscitated after 20 min of cardiac arrest with use of this system of continuous oxygen delivery combined with standard external chest compressions. Mean myocardial perfusion pressure for animals successfully resuscitated was 31 ± 3 mm Hg, while those that could not be resuscitated had a mean myocardial perfusion pressure of only 4 ± 3 mm Hg (p<0.001). No difference in PaO₂ was found between resuscitated and nonresuscitated animals. However, significant differences in PaCO₂ and pH were noted between resuscitated and nonresuscitated animals. The PaCO₂ was 41 ± 1 mm Hg in resuscitated animals and 33 ± 3 mm Hg in animals that could not be resuscitated (p<0.005). Likewise, pH was 7.23 ± 0.01 in resuscitated animals and 7.30 ± 0.02 in nonresuscitated animals (p<0.005).

No pneumomediastinal complications or deaths occurred with this technique of oxygen delivery. Necropsy revealed that lung contusions were very common (78 percent) but were generally minor, involving about 15 percent of the lung. Right and left lungs were equally involved, both in frequency and extent. Other cardiopulmonary resuscitation injuries seen included rib fractures in four animals, serosanguineous peritoneal fluid (30 ml) in two animals, and small liver lacerations in two animals.

**DISCUSSION**

Continuous oxygen delivered through a transtracheal catheter has been shown to be a viable alternative for emergency respiration and ventilation. Alone, such a system can provide excellent oxygenation, but hypercapnia results, creating profound respiratory acidemia. However, when combined with either jet ventilation or external chest compressions and a patent oral airway, excellent oxygenation and ventilation can be achieved. If the transtracheal catheter is large enough, adequate ventilation may be achieved even with complete upper airway obstruction. A major concern with such systems is pneumomediastinal complications. Though an uncommon occurrence, displacement of the intratracheal position of the catheter during continuous oxygen flow can be life threatening.

The use of a pharyngeal-tracheal lumened airway instead of a transtracheal catheter for delivery of the continuous oxygen flow produces similar oxygenation and ventilation without the potentially lethal complications of pneumomediastinum. The pharyngeal-tracheal airway is easy to use because it is placed without illumination guidance into the posterior oropharynx and then merely advanced. Refined skills are not needed, as they are with direct tracheal intubation or effective bag-mask ventilation.

Typically, the device is placed in the esophagus when inserted in this blind fashion. The location of the device was easily discerned by mouth-to-tube breathing while auscultating over the pulmonary and gastric areas. However, intratracheal placement can occur during blind insertion of the device. Though we did not observe this occurrence in our series of 21 large dogs, a report by McMahon et al indicates that
blind insertion of the pharyngeal-tracheal airway into the trachea may occur in 25 percent of patients. Recognition of the position of the distal tip of the airway is crucial since inflation of the distal balloon is advantageous in preventing gastric distension and aspiration when the device is in the esophagus, but can preclude effective ventilation if the device is in the trachea.

Alternatives to auscultation for the detection of the distal tube position include monitoring of expired end-tidal carbon dioxide. If the distal airway tip is in the trachea, expired carbon dioxide should be detectable through the distal tube lumen. However, if the tip is in the esophagus, no or minimal carbon dioxide levels should be present. The use of expired carbon dioxide detectors for ventilatory tube placement in cardiac arrest victims has recently been reported. In separate series, Sayah et al. and Vukmir et al. have shown expired carbon dioxide detectors to be excellent in determining ventilatory tube position in cardiac arrest victims. However, Ornato et al. found a 25 percent incidence of low expired carbon dioxide levels in cardiac arrest victims when ventilatory tubes were placed in the trachea. They postulated that carbon dioxide detectors are useful but can give low readings not only due to incorrect (i.e., intraesophageal) placement, but also due to poor blood flow during cardiopulmonary resuscitation efforts.

If the distal balloon of the pharyngeal-tracheal airway is inflated while in the esophagus, further inflation of the stomach is prohibited, decreasing the possibility of aspiration. Connection of the source of oxygen flow to the secondary airway leading to the distal posterior oropharynx directs oxygen into the trachea since distal flow to the esophagus is blocked by the inflated balloon (Fig 5).

Modification of the original pharyngeal-tracheal airway by removal of the proximal balloon was crucial for an adequate exhalation pathway. When this balloon is inflated, the upper naso-oropharynx is occluded, and the oral airway is sealed off. The remaining luminal airway already contains both the primary airway tube and the oxygen tubing for continuous oxygen flow. The residual luminal area is inadequate for carbon dioxide exhalation and hypercapnia results, in spite of ongoing rhythmic chest compressions. As seen in Table 1, under these circumstances a patent oral airway is essential for the maintenance of normal PaCO₂ and pH. An alternative solution could be to increase the size of the pharyngeal lumen within the pharyngeal-tracheal device.

Oxygenation was significantly higher with the oropharynx sealed off by inflation of the proximal balloon. With this airway open, both oxygen and carbon dioxide are exhaled. It should be noted that the difference in oxygenation with and without the proximal balloon inflated, though statistically significant, is not clinically important since the PaO₂ levels never fell below those achieved during prearrest conditions.

Use of this modified pharyngeal-tracheal airway as the delivery system for a continuous flow of oxygen combined with chest compressions was effective for oxygenating and ventilating. Most impressively, such a system can overcome the hypoxia and hypercapnia associated with brief periods of complete apnea and untreated cardiac arrest. A 5-min period of no ventilation with subsequent hypercapnia and hypoxia was rapidly corrected with this form of artificial respiration in the apneic animal with normal sinus rhythm. The arterial blood hypoxemia was corrected within 2.5 min; the hypercarbia, within 5 min (Table 2). Oxygenation and ventilation utilizing this alternative system during 20 min of cardiopulmonary resuscitation, including 3 min of untreated ventricular fibrillation, were equally effective. Both PaCO₂ and PaO₂ levels were maintained near prearrest levels during the 20 min of ventricular fibrillation and cardiopulmonary resuscitation.

The declining pH while PaCO₂ remained constant indicates that by 20 min of cardiac arrest the primary acid-gas disturbance is metabolic. This decline in pH does not appear to be clinically detrimental. Our data show that pH levels declining to this range did not adversely affect defibrillation success. Indeed, an unanticipated finding was that the mean pH for resuscitated animals was significantly lower than the mean pH of animals that could not be resuscitated (7.23 ± 0.01 vs 7.30 ± 0.02, p < 0.005). This is further evidence that pH is not a primary determinant of cardiac arrest outcome, but may be a secondary reflection of the circulatory state.

Those animals that were resuscitated had significantly higher perfusion pressures than the animals...
that were not resuscitated. Previous work has shown an excellent correlation between perfusion pressure and blood flow. Therefore, the lower pH seen here in the resuscitated animals may be a reflection of better perfusion resulting in a more proficient mobilization of the excess peripheral tissue hydrogen ion accumulation.

Use of this system of continuous oxygen flow did not inhibit the generation of aortic and myocardial perfusion pressures during cardiopulmonary resuscitation. As previously demonstrated, myocardial perfusion pressure correlates with the outcome of resuscitation efforts. Animals subsequently resuscitated had significantly greater perfusion pressures than did the animals that could not be resuscitated. As would be expected with the generation of adequate myocardial perfusion pressures, the overall resuscitation success rate using this form of continuous oxygenation was excellent. Eight of 11 animals were successfully defibrillated and maintained an arterial blood pressure for 60 min, at which time they were killed. This resuscitation success is comparable to that seen in similar cardiac arrest studies (involving 20 min of cardiac arrest, including 3 min of initially untreated ventricular fibrillation) where standard forms of endotracheal intubation and positive-pressure ventilation were used.

Once successful resuscitation has been accomplished, ventilatory support should be provided by elective, illuminated placement of an endotracheal tube and positive-pressure ventilation. If circumstances make this impossible, then a tracheostomy could be performed under controlled circumstances and coupled with positive-pressure ventilation prior to the removal of the pharyngeal-tracheal airway. Once an alternative airway is in place, all balloons on the pharyngeal-tracheal airway are deflated, and the device is removed. A similar approach is recommended by the American Heart Association and the American Red Cross.

In contrast to the lethal complications seen in some animals receiving continuous transtracheal oxygenation and cardiopulmonary resuscitation, no serious morbidity was seen with use of the modified pharyngeal-tracheal airway to deliver continuous oxygen flow. Mild pulmonary hemorrhage was common but not life threatening, though it may have limited the levels of PaO₂ achieved during the later portions of the experiment.

**Conclusions**

A modified pharyngeal-tracheal lumened airway was used successfully as the delivery system for continuous oxygen administration in both an anoxic and a cardiac arrest model. When use of this airway is combined with standard American Heart Association basic life support chest compressions, excellent ventilation and oxygenation can be attained. This alternative emergency artificial respiration technique is easy to initiate and safe to operate. Survival rates seen with this technique following 20 min of cardiac arrest are comparable to those obtained with standard endotracheal intubation and positive-pressure ventilation techniques.

**References**

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15. Dunlap LB. A modified, simple device for the emergency administration of percutaneous transtracheal ventilation. JACEP 1978; 7:42-46