The goal of cardiopulmonary resuscitation (CPR) is to deliver oxygen and substrate to the brain and heart while restoring cardiac function. Despite more than 40 years of research, CPR outcomes in veterinary medicine have changed very little. The success rate in veterinary medicine for return of spontaneous circulation (ROSC) after cardiac arrest and CPR is reported to be 13% in dogs and 15.4% in cats, and the rate of hospital discharge following successful CPR is < 6%. The Reassessment Campaign on Veterinary Resuscitation (RECOVER) has just published the first evidence-based consensus CPR guidelines for small animals, which is free for download from the Journal of Veterinary Emergency and Critical Care. This systematic review of the literature evaluated relevant research and generated a series of evidence-based, consensus guidelines for CPR in dogs and cats. The intention is to standardize training and guidelines, which hopefully will translate into improved outcome for dogs and cats suffering cardiopulmonary arrest (CPA) as it has in human medicine.

Factors that impact survival rates after CPR include the inciting cause of the CPA, concurrent diseases, time between arrest and initiation of basic life support, the immediate availability of qualified personnel and equipment, the effectiveness of CPR techniques used, and the supportive measures instituted post resuscitation. Resuscitative measures are more successful if the arrest is associated with drugs/anesthetics, a rapidly correctable problem (e.g. hyperkalemia from post-renai urinary tract obstruction), and when the arrest is witnessed and CPR is instituted within 5 minutes. Although some factors are not under the control of the resuscitation team, several measures can be taken to enhance survival rates. These include:

1. Receiving basic life support (BLS) and advanced life support (ALS) training from experienced emergency and critical care veterinarians and technicians
2. Maintaining a crash cart or tackle box in each area where critically ill or injured animals are treated (e.g., treatment area, ICU, surgery)
3. Regularly scheduled CPR practice sessions with staff members
4. Staying aware of CPR updates, both in human and veterinary medicine, with knowledge of the fundamental differences between veterinary and human CPA patterns.
5. Having the capability to treat and monitor post-arrest cases or transfer to a 24-hour emergency and critical care facility

HOSPITAL READINESS
Teamwork is essential in any emergent situation. By pre-assigning roles, practicing responses to various life-threatening situations, and employing clear, directed communication, valuable time is saved, and patient morbidity and mortality are decreased. In-hospital training and practice sessions with animal models help the team respond as an effective unit.

Veterinary hospital readiness consists of providing a place for receiving, assessment of and treatment of the emergent patient. The area should be free of obstacles, and transport of the animal to the area should be uncomplicated. The area should have basic equipment and drugs required for resuscitation of the most life-threatening conditions. Hair clippers should be in the ready area for intravenous (IV) catheter placement. Isotonic crystalloid fluids with attached intravenous administration sets can be hanging ready to use in the receiving area. Synthetic colloid fluids should be kept nearby. Cognitive aids such as algorithm and drug dosing charts have been shown to improve performance in human medicine and should be prominently
displayed. It is ideal to have supplemental oxygen and suction units as well as small and large Ambu bags and oxygen administration sets in near proximity of the resuscitation area. This is why many veterinary clinics establish a ready area near the anesthesia equipment.

For those practices that see a large volume of emergencies, setting up a large mobile cart housing the instruments and equipment is of great value. Otherwise, maintaining a tackle box with emergency equipment and drugs can be an inexpensive way to provide emergency care. Having a clipboard with a CPR record and an attached CPR dose schedule (Table CPR Dose Schedule) facilitates record keeping, billing and drug calculation and administration. Equipment and drugs should be inspected daily as well as after each resuscitation attempt, to ensure that the ready area is set up for the next emergency situation. Marking a check-off list, which itemizes the contents, allows anyone to perform the inspection. The equipment and drugs should be rotated with the hospital supply monthly to avoid waste due to expiration. Posters of drugs and dosages used during CPR and a CPR algorithm can be purchased through the VECCS website.

These preparatory measures will make any veterinary team ready for most emergency presentations. Additional preparations can be made as incoming calls are taken and information gathered.

EXPECTED THE UNEXPECTED
At the time of hospital admission, a code status should be obtained for every pet, regardless of the reason for admission. The options we provide include “Full Code” (all resuscitative measures including surgical intervention; open-chest CPR), “Middle Code” (non-surgical intervention; closed-chest CPR), and “No Code” (Do Not Resuscitate, DNR). The pet owner must be counseled as to the predictable success rate of CPR in their pet in addition to the financial investment. A color-coded label is placed on the pet’s cage and identifying tags indicating resuscitation code, so that all staff members are aware of the pet owner’s wishes.

Teamwork is essential in any emergent situation. By pre-assigning roles and practicing responses to various life-threatening situations, valuable time is saved, and patient morbidity is decreased. In-hospital training and practice sessions with animal models help the team respond as an effective unit. A minimum of 2 people is required for BLS and 3 people for ALS. Online training in BLS, certified by the American College of Veterinary Emergency and Critical Care and based on the findings of RECOVER, is available from Veritas (www.veritasDVM.com). CPR drug dosing charts, as well as CPR updates can be obtained through continuing education courses sponsored by the Veterinary Emergency and Critical Care Society (www.veccs.org), as well as other veterinary specialty organizations.

CPR TECHNIQUE

Basic life support (BLS) is the recognition that cardiac arrest has occurred and the administration of artificial respiration and chest compressions to promote the oxygenation and flow of blood. An initial ABC (airway, breathing, circulation) assessment, focused on rapid diagnosis of CPA, and simultaneously obtaining a basic history focused on the duration of signs, current medical issues, and recent drug administration should take no more than 15-30 seconds. If the initial ABC assessment does not yield definitive evidence that the patient is not in CPA, the “CABs of CPR” treatment should be initiated to prioritize BLS intervention when an unconscious animal is not breathing. Evidence suggests that outcome worsens when initiation of chest compressions is delayed, so if the rapid ABC assessment determines that a patient is not breathing and unconscious, chest compressions are initiated first to promote circulation (C), while a patent airway is established (A), and artificial breathing initiated (B).

Chest compressions are usually applied in lateral recumbency at a rate of 100-120 compressions/minute. Chest compressions in the small dog or cat (<10kg) or the very keel-chested dog (e.g., sight hounds) are applied with the animal in lateral recumbency over the 4th-6th intercostal space directly over where the heart lays. Blood is forced out of the ventricles with each compression, and release of the compression allows blood flow into the heart. Chest compressions in markedly barrel-chested dogs (e.g., English bulldog) may be more effective directly over the sternum with the dog in dorsal recumbency. Compressions in the medium to large dog (>10kg) are applied in lateral recumbency over the widest portion of the thorax. The thorax is compressed
approximately 30-50% in an effort to increase intrathoracic pressure, compressing the aorta and lungs moving blood through and out of the left side of the heart. Upon release of the compression, elastic recoil of the chest allows blood to be drawn into the vena cavae, through the right side of the heart and into the lungs. Blood flow occurs in a unidirectional manner because of valves in the venous system. This is termed the “thoracic pump” mechanism.

With a single rescuer, mouth to snout ventilation can be initiated. Following 30 chest compressions, 2 breaths are rapidly administered, and chest compressions are rapidly resumed. With multiple rescuers, chest compressions are immediately initiated, and then the patient is tracheally intubated and ventilation initiated with an Ambu bag and high-flow oxygen at a rate of 10 breaths/minute. Compressions are not interrupted by intubation or ventilation. At this point ECG clips are attached using ECG paste. Alcohol is NEVER used as a contact medium or disinfectant, because it will burn if electrical defibrillation is applied. Once a 2-minute cycle has passed, the rescuers are cycled and the heart is ausculted for a beat and a major artery palpated for a pulse while the ECG rhythm is quickly analyzed. This assessment should take no more than 2-5 seconds, and if there is any doubt as to whether the patient is still in CPA, chest compressions should be resumed for an additional cycle.

When multiple responders are present, interposed abdominal compressions can be applied. The abdomen is compressed while the chest compression is being released. This action increases abdominal pulse pressure, resulting in an increase in right heart filling pressure and faster pump emptying during chest compressions. Interposed abdominal compressions should not be performed if there is any suspicion of intra-abdominal bleeding or diaphragmatic rupture.

End-tidal carbon dioxide monitoring can provide information regarding efficacy of compressions. When blood is flowing through the pulmonary circulatory system, and the lungs are being artificially ventilated, carbon dioxide is >15 mmHg in the expiratory breath. When blood flow is inadequate, expired carbon dioxide is not measurable. A rapid and sudden increase in end-tidal carbon dioxide is also an early indicator of return of spontaneous circulation (ROSC).

**Advanced life support (ALS)** includes steps taken to restore an effective cardiac rhythm and function. It incorporates the recognition of cardiac arrhythmias, electrical defibrillation, and drug administration (e.g., epinephrine, vasopressin, atropine) during CPR. In contrast to humans, who most commonly suffer ventricular fibrillation, dogs and cats more commonly suffer pulseless electrical activity (PEA) and asystole.

**Drugs** are best administered intravenously. Vascular access is obtained through catheterization of a peripheral vein that can be rapidly exposed. The cephalic vein is most routinely accessed. Access of the jugular vein is attempted only by the most experienced. When intravenous access is not readily available, intraosseous catheterization is a method for administering medication during CPR, particularly in the young and small patients. Endotracheal drug administration is also possible; however the dose is doubled and placed in saline or water to promote dispersion. The drug is deposited in the lower airways using a long polypropylene catheter. Intracardiac injections are not used because the injury caused by the injection can exacerbate myocardial dysfunction.

Atropine is administered when a bradyarrhythmia is present or high vagal tone suspected. Epinephrine is administered during PEA or asystole. Vasopressin, a potent vasoconstrictor at V1 peripheral receptors, can be administered in place of epinephrine. High dose epinephrine and/or sodium bicarbonate are not administered unless a prolonged arrest (>10-15 minutes) has occurred or a disease process causing severe acidosis is suspected. High-dose epinephrine is used when administered intratracheally. Amiodarone and/or lidocaine are administered if a ventricular tachyarrhythmia is occurring, or when repeated attempts at electrical defibrillation for ventricular fibrillation fail (see below). Calcium is not administered unless hypocalcemia is contributing to the arrest process.
Electrical defibrillation is applied when ventricular fibrillation is diagnosed on ECG. The dose administered depends on the type of defibrillator, the weight of the animal and whether the chest is open or not. Monophasic defibrillators deliver current along one direction compared to biphasic defibrillators, which deliver a current that reverses in direction during the shock. Lower energy is required for defibrillation with biphasic defibrillators, leading to less myocardial damage. Internal and external paddles are kept clean and disinfected for immediate use. Latex gloves are worn by the person applying the defibrillator, and no personnel are to be in direct contact with the patient or paddles during defibrillation. Chest compressions are immediately resumed for a 2-minute cycle after defibrillation before the ECG is evaluated for response.

Open-chest CPR is recommended when 1. Closed-chest compressions are unsuccessful within 3 minutes; 2. There is a high degree of suspicion for pericardial or intrapleural disease (e.g., pneumothorax, pleural effusion, diaphragmatic hernia); 3. Chest wall injury exists; 4. The arrest is related to a traumatic event; and/or 5. The patient is already in surgery (thoracic or abdominal). Hair is shortened or removed with a single sweep of by hair clippers along the left 4th-6th intercostal space from the costovertebral junction past the costochondral junction. An incision is made through the skin, subcutaneous layers, and external musculature. Scissors are used to penetrate the intercostal muscle and extend the incision. Assisted ventilation is discontinued during the approach, and started once all sharp objects are away from the lung tissue. If the incision is too small to adequately expose the heart, the opening can be enlarged by cutting the costochondral junction in front and behind the incision site, and filleting the ribs. Finocchietto retractors can also aid visualization of and access to the heart. If the thorax contains a large volume of fluid hindering visualization of the heart and lungs, the dorsal part of the thorax is tipped up and the fluid poured out.

The heart is removed from the pericardial sac by cutting the pericardial/diaphragmatic ligament and extending the incision through the pericardium, avoiding the phrenic nerve. With one or 2 hands the heart is massaged from the apex to the base. Assisted ventilation is continued. Any obvious sources of hemorrhage are controlled. The thoracic descending aorta is occluded just caudal to the base of the heart using a modified Romel tourniquet fashioned out of soft, flexible material such as a feeding tube, umbilical tape or Penrose drain. This is performed in an effort to direct blood flow to the brain and the heart. Cardiac massage is continued in addition to recommended ALS procedures. The tourniquet is temporarily loosened every ten minutes to reduce the incidence of paraplegia. When the heart begins contracting spontaneously, the tourniquet is slowly withdrawn. Rapid removal without cranial aortic pressures that are above normal may result in significant hypotension and even repeat arrest.

POST-CARDIAC ARREST (PCA) CARE
Length of CPR is determined by the person in charge of the code and the pet owner’s wishes. In general, when CPR efforts fail to reestablish spontaneous circulation after 20 minutes and/or 10 minutes after aortic occlusion, efforts are stopped; however, in cases of peri-anesthetic arrest or other treatable causes of CPA, longer CPR efforts may be warranted. If the pet owner allows, a complete necropsy may help determine the cause of the arrest, and allow the team to learn from every situation.

When CPR is successful for return of spontaneous circulation, the real work begins! If the thorax has been opened, the patient is more thoroughly prepared for lavage, thoracic tube placement and closure in the surgery suite. PCA care is focused on 3 main goals: (1) respiratory optimization, (2) hemodynamic optimization, and (3) neuroprotection.

Respiratory Support: Spontaneous ventilatory efforts do not equate with adequate ventilatory efforts. Arterial blood gas monitoring and evaluation of oxygen/ventilation parameters is necessary to determine if weaning is appropriate, and if the patient’s efforts are strong enough. Oxygen supplementation titrated to a normal arterial oxygen saturation (95-97%) is recommended. Higher oxygen saturations have been associated with more severe reperfusion injury. Mechanical ventilation may be required after a prolonged arrest to allow more thorough evaluation and monitoring during the recovery process.
**Hemodynamic Support:** Myocardial dysfunction and vasodilation during the PCA period may lead to hypotension and poor perfusion. Fluid support with crystalloids and colloids to restore and maintain intravascular volume is ideally guided using central venous pressure (CVP) monitoring. In cases of persistent hypotension, vasopressor therapy or low dose hydrocortisone therapy may be required. Diligent monitoring of blood pressure to maintain a normal or slightly hypertensive blood pressure is recommended, as is monitoring adequacy of tissue oxygen delivery using central venous oxygen saturation or lactate measurement.

**Neurologic Support:** Neurological function is protected by avoiding hypo- and hyperventilation, hypo- and hyperglycemia, and administration of mannitol or hypertonic saline in some cases. Methylprednisolone administration is not considered part of the recommended strategies for neuroprotection, but may reduce the effects of reperfusion if given just prior to release of an aortic cross clamp. Mannitol or hypertonic saline may be administered with prolonged CPA in animals that remain comatose, have cranial nerve deficits, or show evidence of cortical blindness. Therapeutic hypothermia has been shown to be beneficial in multiple experimental studies in dogs in the PCA period, but is not commonly done in veterinary medicine. However, in patients that develop hypothermia during CPR, slow rewarming at less than 0.25-0.5°C/hour (0.45-0.9°F) is recommended over rapid rewarming.

**Suggested Reading**

*We hope to see you at our next event on Thursday, January 25th, 2018!*

*Topic details coming soon!*