A practical approach to critical care of cardiac disease

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Introduction

The treatment of a patient with severe acute heart failure is a challenge for any clinician. Despite the related stress for the patient and the limited options in private practice, thorough examination and monitoring are very important in the initial approach of the unstable cardiac patient. However, the risk of stressing an unstable patient too much by the initial diagnostic work-up and, as a result, the need for immediate action often forces the clinician to start medical treatment before the patient can be fully assessed. To enable the clinician to act appropriately under these difficult circumstances asks for a profound knowledge of the pathophysiology of heart diseases, cardiac failure, and cardiogenic shock (low arterial blood pressure (ABP)). With this background-knowledge, in combination with the more or less limited information from history and diagnostic work-up, the clinician is able to take the most appropriate measures to stabilize the patient with acute heart failure. This paper will focus on the pathophysiology, the monitoring and medical options used acutely to treat heart failure.

Pathophysiology

Heart failure is the end stage of severe heart disease and is a clinical syndrome seen as congestion and oedema (congestive or backward failure), systemic hypotension and/or poor peripheral perfusion (low output or forward failure). The main heart diseases leading to heart failure in companion animals are myocardial failure (e.g. dilated cardiomyopathy), a non-compliant ("stiff") ventricle (e.g. hypertrophic cardiomyopathy, pericardial disease), valvular regurgitation/stenosis (e.g. mitral insufficiency, aortic stenosis), arteriovenous shunting (e.g. patent ductus arteriosus) and sustained cardiac arrhythmias.

Acute heart failure can develop suddenly with the onset of a new and rapidly progressing disease (rare in veterinary medicine) or from exacerbation of a pre-existing chronic disorder. As a rule, patients with chronic heart failure exhibit signs of congestion and edema before signs of low cardiac output.

It is important to remember that, although the compensatory mechanisms can be very detrimental to a patient with terminal heart failure, these mechanisms are very beneficial to a patient with mild-to-moderate heart disease. Any attempt to eliminate compensatory mechanisms *completely* in terminal heart failure will have serious consequences for the patient.

Congestive or backward failure

Signs of congestive heart failure consist of tachypnoea, orthopnoea, dyspnoea, coughing, ascites, peripheral oedema, and pleural effusion. Congestion and oedema in heart failure

occur as a result of an increase in capillary hydrostatic pressure caused by increased ventricular end-diastolic pressure (EDP) and venous hypertension. An important cause of an increase in ventricular EDP in cardiac failure is an increase in blood volume and venous return by the retention of sodium and water. A ventricle with a “stiff” wall (decreased ventricular compliance as in hypertrophic cardiomyopathy) also cannot accept a normal or increased venous return. An increase in lymphatic drainage can compensate for increases in capillary hydrostatic pressure. A two- to threefold increase in venous pressure (15-20 mmHg) is often necessary to overrule the compensatory mechanisms and cause oedema to develop. In left-sided heart failure this leads to pulmonary oedema. In right-sided heart failure it can lead to ascites or peripheral oedema (in companion animals subcutaneous oedema rarely develops). Pleural effusions can result from both left- or right-sided heart failure but most often are a result of biventricular failure. Cats are more prone to develop pleural effusion than dogs.

Low output or forward failure

A poor cardiac output and, as a result, systemic arterial hypotension and poor peripheral perfusion can cause clinical signs of fatigue, weakness, poor exercise intolerance, cold extremities, slow capillary refill time, poor mucous membrane color, and hypothermia. In response to impaired cardiac output, potent homeostatic mechanisms are activated that are directed at the preservation of the systemic arterial pressure. This maintains perfusion of the brain and the heart but at the expense of vital regional circulations. Preservation of blood pressure mandates alterations in neural, hormonal, renal, and cardiovascular function and structure. Acute compensation of a decrease in systemic arterial blood pressure causes arteriolar vasoconstriction produced by increased circulating concentrations of norepinephrine, angiotensin, vasopressin, and endothelin and by increasing sympathetic nervous system discharge. As far as the cardiac disease allows, increase in contractility and heart rate also aid in the normalization of arterial blood pressure. More chronic compensation occurs by water and sodium retention by the kidneys. The increase in blood volume increases the ventricular enddiastolic volume, which enables more forceful contraction and a larger stroke volume (Starling’s law). The renine-angiotensin-aldosterone system (RAAS) is probably the most important system in water and sodium resorption. Along with altered RAAS, a reduction and changes in renal blood flow aid in the retention of sodium and water. Furthermore, an increase in plasma vasopressin (antidiuretic hormone (ADH)) can cause water retention and stimulate thirst. This can cause hyponatraemia in terminal heart failure.

Atrial natriuretic factor (ANF) is produced and excreted by the atria when atrial pressure rises. By its promotion of diuresis, vasodilatation, and inhibition of RAAS, it counteracts volume retention. However it appears ineffectual in patients with heart failure.

The distinction between backward and forward failure is arbitrary as both the underlying causes and treatment options have an impact on both aspects of cardiac failure.

Monitoring

To make a diagnosis of heart failure, one must document the presence of moderate-to-severe heart disease accompanied by increased capillary or venous pressures, low cardiac output, and/or low arterial blood pressure. Monitoring parameters are related to physical examination, electrocardiography (intermittent or continuous (telemetry)), thoracic radiography, echocardiography, venous and arterial blood pressure measurement, cardiac

catheterization, laboratory examinations, and current therapy. As with every critical care patient, monitoring should be expanded with increasing instability and severity of the disease. The frequent notation of the monitoring indices is important for establishing trends, which help in the correct interpretation of parameters and the assessment of fluid balance. Without extensive monitoring, the institution of an adequate treatment is impossible, as is the adjustment of therapy in order to reach a stable situation for the patient. Here, only a few important indicators of backward and forward failure, which are helpful in monitoring the cardiac patient, are discussed.

Measuring central venous pressure (CVP) from a jugular catheter is the definitive means of identifying *right-sided* congestive heart failure. In a patient with congestive heart failure the CVP will be at least 10 mmHg or 14 cmH_2O. However, in cardiac patients, CVP is not an accurate reflection of pulmonary venous pressure (*left-sided* heart failure). In order to obtain measurements of the mean left ventricular filling pressure, a Swan-Ganz catheter must be advanced into a lobar pulmonary artery to enable the measurement of the so-called pulmonary capillary wedge pressure (PCWP). Pulmonary oedema is often associated with PCWP above 20 to 25 mmHg (At the same time this catheter enables measurement of other parameters like cardiac output (CO).). However, technical and cost restrictions in veterinary medicine make the use of the Swan-Ganz catheter limited to specialized veterinary centres.

Reduced cardiac output in heart failure can result in decreased systemic arterial blood pressure. Measurement of arterial blood pressure (non-invasively or invasively) and, if feasible, CO itself, can help in establishing the presence and severity of low output failure. Poor perfusion leads to a reduced oxygen delivery (DO_2) to the tissues (DO_2 = CO x Ca_{O_2} (= arterial oxygen content). Ca_{O_2} is defined as: [Hb](g/100 ml) x O_2 saturation (%) x 1.34(ml O_2/g Hb). If DO_2 decreases below a critical level, anaerobic metabolism will develop, resulting in lactate production. Therefore, venous blood gas measurement (preferably mixed) and lactate measurement are important indicators of the severity of forward failure.

Medical treatment of heart failure

Tissue hypoxia

Tissue hypoxia is the ultimate reason critical patients, including cardiac patients, die as a result of their disease. Tissue hypoxia can be the result of both backward failure (lung oedema) and forward failure (poor tissue perfusion). Ultimately, heart failure should be controlled to restore oxygen transport to the tissues. In anticipation however, tissue oxygen delivery (DO_2) should be increased and oxygen consumption (VO_2) should be reduced as much as possible.

Reduction of oxygen consumption (VO_2)

Cage rest and stress reduction are essential for the reduction of VO_2. Patients with severe heart failure and lung oedema can be very restless and stressed as a result of “air hunger”, thereby increasing oxygen demand. Sedation may be necessary (dog: methadone/ morphine: 0.1-0.3 mg/kg IV or butorphanol 0.25 mg/kg IM; cat: buprenorphine: 20 microg/kg (combined with acepromazine: 0.1 mg/kg) IM or butorphanol 0.25 mg/kg IM).

Increase in oxygen delivery (DO_2)

Oxygen supplementation should be instituted to resolve arterial hypoxemia and decreased oxygen delivery (DO_2) to the tissues. To reduce lung oedema, left atrial and pulmonary

venous pressure should be decreased rapidly (see backward failure). An oxygen rich environment can be obtained by means of an oxygen cage but this limits the accessibility of the unstable patient. In the acute phase, an oxygen mask, intranasal or transtracheal catheter is often preferred in dogs as the patient is more accessible and it does not cause distress to the animal. Nevertheless, in cats an oxygen cage is often preferred because the excessive handling and stress associated with tube placement can be detrimental.
Thoracocentesis (especially in cats) and abdominocentesis should be performed if liquothorax or ascites have a negative effect on respiration. Patients in extreme respiratory distress may benefit from anaesthesia, endotracheal intubation, controlled ventilation, and 100% oxygen.

Backward failure

The most life-threatening sequela of backward failure is left-sided backward failure resulting in lung oedema and pleural effusion. Lung oedema should be treated by reduction of the capillary hydrostatic pressure by means of decreasing volume overload or increasing the venous capacity.

Diuretics

Reduction in total blood volume can be achieved with a potent diuretic. In veterinary medicine, loop diuretics are the most important and efficacious class of drugs used for treating heart failure. Furosemide in the short-term emergency situation of pulmonary oedema is dosed intravenously at 2-8 mg/kg q1-6 h in the dog and 1-4 mg/kg q1-6 h in the cat. Furosemide also has an additional and very beneficial venodilator effect when administered IV. Excessive dosing can lead to dehydration, electrolyte depletion, low cardiac output and circulatory collapse, inducing renal failure. Therefore, monitoring of renal function including serum electrolytes and urine production is essential.
Thiazide diuretics act on the proximal portion of the distal tubule. They are mildly to moderately potent diuretics and are not often used in emergency cardiac failure. The potassium-sparing diuretics, like spironolactone, act on the distal portion of the distal tubule and are mainly used in patients that become hypokalaemic.

Venodilators

The prior is achieved the most quickly with a venodilator such as nitroglycerine 2% ointment (dog: 6 mg/10 kg q 8 hrs; 6 mg = 1cm; cat: 0.5-0.75 cm q8h). It is applied to a hairless, well-perfused area of the skin (ear pinna or groin). Gloves should be worn to apply the ointment. Nitroglycerine can have also some dilatory effect on arterioles. Therefore, it is best to use nitroglycerine only in combination with arterial blood pressure measurement. Patients become refractory to nitrates with long-term administration. Therefore nitroglycerine should only be used for a maximum of three to five days for the initial control of pulmonary oedema.
Nitroprusside (dog: 1-10 µg/kg/min IV) is a mixed vasodilator and also has an effect on afterload (see arteriodilators).

Improved ventricular filling

In hypertrophic and restrictive cardiomyopathy, β-receptor blocking agents and diltiazem have been advocated to improve left ventricular filling and cardiac performance. But the negative inotropic effect can cause a serious hypotensive effect. Pericardiocentesis is performed with pericardial effusion to improve ventricular filling and resolve backward failure. Improvement of diastolic function can also improve cardiac output, i.e. forward failure.

Forward failure

Sympaticomimetics

Sympaticomymetic drugs are the preferred drugs for acute short-term inotropic support of patients with cardiac disease as a result of myocardial failure/cardiogenic shock. Their efficacy decreases rapidly because of the decrease in β-receptor numbers and sensitivity as a result of constant stimulation. Because of their very short half-lives they have to be administered as a constant-rate infusion (CRI) and because of the increased risk of sinus tachycardia and ventricular arrhythmias continuous ECG monitoring is important.

The effect of sympaticomimetics is dose-dependent and varies among cardiac patient. Therefore, the hemodynamic effects should be measured and used to adjust the dosage.

The dosage of dopamine is 5 to 15 µg/kg/min CRI in dogs and 2.5-10 µg/kg/min in cats. In higher dosages (10-20 µg/kg/min) it can cause peripheral vasoconstriction mediated by α-receptors resulting in an increase in cardiac afterload. The dosage of dobutamine is 5-20 µg/kg/min CRI in dogs and 1.25-10 µg/kg/min CRI in cats. Dobutamine is less arrhythmogenic and has less effect on heart rate compared to other sympaticomimetics but is more expensive than dopamine.

Bipyridine compounds

Amrinone (1-3 mg/kg (loading dose); 10-100 µg/kg/min (CRI;start low; titrate)) and milrinone improve contractility by inhibition of phosphodiesterase fraction III. This effect is in the same order in dogs as with sympatomimetics. The phosphodiesterase inhibition also causes systemic arterial vasodilation and reduces afterload. The role of bipyridine compounds in the acute treatment of severe heart failure is still under investigation.

Pimobendan, a calcium-sensitizing drug, recently came available on the veterinary market and has similar effects as the bipyridine compounds: positive inotropic and vasodilatory properties. Its current formulation is only for oral use (0.1-0.3 mg/kg PO q12h) and clinical experience in acute heart failure is still limited.

Digitalis glycosides

Digitalis glycosides are relatively weak positive inotropic agents and have limited value in the acute treatment of myocardial failure. In acute heart failure they are mainly used to slow the heart rate, especially in patients with supraventricular tachyarrhythmia, e.g atrial fibrillation. The rapid reduction in heart rate often necessitates an intravenous digitalisation of the patient that is not without serious risks of digitalis toxicity. The most commonly used glycoside is digoxin in a maintenance dose for dogs of 0.22 mg/m^2 PO q 12 h and cats of 0.005-0.008 mg/kg q 24h. If administered intravenously the dose is given in a stepwise manner (dog: 0.0025 mg/kg q 1 h for 4 h (total 0.01 mg/kg)) to reduce the risk of overdosing.

Arteriodilators

Nitroprusside (dog: 0.5-5 µg/kg/min CRI), a mixed vasodilator, and hydralazine, a systemic arteriolar vasodilation, reduce afterload and improve cardiac output. They are indicated in severe mitral and aortic regurgitation, and ventricular septal defects that are refractory to conventional therapy, and cardiac failure with systemic hypertension. By improving forward flow it can also reduce backward failure and oedema formation. Hydralazine (dog: 0.5-3 mg/kg q12h PO; titrate dose) is an oral arteriodilator. Arteriodilators should be used with caution and have to be started at a low dose and titrated to an effective endpoint. In acute heart failure in which a more rapid titration is necessary it requires accurate haemodynamic monitoring to prevent severe hypotension.

With the use of an arteriodilator the mean arterial blood pressure (MAP) is usually reduced by 10 to 40 mmHg and MAP should be maintained above 70 mmHg.
Common side effects of hydralazine include first-dose hypotension and anorexia, vomiting and diarrhoea. Adverse effects of nitroprusside are hypotension and cyanide toxicity. The latter restricts its use to a period not longer than 16 h at a dose of 10 µg/kg/min.
Another group of arteriodilators that are often used in the treatment of chronic heart failure, the angiotensin converting enzyme (ACE) inhibitors, are not indicated in the management of acute heart failure. Their slower onset of action, oral route of administration, and relatively mild arterial dilation produced as compared to other arteriodilators, make them less useful in acute emergencies.

Cardiac arrhythmias

Antiarrhythmic drug therapy is not always indicated. In general, any arrhythmia that is suspected to have a (potentially) serious negative effect on the circulation should be treated. Oxygen supplementation and normalization of plasma potassium and magnesium levels form the basis of antiarrhythmic treatment. The most common arrhythmias in acute heart failure are supraventricular, e.g. atrial fibrillation, and ventricular arrhythmias. Supraventricular tachyarrhythmias can be treated with digoxin and/or diltiazem (dog: 0.1-0.2 mg/kg bolus, then CRI 2-6 µg/kg/min). Propranolol (0.01-0.1 mg/kg as a slow bolus) or a newer β-receptor blocking agent, esmolol, can also be considered (dog and cat: 50-100 µg/kg as a slow bolus (repeat up to a maximum of 500 µg/kg; maintenance dose 50-200 µg/kg/min). The negative inotropic effects of calcium antagonists (diltiazem) and β-receptor blocking agents can limit their use in acute heart failure. Ventricular arrhythmias can be treated with a wide range of antiarrhythmic agents, but it is beyond the scope of this presentation to discuss them all in detail. Lidocaine (dog: loading dose: 2-4 mg/kg slow bolus over 1 to 3 minutes, maintenance dose 40-100 µg/kg/min) and procainamide (dog: 2 mg/kg slow bolus over 5 minutes, maintenance dose 20-50 µg/kg/min) are often used to control ventricular tachyarrhythmias in acute heart failure.

References and further reading

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