CARDIOPULMONARY CEREBRAL RESUSCITATION

Tim B. Hackett, DVM, MS

He’s dead Jim!

DEFOREST KELLY, STAR TREK

Cardiopulmonary arrest (CPA) is defined as the abrupt and unexpected cessation of spontaneous and effective ventilation and circulation. CPA can be the natural ending of a normal and long life. When CPA is the result of a reversible problem in an animal that has a treatable medical condition, rapid recognition and treatment may make the difference between a happy ending and premature death. Cardiopulmonary resuscitation (CPR) provides artificial ventilation and circulation until advanced cardiac life support can be provided and spontaneous cardiopulmonary function is restored. CPR is divided into three phases: basic life support (BLS), advanced life support (ALS), and prolonged life support (PLS).

The term cardiopulmonary cerebral resuscitation originated in the early 1960s in recognition of the severe central nervous system complications of prolonged cardiac arrest in human beings. Although neurologic complications of CPA may not be as noticeable in companion animals, newer brain-sparing strategies that recognize the consequences of reperfusion injury and the inflammatory cascade may some day offer improved survival.

From the Department of Clinical Sciences, Veterinary Teaching Hospital, Colorado State University, Fort Collins, Colorado
HISTORICAL PERSPECTIVES

O, that I could but call these dead to life!

WILLIAM SHAKESPEARE, KING HENRY VI

God breathing the breath of life into Adam may well be the first reported "suscitation"; however, the first account of "resuscitation" was by the prophet Elijah, from Kings I in the Hebrew Bible. A mother, in tears, brings her child to Elijah. From the account, "and his illness was so severe that there was no breath left in him," the child was placed on Elijah’s bed, where the prophet prayed to the Lord. Elijah then stretched across the child three times. It continues, "And the Lord Hearkened to the voice of Elijah, and the soul of the child came into him again, and he revived."12

The first account of mouth-to-mouth resuscitation occurred in 1732 when William Tossach, a Scottish surgeon, was called to see a man who had been "overcome by a nauseous steam arising from coals set on fire in the pit." Finding the man cold, with "not the least pulse in either heart or arteries," and with no observed breathing, Tossach applied his mouth close to the patient and "blowed" his breath as strong as he could. Realizing that much of the breath went straight out the nostrils, he tried again after "taking hold of them with one hand." This time, when he blew again, he was able to raise the chest fully and "immediately felt six or seven beats of the heart." An hour later, the man was back to his sences and feeling good enough to have a drink before walking home. The story was spread around London by Dr John Fothergill, who advocated mouth-to-mouth respiration for all cases of drowning and suffocation.12

In 1906, a report by Crile and Dolley7 described an experimental method of resuscitation in dogs using thoracic compression, artificial ventilation, and parenteral epinephrine. They described "direct" (i.e., open-chest) and "indirect" cardiac massage and anticipated the thoracic pump theory of circulation by stating the "pressure upon the thorax alone is capable of producing an artificial circulation. This is by no means accomplished by its action upon the heart solely, but by its action upon all the large vessels: arteries, veins, and capillaries together."7 The most significant modern CPR work came in the late 1950s and early 1960s. In 1961, a landmark report on the effectiveness of external cardiac compression led to the training of hospital and emergency personnel in the recognition and treatment of CPA.18

Little has changed in the actual treatment of cardiac arrest over the last 20 years. With success rates (survival to hospital discharge) ranging from 0% to 29% reported for human patients suffering in-hospital cardiac arrest,2 the experience in treating CPA is not encouraging. In a review of 265 nonanesthetized critical care unit cases undergoing CPR, only 4.1% of dogs and 9.6% of cats were ultimately discharged from the hospital.32 Many clinicians are understandably skeptical about the usefulness of current treatment protocols.
The guidelines for CPR in people have evolved through multiple national conferences starting in 1966.27 The purpose of these conferences has been to review and update published materials concerning CPR in the light of scientific advances and clinical experience. Because many of these guidelines have been drawn from experimental animal studies, they are directly relevant to veterinary medicine and are included in these recommendations. Although there are no universally accepted CPR standards in veterinary medicine, it is generally agreed that CPR provides a narrow window of opportunity. For CPR to be successful, oxygenation and circulation must be established as soon as possible.15-17

**READINESS**

Changes in respiratory rate, the depth of respiration, hypotension, bradycardia or other cardiac arrhythmias, cyanosis, and hypothermia are all warning signs of impending CPA.16 By recognizing animals at increased risk of CPA and providing prior training of technical and support staff, CPR can be initiated in a timely and coordinated manner. When the underlying cause of CPA is reversible, every effort should be made to support vital circulation and oxygenation in a coordinated attempt to save the life. The major reasons for unsuccessful resuscitation include delay in the diagnosis of CPA and subsequent delay in administering appropriate therapy. For the benefit of patients with potentially reversible problems, hospitals should have a fully stocked “crash cart” available, and the staff should be trained in the three parts of CPR: BLS, ALS, and PLS.

ALS with electric defibrillation and emergency drug administration also involves advanced planning. Calculating emergency drug dosages in the environment of the arrest is difficult. The use of computer programs, clinical algorithms, and prepared charts giving intravenous (IV) and intratracheal dosages of the commonly used emergency drugs can be invaluable during an arrest (Table 1).

All hospital personnel can be trained in some aspect of managing an arrest. For example, nontechnical staff can learn to ventilate patients after intubation, administer abdominal counterpressure, draw up syringes of drugs and saline flush, and even record the drugs administered and time intervals during CPR for later review. Having regular CPR drills with stuffed animals or resuscitation mannequins helps to foster a team approach. Staff meetings in which all members of the hospital are present serve as an ideal time to practice basic life support in a coordinated low-stress setting.

**Do Not Resuscitate Orders**

CPA is the terminal event in most disease processes and the underlying conditions should always be considered before CPR is attempted.23
Table 1. COMMON DRUGS AND DOSAGES USED DURING AND AFTER CARDIOPULMONARY RESUSCITATION

<table>
<thead>
<tr>
<th>Drug</th>
<th>Indications</th>
<th>Dosage(s)</th>
</tr>
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<tbody>
<tr>
<td>Atropine sulfate</td>
<td>Ventricular asystole, sinus bradycardia, AV block</td>
<td>0.04 mg/kg IV, IO 0.4 mg/kg IT</td>
</tr>
<tr>
<td>Bretylium tosylate</td>
<td>Refractory ventricular fibrillation</td>
<td>5–10 mg/kg IV, IT, IO</td>
</tr>
<tr>
<td>Epinephrine</td>
<td>Asystole, pulseless electric activity</td>
<td>Low dose: 0.02 mg/kg IV, IT, IO</td>
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<tr>
<td></td>
<td></td>
<td>High dose: 0.2 mg/kg IV, IT, IO</td>
</tr>
<tr>
<td>Isoproterenol</td>
<td>Atropine resistant bradycardia, complete AV block</td>
<td>0.04–0.08 μg/kg/min IV CRI</td>
</tr>
<tr>
<td>Lidocaine</td>
<td>Ventricular arrhythmias</td>
<td>2–8 mg/kg IV, IT, IO bolus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>followed by 60–100 μg/kg/min IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CRI</td>
</tr>
<tr>
<td>Magnesium chloride</td>
<td>Ventricular arrhythmias, refractory ventricular</td>
<td>30 mg/kg slowly IV</td>
</tr>
<tr>
<td>Mannitol</td>
<td>edema</td>
<td></td>
</tr>
<tr>
<td>Naloxone</td>
<td>Cardiopulmonary depression secondary to narcotic</td>
<td>0.5–1 g/kg IV</td>
</tr>
<tr>
<td></td>
<td>administration, pulseless electric activity</td>
<td>0.03 mg/kg IV, IO, IT</td>
</tr>
<tr>
<td>Sodium bicarbonate</td>
<td>Severe metabolic acidosis, prolonged cardiac</td>
<td>1–2 mEq/kg IV, IO every 10–15</td>
</tr>
<tr>
<td></td>
<td>arrest</td>
<td>minutes of CPA (do not give IT)</td>
</tr>
</tbody>
</table>

AV = atrioventricular, IV = intravenous, IO = intraosseous, IT = intratracheal, CRI = continuous rate infusion, CPA = cardiopulmonary arrest.

When communicating with the owners of pets in critical condition, clinicians should discuss the possibility of CPA, prognosis, and associated expenses so that the owners of terminally ill animals can be actively involved in the decision-making process. Before beginning CPR, it is reasonable to consider how worthwhile an extensive resuscitative effort might be. When decisions need to be made quickly, it is helpful to have a clear understanding of what is to be done in the event of an arrest. Do not resuscitate (DNR) orders should be clear to everyone taking part in the care of the critical patient. At our hospital, patients with a standing DNR order have yellow tags placed on their cage. Levels of CPR are further delineated with open-chest CPR, full CPR (closed chest with drugs), CPR only (basic life support measures), and DNR clearly noted on the daily treatment sheet. Clinicians filling out these orders are asked to make a decision concerning CPR status on a daily basis.

**BASIC LIFE SUPPORT**

The decision to begin CPR needs to be made immediately when a patient is found to be unresponsive, breathless, and pulseless. The single rescuer should alert other hospital staff, beginning an organized effort to resuscitate the patient. For CPR to be effective, oxygen must be
delivered to the myocardium and brain. Myocardial oxygen delivery is dependent on myocardial blood flow (the difference between aortic diastolic pressure and right atrial pressure) and arterial oxygen content. Cerebral perfusion depends on cardiac output and cerebral vascular resistance. Intubation and ventilation with 100% oxygen should be performed as soon as possible to maximally saturate hemoglobin and improve arterial oxygen content. For years, the “ABCs” of CPR were used to teach caregivers to assess and establish airway, breathing, and circulatory support in that order. Although the airway first approach is important in human CPA patients (whose airways tend to kink and obstruct with unconsciousness), animals with straight patent airways probably benefit from a “CAB” approach: compressions first, followed by airway and then breathing. Chest compressions provide some gas exchange. The advantage to this approach is treating the circulatory failure and the failure of ventilation at the same time. Animals are placed in either lateral or dorsal recumbency depending on body size. Larger (>7 kg) and rounder chested animals should be placed in dorsal recumbency, and smaller animals as well as those with narrow chests can be kept in lateral recumbency. Chest compressions are initiated at a rate of 80 to 120 times a minute. Compressions are done at a 50:50 ratio of compressions to the relaxation cycle. The chest is compressed 25% to 30% of its dimension. The larger the patient, the less likely it is that direct cardiac compression can occur. In these animals, chest compressions result in global elevation of intrathoracic pressure and the development of a pressure gradient across the thoracic inlet. Blood is squeezed from the pulmonary vascular bed through the heart (a passive conduit) and into peripheral vessels.

As more people arrive to assist, the senior person performing the CPR should make assignments. The first priority is chest compressions, followed by intubation and breathing. With two rescuers, one can perform chest compressions while the other breathes for the patient, ideally using 100% oxygen via a cuffed endotracheal tube. Applying a breath with each compression (simultaneous compression and ventilation) is another strategy to increase intrathoracic pressure throughout the chest, favoring forward blood flow.

An electrocardiogram and, if available, an end-tidal carbon dioxide (ET\(_{\text{CO}_2}\)) monitor should be attached to the patient. The crash cart should be brought close by, and emergency drugs (epinephrine and atropine) should be drawn up for administration. If personnel become tired, they should trade off or change positions. It is often much easier to perform CPR standing on a stool slightly above the patient.

A third rescuer can begin performing interposed abdominal compression, or abdominal compressions can be performed by the person doing the chest compressions. Direct pressure applied to the abdomen and directed craniad toward the heart during the relaxation phase of the chest compression cycle may cause retrograde aortic flow and improve cardiac preload. The senior rescuer can make this ballet easier by calling out compressions and relaxation. If the rescuer calls out “one
and two and three” while giving chest compressions on the count and relaxation on the “and,” the person breathing knows to give breaths during the chest compression and the person in charge of interposed abdominal compressions can press down and forward during the relaxation. This sort of team work functions best when practiced regularly.

The team should continually assess their efforts at CPR. Recommendations concerning body positioning are just that. Check to see if the efforts are generating a palpable pulse. If no pulse is felt, try changing positions, try deeper compressions, or place a fist under the chest. Stop periodically to assess the electrocardiogram. Different cardiac arrhythmias may require specific treatments. The efficacy of CPR can most easily be assessed using ET$_{\text{CO}_2}$. Experiments using a canine CPA model demonstrated better survival in patients with a higher ET$_{\text{CO}_2}$.

**Open-Chest Cardiac Massage**

The blood flow generated by external cardiac compression is only 25% of normal. Experimental studies have shown that cardiac output with open-chest (direct) cardiac massage is approximately double that obtained by external cardiac compression.\textsuperscript{10} There are numerous studies demonstrating improved blood pressure, cerebral and coronary blood flow, and short-term survival with improved neurologic recovery.\textsuperscript{10, 33} What is not as clear is if the outcome (survival to hospital discharge) in clinical CPA is improved with this technique. Any animal suffering CPA during surgery (either thoracic or abdominal) should have direct cardiac massage instituted immediately. Patients suffering thoracic trauma or with conditions of the chest or abdomen that preclude effective external compressions should also be considered candidates for direct cardiac compression. Other intrathoracic problems that warrant emergency thoracotomy include arrest caused by pericardial tamponade, penetrating trauma or open chest wounds, and tension pneumothorax.\textsuperscript{23}

The decision to begin direct cardiac compression should not wait until closed cardiac compressions have clearly failed. Ideally, this decision should be made early, because it is unlikely to be effective when the arrest has lasted more than 15 minutes.\textsuperscript{15}

In right lateral recumbency, the left fifth intercostal space is quickly shaved and prepared. An incision is quickly made down to the intercostal muscles. Blunt scissors are used to enter the pleural space and incise the intercostal muscles, allowing quick access to the heart. The phrenic nerve overlying the pericardial sack is identified, and the pericardium is incised ventral to the nerve. If the CPA occurs during abdominal surgery, the chest is approached through the diaphragm, and the pericardium is entered with the same concerns about the phrenic nerve. The heart is then gently massaged from the apex to the base. With the hands on the patient’s heart, diastolic filling can be assessed, and the need for intravenous fluids can be adjusted accordingly. If more hands are available, the descending aorta can be occluded to maximize cerebral and
coronary blood flow. With return of spontaneous circulation, the occlusion of the descending aorta should be released gradually to avoid potential reperfusion injury to vital abdominal structures.\textsuperscript{15}

**ADVANCED LIFE SUPPORT**

After instituting BLS and with the aid of an electrocardiogram, advanced measures (drugs and defibrillation) can proceed. Any CPA patient that has received narcotic analgesics should receive naloxone (0.03 mg/kg IV) to counteract any cardiopulmonary depressant effects. Further drugs should be based on electrocardiographic findings. The three most common arrhythmias in veterinary CPA patients are asystole (epinephrine and atropine), pulseless electric activity (epinephrine and atropine), and ventricular fibrillation (electric defibrillation, magnesium chloride, and bretylium tosylate).\textsuperscript{25}

A central IV catheter is the route of choice for administering emergency drugs. When intravascular access is difficult or unavailable, epinephrine, atropine, naloxone, and lidocaine can be effectively absorbed into the circulation by intratracheal administration.\textsuperscript{23} Drugs are diluted with sterile saline and administered into the small airways using a 5- to 8-French urinary catheter. After administration, several large-volume breaths are administered to hasten drug absorption. If hypovolemia contributed to the arrest, efforts should be made to establish vascular access either through intraosseous catheterization or central venous cut-down.

Pure \(\alpha\)-agonists, pure \(\beta\)-agonists, and agents with both sympathomimetic activities have been tested in experimental models of cardiac arrest. The most consistent finding is that \(\alpha\)-agonist activity is crucial to the return of spontaneous blood flow.\textsuperscript{24} \(\alpha\)-Stimulation results in increased aortic pressures, increased coronary perfusion pressures, increased venoconstriction, favorable redistribution of cardiac output, and preservation of myocardial perfusion.\textsuperscript{22, 24} \(\beta\)-Stimulation increases the inotropic state, heart rate, and automaticity and vasodilates the coronary bed. Because \(\beta\)-stimulation increases myocardial oxygen consumption, benefits in myocardial blood flow may not be justified with potentially refractory ventricular arrhythmias and increased oxygen demand.\textsuperscript{24}

**Epinephrine**

Epinephrine is the most effective adrenergic drug used for CPR.\textsuperscript{5, 22, 24} A positive chronotrope and inotrope along with the \(\alpha\)-receptor–induced vasoconstriction improves coronary and cerebral perfusion pressures. The peripheral \(\alpha\)-receptor effects of epinephrine restore blood pressure in prolonged (>2 minutes) cardiac arrest.\textsuperscript{24} The \(\beta\)-effects of epinephrine may improve blood flow to the heart and brain. Epinephrine can pro-
duce ventricular fibrillation, although it can also convert fine ventricular fibrillation into a coarse fibrillation more likely to be responsive to electric defibrillation. \(^5\), \(^22\), \(^24\)

Optimal epinephrine dosing has been the subject of recent controversy. \(^29\) The current recommended low-dose protocol is 0.02 mg/kg IV or intraosseously (IO) repeated every 3 to 5 minutes until the return of spontaneous circulation. If a central catheter is not available, the dose of epinephrine should be doubled and diluted in 5 to 10 mL of 0.9% sodium chloride. \(^24\) Experimental studies in pigs in the 1980s using high-dose epinephrine (0.2 mg/kg IV) demonstrated improved myocardial and cerebral blood flow with enhanced return of spontaneous circulation. \(^4\) Clinical studies using 5 to 10 times the low dose of epinephrine in human beings showed improved return of spontaneous circulation but no difference in cerebral outcome. \(^5\) High-dose epinephrine should probably be used only if low-dose epinephrine has failed to restore spontaneous circulation. \(^23\)

One of the negative effects of epinephrine (especially high-dose epinephrine) is an intense tachycardia sometimes seen after restoration of a perfusing rhythm. Because of this, other \(\alpha\)-receptor agonists (methoxamine, norepinephrine, phenylephrine, and metaraminol) have been evaluated but have yet to be proven in clinical trials. \(^24\) Vasopressin has shown some promise in improving peripheral vasoconstriction either directly or by potentiating the effects of other \(\alpha\)-agonists. \(^20\)

**Other Adrenergic Drugs**

Sympathomimetic drugs with strong \(\beta\)-effects such as isoproterenol, low-dose dopamine, and dobutamine do not aid in restoration of spontaneous circulation. \(^24\) Dopamine at higher doses of 10 to 40 \(\mu\)g/kg/min has major \(\alpha\)-effects and is the vasopressor of choice for elevating blood pressure in the early postarrest period. Because dobutamine is primarily a \(\beta_1\)-agonist, it should not be used alone during CPR. Isoproterenol, the most potent \(\beta\)-agonist, is only indicated for atropine-resistant bradyarrhythmias such as complete atrioventricular block. \(^29\)

**Atropine**

Atropine, an anticholinergic agent, lowers vagal tone that may be elevated in the early phases of cardiac arrest and may stop the progression of unstable bradycardia to asystole. In addition to bradycardia, atropine is also recommended for pulseless electric activity (also known as electromechanical dissociation). \(^9\)

**Bicarbonate**

Acidemia can attenuate the response to \(\alpha\)-agonists and decrease the fibrillation threshold, cardiac contractility, and rate of spontaneous
The use of sodium bicarbonate has been somewhat controversial because of concerns of paradoxic central nervous system acidosis, hyperosmolarity, increased cerebral vascular resistance, iatrogenic hypokalemia, and decreased tissue oxygenation with the leftward shift of the oxyhemoglobin dissociation curve. Although calculation of the bicarbonate deficit may be difficult during CPR, conservative replacement (1 mEq/kg) in prolonged resuscitative attempts (>10 minutes) is probably indicated.

**Defibrillation**

Early direct-current defibrillation is the treatment of choice for ventricular fibrillation. The optimal dose of energy is approximately 2 to 4 J/kg. To ensure maximal efficacy, transthoracic impedance can be reduced by using large paddles and an appropriate electric current-conducting paste (ultrasound gel is not appropriate) and by applying pressure to the paddles to eliminate as much air as possible from the thorax. Because time is critical to the success of electric defibrillation, a patient found to be in ventricular fibrillation should forego the ABCs of CPR in favor of rapid electric defibrillation. If defibrillation is unsuccessful, some chest compressions with simultaneous ventilation and interposed abdominal compression should be used to try to improve myocardial oxygenation before repeating electric defibrillation with brief intervals between a series of three shocks. Care must be taken when using a defibrillator to prevent serious injury to the operator or nearby rescuers.

Chemical defibrillation with lidocaine, bretylium tosylate, and magnesium chloride has been reported but is generally less effective. Lidocaine is more effective in preventing the recurrence of ventricular fibrillation and should be administered by continuous infusion (60–80 μg/kg/min) after the return of a perfusing sinus rhythm. Lidocaine should be avoided when the initial perfusing rhythm is ventricular in origin (either a ventricular rhythm or complete atrioventricular block). Bretylium (5 mg/kg IV) can be used in ventricular fibrillation unresponsive to electric countershock. In addition to antiarrhythmic effects, bretylium has vasodilatory properties and can promote norepinephrine release.

Hypomagnesemia may be the most underdiagnosed electrolyte disorder in the critically ill patient and has been implicated as a predisposing cause of numerous problems, including atrial fibrillation, supraventricular tachycardia, ventricular tachycardia, torsade de pointes, and ventricular fibrillation. Although magnesium chloride (2 mg per 70 kg of body weight administered slowly IV) has been suggested to improve the response to electric defibrillation, randomized double-blind studies comparing magnesium chloride with placebo in hospitalized human patients suffering CPA failed to demonstrate any significant change in outcome.

Amiodarone, a class III antiarrhythmic agent, has recently showed
promise as a front-line antiarrhythmic agent in CPR. In a randomized, double-blind, placebo-controlled study, human patients with cardiac arrest with ventricular fibrillation who had not been resuscitated after receiving three or more precordial shocks were randomly assigned to receive 300 mg of IV amiodarone or placebo. Out-of-hospital recipients of amiodarone were more likely to survive and be admitted to the hospital. Because of its highly lipophilic and highly protein-bound properties, optimal dosing in veterinary patients has yet to be determined.

Cerebral Resuscitation

The brain is the most sensitive organ to hypoxia. When blood flow is interrupted for as short as 10 seconds, unconsciousness results. By 60 seconds, the pupils become fixed and dilated. Energy stores are depleted after 5 minutes, and irreversible injury begins. Human studies have reported that 10% to 40% of long-term human CPR survivors have some permanent brain injury. Postarrest cerebral edema is a common complication of cerebral hypoxia. Mannitol (1 g/kg IV) is commonly administered to patients showing signs of neurologic impairment immediately after CPR.

PROLONGED LIFE SUPPORT

Vital organ function must be monitored closely after the return of a perfusing rhythm and spontaneous respiration. Sixty-eight percent of dogs and 38% of cats suffering CPA that were successfully resuscitated rearrested, most within 4 hours of the initial CPA. Continuous electrocardiograms and apnea monitors can alert the team to rearrest. Continual reassessment of vital organ function is also necessary. Continuous body temperature and blood pressure monitoring along with subjective evaluation of perfusion should be combined with more objective measures. The placement of an indwelling urinary catheter allows continual assessment of urine output. Serum electrolytes and blood gas analysis also help to guide supportive care. Oxygen supplementation, cardiotonic and vasoactive drugs, and individual attention to underlying causes of the cardiac arrest should be individualized for each patient.

FUTURE DIRECTIONS

What we’ve got here, is failure to communicate...

STROTHER MARTIN, COOL HAND LUKE

As current recommendations have been implemented and become standard practice without any strong scientific support, critical evalua-
tion of new and even standard procedures is hampered by a lack of uniformity in reporting clinical treatments and outcomes. The "Utstein style" for uniform reporting of data from human in-hospital cardiac arrest patients has been put forward as the standard method of reporting cardiac arrest and resuscitation data. Outcome measures limited to survival rates alone are of little value. Outcome measures after CPA must include a measure of duration and quality of survival. By establishing standards like the Utstein reporting scheme, veterinary intensivists should be better able to compare treatments and results.

References


Address reprint requests to
Tim B. Hackett, DVM, MS
Department of Clinical Sciences
Colorado State University
Fort Collins, CO 80523

e-mail: tim.hackett@colostate.edu