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EMERGENCY PRESENTATIONS ASSOCIATED WITH CARDIOVASCULAR DISEASE IN EXOTIC HERBIVORES

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Abstract

Exotic animals, including small herbivores, are increasing in popularity as companion animals. Commonly owned exotic herbivores include guinea pigs, chinchillas, and rabbits. These animals fall into the category of prey species with an inherent instinct to hide their illness until severely affected by the disease process. Therefore, any of these animals presented as an emergency case must be carefully evaluated for chronic underlying illness. Cardiovascular emergency and critical care principles are similar across all mammalian species. However, specialized techniques and adaptations are occasionally required because of the unique physiology and natural behaviors of these animals. It is essential to evaluate and stabilize these patients before attempting definitive diagnostic plans. Emergency cardiovascular presentations, as in other mammals, consist of congestive heart failure, arrhythmias, pericardial effusion, and toxicities that can result in cardiac and pulmonary arrest. Cardiac disease is a relatively common finding in small exotic mammals, but there are few peer-reviewed reports regarding diagnosis and treatment of heart disease in these species. Diagnostic testing and treatment options are generally based on knowledge of small animal medicine. Copyright 2012 Elsevier Inc. All rights reserved.

Key words: cardiovascular; critical care; emergency care; rabbits; rodents; small exotic mammals

Assessing the cardiovascular system of small exotic mammalian patients (e.g., rabbits, guinea pigs) can be a challenge. A visual examination should always be performed before handling the animal to evaluate the character and resting respiratory rate, as well as overall demeanor of the patient. A systematic cardiovascular examination should include the evaluation of mucous membranes for color, hydration, and capillary refill time, as well as thoracic and cardiac auscultation. The rabbit central ear artery and femoral artery of guinea pigs and chinchillas can be used to gauge the strength and regularity of peripheral arterial pulses.^{1,2}

Because of small patient size and rapid respiratory and heart rates, auscultation can be challenging in these patients. The use of a pediatric stethoscope is recommended to maintain proper contact with the patient and avoid environmental noises. The normal heart rate of exotic herbivores varies among rabbits, guinea pigs, and chinchillas, with reported values ranging between 160 and 300 beats/min. If the animal is stressed, higher heart rates should be expected because of an increased sympathetic tone. A wide range of respiratory rates in these species has been re-

ported, with 30 to 60 breaths/min considered normal, although this can significantly increase when the patient is stressed.^{3,4} As with domestic small animals (e.g., dogs, cats), decreased intensity or muffled respiratory and cardiac sounds may indicate pleural effusion in exotic herbivores. Muffled cardiac sounds are often associated with pericardial effusion. Increased bronchovesicular sounds and/or crackles may be noted when the animal has pulmonary edema. However, absence of abnormal respiratory sounds does not necessarily exclude pulmonary edema

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from the problem list when examining exotic herbivores. This is especially important to consider in patients that have a rapid and superficial breathing pattern.^{5,6} Rabbits normally have a rapid respiratory rate, and lower airway sounds overlying heart sounds can mimic a murmur. Respiratory abnormalities accompanying cardiac disease may be difficult to detect during examination.

Arrhythmias are first detected and/or suspected based on auscultation; however, this condition should always be confirmed with an electrocardiogram (ECG) as soon as possible without further compromise to the patient. Murmurs are usually systolic in timing and mild to moderate in intensity, and they are often detected on the left or right sternal border.⁵ The veterinarian must not mistake murmurs with respiratory sounds that mimic heart murmurs when the respiratory rate approximates the heart rate.⁵ If respiratory sounds are too loud and interfere with auscultation of the heart, the examiner can place a hand on the nose of the animal to briefly stop the loud respiratory sounds. The clinician should auscultate the thorax until he or she is able to separate respiratory from cardiac sounds. Subsequently, an echocardiogram may be indicated when a murmur is audible and an underlying cause is not known. Small exotic animals commonly have a normal sinus rhythm on auscultation but, unlike dogs, do not usually have a sinus arrhythmia associated with respiration.²

The effects of catecholamines on cardiac function have been extensively studied in the rabbit. Coronary vasoconstriction and myocardial ischemia have been associated with high levels of norepinephrine.⁷ To limit stress and the subsequent production of excessive catecholamines, the rabbit should always be maintained in a quiet environment and handled in a gentle manner while hospitalized. Handling of these patients by the veterinarian and veterinary nurses should always be minimal. If the animal appears distressed or becomes frantic during diagnostic examinations or treatments, mild sedation may be beneficial. Butorphanol, an mixed opioid, and midazolam, a benzodiazepine that has limited side effects on the respiratory and cardiovascular systems of small exotic herbivores, can be used to calm the patient, thus limiting stress and aiding in ease of handling of the patient. Butorphanol can be used at 0.4 to 0.6 mg/kg and midazolam at 0.25 to 0.5 mg/kg administered by intramuscular injection 10 minutes before the examination of small exotic herbivores. Al-

though the intramuscular route of therapeutic administration is most commonly used, intravenous, subcutaneous, and intranasal routes are alternative options.

For any animal that presents with a cardiovascular crisis, supplemental oxygen should always be available. Administration of oxygen can be provided by facemask, cage, or tent if tolerated by the patient.² Allowing the animal to rest in a quiet enclosure will also decrease the animal's overall oxygen requirements.¹ Sedating the animal with the above-mentioned midazolam dose is indicated for the fragile patient before an examination to avoid excessive catecholamine excretion.

CLINICAL SIGNS

Clinical signs of cardiovascular disease are often difficult to assess in prey species. Poor body condition and signs referable to the respiratory system such as dyspnea, open-mouth breathing, elbow abduction, sternal recumbency, neck extension, reluctance to move, abnormal lung sounds, or lack of respiratory sounds may indicate cardiovascular compromise. Vascular and cardiac clinical abnormalities may be similar to those of the small companion mammal, including episodes of syncope, distended jugular veins, or abdominal distention. Exophthalmia can occur with severe venous congestion and may indicate a underlying cardiac disease.¹ In addition, thymoma is a common cause of exophthalmus in the rabbit, especially if the patient has normal cardiac sounds evaluated through auscultation.⁸

DIAGNOSTIC TESTS

Thoracic Radiographs

The interpretation of heart and lung abnormalities by use of survey radiographic images can be challenging because of the relatively small thoracic cavity of small exotic herbivores (Figs 1-4). On a lateral view, the cranial border of the heart is often indistinguishable (border effaced) from the soft-tissue opacity (mainly thymus) in the cranial mediastinum. In addition, obese animals may also have a markedly enlarged cardiac silhouette caused by the accumulation of pericardial fat. The cardiac silhouette of exotic herbivores extends from the second rib to the caudal border of the fifth rib or from the third to the sixth ribs. The lung fields are relatively small and surround a wide cranial mediastinum. The

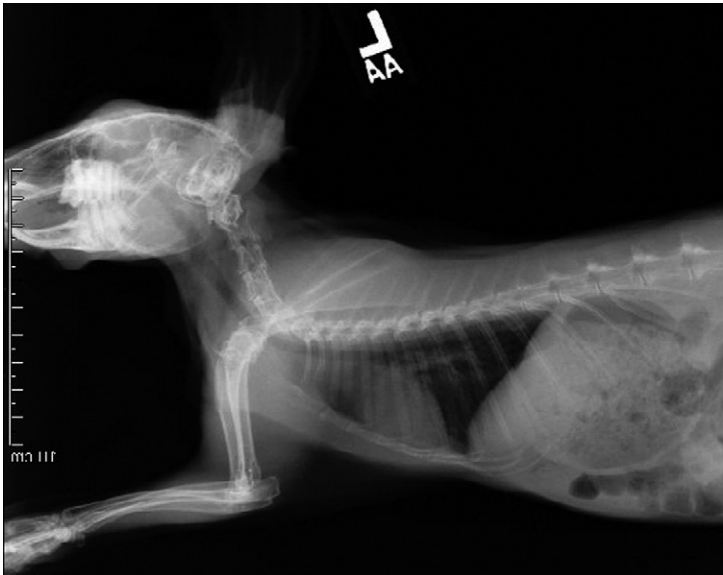


FIGURE 1. Lateral radiographic view of a clinically normal rabbit. Note the small size of the thorax relative to the rest of the body.

aorta and caudal vena cava are normally visible as are pulmonary vessels. The tracheal carina is present at the fourth or fifth intercostal space. Abnormal calcification of the aorta may be best visualized on a lateral radiographic image.⁵ Cardiomegaly should be considered if the heart extends beyond 2.5 to 3 rib spaces (wide) on the lateral image.⁵ The diagnosis of cardiomeg-



FIGURE 2. Ventrodorsal radiographic view of a clinically normal rabbit. Note the small size of the thorax relative to the rest of the body.

aly is usually consistent with cardiac chamber dilation or hypertrophy, pericardial effusion, or the presence of a cardiac mass. Cardiogenic edema may be evident via increased pulmonary densities, and tracheal elevation due to cardiac enlargement may occur.

When one is interpreting the lung fields, consideration should be given to the phase of respiration, because full inspiration is rarely achieved given the rapid respiratory rate.^{9,10} Ideally, the animal should be intubated and a positive-pressure thoracic radiograph obtained for optimum evaluation of the lungs. Thymomas in rabbits must also be considered with craniodorsal elevation of the trachea or with soft-tissue opacity near the cranial cardiac silhouette. These rabbits also typically present with exophthalmus and increased respiratory effort because of the compression of the tumor on the lung field and greater vasculature.⁸ Thymomas and heart disease can be differentiated with thoracic ultrasound.

Electrocardiography

Normal ECG values have been reported for the rabbit and guinea pig (Tables 1 and 2). The ECG is usually recorded and the patient gently restrained in sternal recumbency with alligator clips. The normal cardiac activity of exotic herbivores results in a positive P wave, followed by a primarily upright QRS complex in lead II. The T wave is usually positive and reflects ventricular repolarization. The ECG of normal rabbits includes a pointed P wave in some breeds, peaked T waves, and a relatively long ST segment. The guinea pig ECG tracing more closely mimics that of humans when compared with other exotic herbivores because of the similarity of ion channels in the myocardium.^{11,12,16} An ECG should be used to diagnose arrhythmias when an irregular rhythm is detected on auscultation. Little is known about the ECG changes associated with cardiac diseases in exotic herbivores, and therefore the use of P-wave and QRS-complex morphology changes to assess cardiac chamber dilation or hypertrophy is not recommended. Radiographic images or, ideally, an echocardiogram should be obtained to evaluate cardiac size in small exotic herbivores if concerns exist.¹³

Blood Pressure Measurement

Specific therapeutic measures may be necessary to correct blood pressure abnormalities. Hypotension can result from poor cardiac output caused by cardiac failure or severe dehydration. A

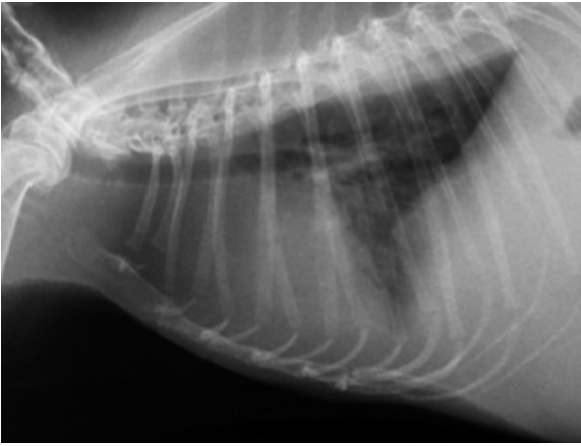


FIGURE 3. Lateral radiographic view of a rabbit with cardiomegaly. (Images are courtesy of Dr. David Eshar, University of Guelph.)

noninvasive technique for measuring arterial pressure is invaluable to diagnose abnormalities as well as follow response to therapy. Indirect blood pressure measurements in exotic herbivores are usually obtained by Doppler or oscillometric techniques. Normal blood pressures in exotic herbivores do not differ significantly from those in their counterparts in small animal medicine. The normal range of mean arterial pressure in rabbits is 80 to 91 mm Hg; systolic arterial pressure, 92.7 to 135 mm Hg; and diastolic arterial pressure, 64 to 75 mm Hg.^{1,17} However, if the animal is stressed, the patient's systolic blood pressure can be as high as 180 mm Hg.⁵

Echocardiography

Echocardiography provides valuable information about cardiac anatomy and function, the presence of abnormal communications between cardiac chambers or vessels, and cardiac blood flow. Similar to most mammals, in healthy exotic herbivores the left atrial diameter is 1.0 to 1.5 times the diameter of the aorta, the left and right atria are comparable in size, the aorta and the main pulmonary artery have the same diameter, and the left ventricular free wall thickness is similar to the interventricular septum thickness. The thickness of the right ventricular free wall and the diameter of the right ventricular chamber are one-third to one-half of their counterparts in the left ventricle.^{5,18}

EMERGENCY CARDIOVASCULAR DISEASES

All animals should be initially assessed and stabilized with supportive care before additional diagnostic tests are performed. Heart failure is a

clinical syndrome caused by cardiac disease that results in systolic or diastolic cardiac dysfunction, or both. Systolic failure describes decreased myocardial performance, and diastolic failure results from abnormal filling of the ventricles. Right-sided congestive heart failure can manifest as jugular distention, subcutaneous edema, hepatic congestion, ascites, and/or pleural effusion. Left-sided congestive heart failure presents as pulmonary edema.³ The immediate treatment objective for acute congestive heart failure is to reduce pulmonary venous pressure. Treatment for acute congestive heart failure is achieved with diuretics to reduce total blood volume, a vasodilator to redistribute intravascular fluid volume, inotropic support, and adjunct therapy.¹⁹ Causes of congestive heart failure in small exotic herbivores include valvular disease, cardiomyopathies, cardiac tamponade, arrhythmias, and myocarditis/endomyocarditis.

Valvular Heart Disease

Chronic degeneration atrioventricular (AV) valve disease is the most common valvular disease in exotic herbivores which is associated more often in older rabbits and chinchillas.^{5,20} The primary



FIGURE 4. Ventrodorsal radiographic view of a rabbit with cardiomegaly. (Images are courtesy of Dr. David Eshar, University of Guelph.)

TABLE 1. Reference electrocardiographic measurements of small exotic herbivores^{1,11-13}

Parameter (Units)	Guinea Pig	Rabbit
P wave duration (sec)	0.015-0.035	0.01-0.05
P wave amplitude (mV)	0.01	0.04-0.12
P-R interval (sec)	0.048-0.060	0.04-0.08
QRS duration (sec)	0.008-0.046	0.02-0.06
R wave amplitude (mV)	1.1-1.9	0.03-0.39
QT interval (sec)	0.106-0.144	0.08-0.16
T wave amplitude (mV)	0.062	0.05-0.17
Mean electrical axis (degrees)	120 to 180	-43 to +80

anatomic location affected by this disease is the mitral valve, although lesions may also develop on the tricuspid valve.^{2,20} A retrospective study comprising 13 rabbits with heart disease showed that 8 of the rabbits had degenerative AV valve disease and 1 had aortic stenosis and chordae anomaly of the mitral valve.¹⁰ Systolic murmurs are best auscultated on the left sternal border. The intensity of the murmur depends on the severity and direction of the regurgitation jet. Disease development is unknown in small exotic herbivores; however, it is believed to be a chronic process. As chronic degenerative AV valve disease progresses into congestive heart failure, the left atrium usually becomes severely dilated while the contractility of the enlarged left ventricle remains. Treatment for chronic degenerative AV valve disease is aimed at maintaining cardiac contractility, relieving congestion, and reducing vasoconstriction.¹⁴

Cardiomyopathies

In small exotic herbivores, cardiomyopathies are occasionally diagnosed but rarely reported. Experimental and natural cases of dilated and hypertrophic cardiomyopathies have been reported in rabbits, guinea pigs, and chinchillas.^{2,15,20-23} In the previously mentioned retrospective study, 4 of the 13 rabbits with cardiac disease were diagnosed with dilated cardiomyopathy.²¹ Dilated cardiomyopathy is the most common cause of heart failure in rabbits, with giant-breed rabbits (e.g., New Zealand, Californian, Flemish Giant, Chinchilla) more prone to disease development.² Echocardiography should be used for the diagnosis and characterization of cardiomyopathies in animals that present with signs of left- or right-sided congestive heart failure, arrhythmias, and collapsing episodes. Specific etiologies for cardiomyopathies are rarely identified, but stress and advanced age are considered predisposing fac-

tors.² Treatment is similar to that described for valvular heart disease, with an emphasis on improving cardiac contractility.¹

Cardiac Tamponade

Pericardial effusion is defined as an abnormal accumulation of fluid within the pericardial sac. Fluid within the pericardial sac is often the result of neoplasia, but it can be due to coagulopathies, trauma, and atrial tears or may be iatrogenic (e.g., cardiocentesis). The effects of pericardial effusion depend on the rate and volume of the fluid accumulation and the compliance of the pericardium. Cardiac tamponade occurs when sufficient pericardial fluid accumulates within the pericardial space to increase the intrapericardial pressure above right atrial pressure, causing compression of the right side of the heart first, although the left side of the heart also can be affected as intrapericardial pressure increases. This impairment of ventricular filling leads to a decreased cardiac output and arterial hypotension.^{19,24} Though rarely diagnosed in small exotic herbivores, pericardial effusion has been reported in guinea pigs, chinchillas, and rabbits.^{1,25} Affected animals have been reported to present with ataxia and/or right-sided heart failure. Physical findings include muffled heart sounds, distended jugular veins, arterial hypotension, tachycardia, and pulsus paradoxus. The disease diagnosis is usually confirmed with echocardiography. Emergency pericardiocentesis is required to relieve cardiac tamponade.¹⁹ To reduce patient anxiety during the pericardiocentesis procedure, the animal can be pre-

TABLE 2. Reference echocardiographic measurements of small exotic herbivores^{1,14,15}

Parameter (mm)	Rabbit	Guinea Pig	Chinchilla
LVIDd	12.88-15.86	6.49-7.21	5.1-6.9
LVIDs	8.83-11.27	4.18-4.52	2.3-4.3
LVPWd	1.91-2.41	1.12-1.70	2.0-2.8
LVPWs	2.93-4.03	1.91-2.61	—
IVSd	1.66-2.40	1.88-2.68	1.5-2.3
IVSs	2.60-3.5	2.22-3.38	—
LA	8.52-10.80	4.61-5.29	4.3-5.9
AO	7.50-9.02	4.40-4.90	3.7-6.0

Range is derived from mean \pm 1 SD, animals anesthetized in most instances.

Abbreviations: AO, aorta; d, diastolic; HR, heart rate; IVS, internal ventricular septum; LA, left atrium; LVID, left ventricular internal diameter; LVPW, left ventricular posterior wall; s, systolic.

medicated with butorphanol and midazolam. Pericardiocentesis is contraindicated when patients have coagulopathies or if hemopericardium is due to an atrial tear. Because cardiac tamponade involves decreased preload, increasing intravascular volume cautiously with a fluid bolus is warranted. Attempts to lower venous pressures using medical therapy should be avoided. Treatment to lower venous pressures will exacerbate the condition by further reducing preload, resulting in significant reduction in cardiac output and hypotension.¹⁹

Arrhythmias

Arrhythmias can occur spontaneously or be linked with structural cardiac diseases. Severe bradycardia or rapid ventricular tachycardia may result in syncopal episodes or lead to cardiogenic shock. Arrhythmias requiring treatment are relatively uncommon in exotic herbivores and only arrhythmias associated with or likely to cause clinical signs should be treated.⁵ Experimentally induced bradyarrhythmias and tachyarrhythmias in rabbits and guinea pig have led to cardiac failure.²⁶⁻²⁸

Bradyarrhythmias

Bradycardia, defined as heart rate lower than 120 bpm, is the most common dysrhythmias seen in rabbits.²⁹ Severe bradycardia can cause decreased cardiac output, resulting in cardiac insufficiency and dysfunction. The most common bradyarrhythmias requiring emergency treatment are high-grade second- or third-degree AV block. With high-grade AV blocks, there is a malfunction of the AV nodal conduction and escape complexes from the bundle of His, bundle branches, or Purkinje fibers are necessary for induction of ventricular contraction. Ventricular escape rates may be adequate for animals at rest, but rates may also be slow enough to result in a reduced cardiac output with the potential for cardiogenic shock to ensue.³⁰ High-grade AV blocks have responded to oral theophylline therapy, although pacemaker implantation may be required if clinical signs of exercise intolerance or syncope persist.

Tachyarrhythmias. Insufficient ventricular filling occurs at elevated heart rates. End-diastolic volume is largely dependent on venous return, with atrial contraction contributing little to normal preload. Sustained tachycardia can result in myocardial failure.^{31,32} A research investigation determined that pacing of a rabbit's right atrium or

ventricle at rates between 350 and 400 beats/min over a period of several weeks produced myocardial depression and clinical signs of heart failure (malignant tachycardia).²⁸ In small animals the most common cause of malignant tachycardia is a supraventricular tachycardia. The development of malignant tachycardia can occur through primary cardiac disease or a cardiac manifestation of another systemic disease process. Medical therapy includes calcium channel antagonists or β -blockers to slow the heart rate, as well as management of the underlying disease condition. Rapid ventricular tachycardia may respond to intravenous administration of lidocaine. Diltiazem is a calcium channel blocker also used to reduce AV conduction and, subsequently, heart rate. However, diltiazem depresses myocardial contractility and may cause hypotension. Other antiarrhythmic drugs, mexiletine and sotalol, have been tested experimentally in rabbits to treat ventricular tachycardias as well as atrial fibrillation, but their chronic use has not been evaluated in the pet rabbit.³³ Dosages of cardiac drugs are found in Table 3.

Endomyocarditis/Myocarditis

Endomyocarditis is a focal or diffuse inflammation of the endomyocardium and myocarditis is a focal or diffuse inflammation of the myocardium, with myocyte degeneration or necrosis causing an adjacent inflammatory infiltrate. There have been numerous underlying etiologic causes (e.g., viral, bacterial, protozoal) associated with the development of endomyocarditis; however, reports of endomyocarditis in rabbits have been limited to *Pasteurella multocida*, *Staphylococcus* spp., *Salmonella* spp., *Streptococcus viridans*, coronavirus, *Clostridium piliforme*, and *Encephalitozoon cuniculi*.^{2,35} There are a number of research studies in which myocarditis has been experimentally induced in rabbits, guinea pigs, and chinchillas. Blood culture/sensitivity should be obtained from affected animals. Abnormal findings from a complete blood count often include a neutrophilic leukocytosis. If an active bacterial infection is present, band neutrophils are often identified, whereas with chronic infections, a monocytosis is common. Echocardiography is the diagnostic test of choice for this

Bradycardia, defined as a heart rate lower than 120 beats/min, is the most common dysrhythmia diagnosed in rabbits.²⁹

TABLE 3. Exotic herbivore cardiovascular drugs^{1,34}

Drug	Dose	Route	Frequency
Furosemide	0.3-4 mg/kg	PO, SC, IM, IV	Q 8-24 hrs
Glyceryl trinitrate	2-3 mm	Topical	Q 6-12 hrs
Enalapril	0.1-0.5 mg/kg	PO	Q 24-48 hrs
Atenolol	0.5-2 mg/kg	PO	Q 24 hrs
Pimobendan	0.1-0.3 mg/kg	PO	Q 12-24 hrs
Diltiazem	0.5-1 mg/kg	PO	Q 12-24 hrs
Digoxin	0.003-0.03 mg/kg	PO	Q 12-48 hrs

Abbreviations: IM, intramuscularly; IT, intratracheally; IV, intravenously; PO, orally; SC, subcutaneously.

disease, because collection of myocardial biopsy specimens is not an option for the majority of cases. Echocardiography usually reveals chamber dilatation and poor contractility, with the valve structure and function remaining normal. Treatment is aimed at improving cardiac contractility, relieving congestion, reducing vasoconstriction, sterilizing lesions, and eliminating the spread of infection.³⁶

TREATMENT OF CARDIOVASCULAR EMERGENCIES IN SMALL EXOTIC HERBIVORES

Treatment of cardiovascular emergencies in rabbits, guinea pigs, and chinchillas is based on anecdotal reports; research data using these animals as models for human cardiovascular disease; and extrapolation from small animal cardiology. Goals of treatment should be to resolve any signs associated with congestive heart failure; alleviate any buildup of fluid in the lungs, chest, and/or abdomen; improve the force of heart muscle contractions; control any life-threatening irregular heart rhythms; relieve discomfort; and improve the animal's overall quality of life. Animals that present with cardiovascular emergencies should be assessed, stabilized, provided oxygen, and administered appropriate medications as needed. Drugs that have been used to treat small exotic herbivores for cardiovascular emergency presentations include furosemide, nitroglycerin, angiotensin-converting enzyme inhibitors, positive inotropic drugs, calcium channel blockers, and β -blockers.^{1,2,5,34} However, there are relatively few scientific pharmacokinetic/pharmacodynamic studies investigating the cardiac therapeutic agents listed above in small exotic herbivores.

Furosemide is the diuretic of choice for relieving acute pulmonary edema and normaliz-

ing cardiac filling pressures. When one is initiating furosemide treatment, a higher dose can be used to induce diuresis. Nitroglycerin, a venodilator, is recommended to reduce congestion. Augmentation of systolic performance is important with acute congestive heart failure due to dilated cardiomyopathy and other disease processes affecting contractility (e.g., chronic mitral regurgitation). Positive inotropic agents are commonly used to increase intracellular cyclic adenosine monophosphate.¹⁹ Though short acting and administered intravenously as a continuous-rate infusion, dobutamine and dopamine can be used to improve cardiac contractility. Both drugs are sympathomimetic agents that bind to β 1-receptors, thereby increasing production of cyclic adenosine monophosphate.³⁷ Dopamine also affects α 1-receptors and therefore must be used with caution because of its effects on vasoconstriction and heart rate. A positive inotrope should be added to the treatment protocol if systolic function is moderately to severely impaired. Pimobendan is a phosphodiesterase inhibitor and benzimidazole-pyridazinone derivative approved for the treatment of congestive heart failure in dogs. It is a calcium sensitizer with positive inotropic and vasodilator effects.³⁸ Its use has been reported in a rabbit with heart failure due to myxomatous disease affecting the mitral and tricuspid valves. The rabbit responded well to initial therapy and survived for 7 months despite the presence of advanced cardiac disease at the time of diagnosis.⁵ Digoxin, a cardiac glycoside, is another example of a positive inotropic agent. It has been used successfully in rabbits to manage atrial fibrillation, mitral and tricuspid valve regurgitation, and dilated cardiomyopathy.¹ Strict cage rest and the reduction of stress within the patient's environment are also important when

one is managing or treating a congestive heart failure patient.

CARDIOPULMONARY ARREST AND RETURN OF SPONTANEOUS CIRCULATION

Cardiopulmonary arrest is a potential consequence of acute or chronic cardiac disease. Cardiopulmonary arrest occurs in small exotic herbivores that are presented to veterinary hospitals as a result of an underlying disease condition, anesthesia, or other physiologic stress process.

The clinical signs of cardiopulmonary arrest can be divided into those of impending arrest (e.g., irregular pulse, progressive arrhythmias, changes in ventilatory pattern) and those of definite arrest (e.g., unconsciousness, apnea, absence of heartbeat, fatal arrhythmias). Cardiopulmonary resuscitation (CPR) provides artificial ventilation and circulation in an attempt to restore cardiopulmonary function. It is imperative that the veterinarian immediately recognize clinical signs associated with cardiopulmonary arrest. In veterinary medicine, basic life support is performed based on the ABCDE approach: airway, breathing, circulation, drug administration, and evaluation.^{39,40}

Ideally, animals should be rapidly intubated with a cuffed endotracheal tube to ensure a patent airway and allow for artificial ventilation. Intubation of small exotic herbivores is difficult because of their relatively small oral cavity, large fleshy tongue, distal glottis, and laryngospasms, as well as the relative ease of causing iatrogenic damage to the pharynx and larynx. If the airway is not readily accessed, a tightly fitting mask may be used for positive-pressure ventilation. A retrospective study on cardiopulmonary arrest in rabbits reported that 5 of 7 animals recovered when using only a tight-fitting mask during CPR. This study suggests that a tight-fitting mask is an effective method for providing ventilation and may negate the need for emergency intubation in many rabbit cases that require CPR.⁴⁰ Blind intubation should not be used because this technique requires normal patient respiration. If possible, one may use a small endoscope to observe the tracheal opening for a fast, reliable method of intubation. Though not as effective, a small, flat-bladed laryngoscope can be used to assist with intubation. To properly intubate a small exotic herbivore, the animal should be placed in sternal or dorsal recumbency with its neck extended. The soft palate may need to be directed away from the epiglottis for adequate exposure

of the laryngeal opening. A stylet placed inside the endotracheal tube can be used to facilitate intubation. If it is not possible to establish an adequate airway using the methods described above, a tracheostomy is the procedure of choice.⁴¹ Once a patent airway is in place, ventilation is initiated by use of an Ambu bag or a mechanical ventilator to deliver air or preferably 100% oxygen to the patient. The recommended ventilation rate for small exotic herbivores is approximately 10 to 24 breaths/min with a tidal volume of 10 to 15 mL/kg and a peak inflation pressure of 20 cm H₂O. The volume of air/oxygen delivered should produce a visible chest rise of approximately 25% to 30% from resting state.^{39,42,43}

Once the airway is established, circulation must be addressed. In the absence of a palpable heartbeat or peripheral pulses, chest compressions should be initiated. Circulatory arrest can be correlated to a lack of electrical activity, a severe bradyarrhythmia, tachyarrhythmia (e.g., ventricular flutter, fibrillation), or electromechanical dissociation.^{40,42,44} The critical patient should be positioned in lateral recumbency, with the resuscitator's hand placed near the fifth intercostal space over the costochondral junction. Chest compressions can be performed either with one hand or with both hands placed on either side of the chest. Each chest compression should compress the chest by 25% to 33%. This force of compression is needed to adequately move blood and maintain circulation. Adequate cardiac massage can result in palpable arterial pulses and improved membrane color and perfusion or can lead to spontaneous return of heartbeats. The number of chest compressions delivered per minute during CPR is an important factor in the return of spontaneous circulation to the patient and, ultimately, its survival with few to no neurologic side effects. The actual number of chest compressions delivered per minute is undetermined at this time for small exotic herbivores, but it should correlate to the recommendations in small animal (e.g., dog, cat) emergency medicine of 110 to 120 beats/min. In most studies, more compressions are associated with higher survival rates and fewer compressions are associated with lower survival rates; however, it is unrealistic to maintain rapid chest compressions for an extended period of time.

Cardiopulmonary arrest is defined as a cessation of ventilation and effective circulation.

TABLE 4. Exotic herbivore emergency drugs^{1,34}

Drug	Dose	Route	Frequency
Epinephrine	0.2-0.4 mg/kg	IM, IV, IT	Bolus
Vasopressin	0.5-0.8 units/kg	IM, IV	Bolus
Atropine*	0.05-0.5 mg/kg	IM, IV, IT	Bolus
Dopamine	5-10 μ g/kg/min	IV	Continuous rate infusion
Dobutamine	7-15 μ g/kg/min	IV	Continuous rate infusion
Glycopyrrate	0.01-0.1 mg/kg	SC, IM, IV, IT	Bolus
Mannitol	0.25-1.0 g/kg	IV	Administration over 15 minutes
Lidocaine	1-4 mg/kg	IV	Bolus
Mexiletine	0.2 mg/kg	IM, IV	Bolus
Sotalol	0.5-5 mg/kg	IM, IV	Bolus
Naloxone	0.01-0.02 mg/kg	IM, IV	Bolus
Midazolam	0.4-1 mg/kg	IM, IV	Bolus

Abbreviations: IM, intramuscularly; IT, intratracheally; IV, intravenously; PO, orally; SC, subcutaneously.
 *Sixty percent of domestic rabbits possess atropine esterases, which can rapidly break down atropine to reduce its efficacy and duration of action.

Emphasis should not only be placed on proper compression technique and rate but also on minimizing interruptions. Even with optimal technique being used, closed-chest CPR is capable of producing only 20% of the cardiac output compared with spontaneous heartbeats.^{42,45}

Peripheral venous access through catheterization should be established as quickly as possible for the critical patient. Alternatively, if venous access is not possible, an intraosseous catheter may be placed.

Drugs may be administered intratracheally if venous access is not achieved.

Epinephrine, atropine, lidocaine, naloxone, and vasopressin are all absorbed through tracheal administration but may result in a lower blood concentration compared with intravenous administration. The recommendation for intratracheal drug administration in dogs and cats is to increase the drug dose 2

to 2.5 times and dilute with sterile saline solution or water to facilitate absorption. To facilitate the distribution, a red rubber catheter can be passed down the endotracheal tube to the level of the carina, and by use of 2 positive-pressure breaths, the medication is delivered.³⁹ As a general rule, drugs selected as treatment options during cardiopulmonary arrest are designed to either initiate spontaneous heartbeats, increase contractility, or correct an inappropriate heart rate or rhythm (Table 4).⁴⁰

The recommended drug to resuscitate animals in all forms of cardiac arrest is epinephrine. Epinephrine, an endogenous catecholamine with both α -

and β -adrenergic activity, is the vasopressor of choice for use during CPR. Epinephrine's potent α 1- and α 2-adrenergic effects improve cerebral and myocardial blood flow by preventing arterial collapse and by increasing peripheral vasoconstriction.^{39,46} The value and safety of the β -adrenergic effects of epinephrine are controversial because they may increase myocardial work and reduce subendocardial perfusion.³⁷ In an experimental study, epinephrine yielded a better response than vasopressin in rabbits in asphyxial cardiac arrest.⁴⁷

Similar to epinephrine, vasopressin may be used in pre- and post-arrest conditions. Vasopressin is a neurohypophysial hormone and non-adrenergic peripheral vasoconstrictor that causes an increase in peripheral vascular resistance to increase arterial blood pressure. Several human and swine CPR studies indicate that vasopressin may improve blood flow to vital organs, cerebral oxygen delivery, ability to be resuscitated, and neurologic outcomes.⁴⁸ It is believed that administering vasopressin during CPR in small animal patients with pulseless electrical activity or ventricular asystole may be beneficial for myocardial and cerebral blood flow.⁴⁹ Future studies are required to determine the advantage of using vasopressin in small exotic herbivores.

Atropine is a parasympatholytic agent that acts to elevate a patient's heart rate by antagonism of muscarinic receptors, thereby increasing the rate of discharge from the sinoatrial node. It is the drug of choice for treating vagally mediated asystole. If sinus bradycardia is present during the initial evaluation of a critical patient, atropine is the recommended treatment, not epineph-

rine.^{39,40} It is important to know that 60% of domestic rabbits possess atropine esterases, which can rapidly break down atropine to reduce its efficacy and duration of action.⁵⁰ Atropine can still be administered to domestic rabbits and have an effect; however, repeated injections may be required. Glycopyrrolate is a quaternary ammonium anticholinergic compound that, being highly polar, does not cross the blood-brain barrier. Glycopyrrolate is twice as potent and has a longer duration of action than atropine.⁵¹ In rabbits the use of glycopyrrolate is recommended over atropine; however, its slower onset of action and shorter half-life may be of concern in an emergency situation.⁵¹

Naloxone is a μ - and κ -receptor antagonist that was initially believed to increase arterial pressure in cases of hemorrhagic and septic shock. However, further studies performed in small animal (e.g., dogs, cats) medicine have shown that naloxone may only be of benefit in the management of electrical mechanical dissociation after counter-shock therapy. Currently, there are no published studies on the cardiovascular effects of naloxone in small exotic herbivores.⁵²

Dopamine and dobutamine are often used to treat hypotension, especially when associated with clinical evidence of bradycardia or after return of spontaneous circulation. If hypotension still persists after filling pressures are optimized, a combination of these two drugs or other vasopressors may be used.³⁷

Lidocaine is a local anesthetic as well as an antiarrhythmic drug used primarily for the treatment of ventricular arrhythmias.³⁹ The administration of lidocaine intravenously is relatively safe in rabbits and guinea pigs with a lethal dose of 50 percent of the animals (LD50) levels of 25.6 mg/kg and 24.5 mg/kg, respectively.⁵² A study determining the effects of intravenous lidocaine use on the isoflurane minimum alveolar concentration of rabbits described using a loading dosage of 2 mg/kg and a continuous-rate infusion of 100 μ g/kg per minute, with no negative cardiovascular effects noted.⁵³

In cases of ventricular fibrillation, the treatment of choice is electrical defibrillation. However, no studies have evaluated the efficacy of defibrillation in small exotic herbivores. Many defibrillators do not have a range that is low enough to deliver the recommended energy level in these patients, and standard paddles are generally too large.³⁹

Although calcium ions are critical for myocardial contraction and impulse formation, retro-

spective and prospective studies have shown no benefit from calcium administration during cardiac arrest. Furthermore, high serum calcium levels induced by intravenous administration may be detrimental. However, calcium supplementation can be useful when one is treating severe hyperkalemia, ionized hypocalcemia, or calcium channel blocker toxicity. Ideally, the ionized calcium concentration should be measured because the total calcium concentration does not correlate well with the ionized concentration in critically ill patients.^{39,54}

Tissue acidosis during cardiac arrest and resuscitation results from little to no blood flow during arrest and CPR attempts. The severity of the acidemia is linked to the duration of the event, the amount of blood flow, and the arterial oxygen content during CPR. There are few published reports to support the use of bicarbonate to treat tissue acidosis. Moreover, a wide variety of adverse effects have been linked to bicarbonate administration. Severe alkalosis can shift the oxyhemoglobin saturation curve and inhibit oxygen release to the tissues. Bicarbonate can also produce excess carbon dioxide (CO₂), which is capable of diffusing freely into myocardial and cerebral cells. This may contribute to intracellular acidosis and may inactivate simultaneously administered catecholamines.³⁹ It is the restoration of tissue oxygenation with appropriate ventilation and tissue perfusion through chest compressions, as well as rapid return of spontaneous circulation, that restores acid-base balance produced in cardiac arrest.⁵⁴

Currently, there is little evidence to guide fluid therapy in all small exotic herbivores during and after cardiac arrest. Volume loading during cardiac arrest can have detrimental effects by increasing right atrial pressure relative to aortic pressure, which can effectively decrease coronary perfusion pressure. A study in dogs found that there was no added benefit to either intravenous or intra-aortic fluid boluses on coronary perfusion pressure when compared with epinephrine administration during CPR.⁵⁵ However, if patients present with signs of circulatory shock associated with extreme volume loss advancing to pulseless electrical activity, intravascular volume should be promptly restored.^{42,56}

Monitoring during cardiopulmonary arrest is critical to determine patient outcome. ECGs are essential to monitor small exotic herbivores during cardiac arrest by allowing the clinician to determine the appropriate treatment and monitoring the return of spontaneous cardiac activity.

Other equipment including pulse oximetry will not function because there is a lack of adequate pulsatile blood flow in peripheral tissue beds. After the initiation of cardiac compressions, detection of a pulse by oximetry indicates that chest compressions are being performed in an appropriate manner. Multiple human and small animal studies of arterial blood gas monitoring have shown that it is an inaccurate indicator of tissue hypoxemia, hypercapnia, or acidosis during a cardiac arrest event.⁵⁷ Capnography is an important tool for monitoring the success of resuscitation, and monitoring end-tidal CO₂ of a cardiac arrest patient can be used as an indicator of cardiac output generated during CPR. This indicator of cardiac output generated during CPR may be an early prognostic indicator for the return of spontaneous circulation. Studies have shown that patients who were successfully revived after cardiac arrest had significantly higher end-tidal CO₂ levels than patients who could not be resuscitated.⁵⁸ Higher end-tidal levels during CPR are associated with increased myocardial perfusion pressure, whereas low end-tidal levels represent ineffective elimination of CO₂ due to low blood flow.⁵⁸

POST-RESUSCITATION CARE

After resuscitation has been successful, it is imperative to identify the underlying cause of the arrest. Cardiovascular and ventilatory support is necessary to maintain cardiopulmonary function and cerebral blood flow. Continuous ECG monitoring is vital, because myocardial hypoxia can lead to severe dysrhythmias. Alterations in rate or rhythm may also indicate other systemic abnormalities such as hyperkalemia or increased intracranial pressure. If an increase in intracranial pressure is suspected, treatment with mannitol is indicated. If a patient is unable to maintain adequate oxygen or CO₂ levels, mechanical ventilation is recommended. The impairment of blood flow and ischemic damage to the gastrointestinal tract during cardiac and pulmonary arrest should always be a concern in small exotic herbivores. Any damage to the gastrointestinal tract in a small exotic herbivore patient may lead to impaired mucosal integrity, dysbiosis, translocation of bacteria, and toxins in the bloodstream. Poor perfusion to the kidneys can lead to acute renal failure; therefore, attentive monitoring of electrolyte status and urine output is recommended to prevent adverse health effects. It is very important to maintain adequate blood pressure in

these patients using appropriate fluid therapy and vasopressors or inotropic drugs, as needed.³⁹

SUMMARY

Similar principles used for cardiovascular emergencies in small animals can be applied to small exotic herbivores. Unfortunately, many of these patients are presented at a late stage in the disease process, when they are in critical condition and the prognosis is poor. Thorough assessment and evaluation of each individual patient that presents in critical condition are imperative to ensure appropriate treatment is administered and the best possible outcome achieved.

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