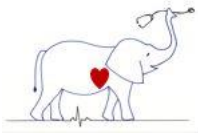
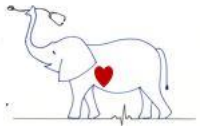




Updated 03/31/2020

CONGENITAL HEART DISEASE

John E. Rush, DVM, MS, DACVIM (Cardiology), DACVECC
Cummings School of Veterinary Medicine at Tufts University

MAJOR OBJECTIVES

1. Be able to describe the anatomic location and physiologic consequences of the common congenital defects (PDA, pulmonic stenosis, aortic stenosis, ventricular septal defect, atrial septal defect, mitral and tricuspid dysplasia/insufficiency, Tetralogy of Fallot).

2. Given a set of findings from physical examination, ECG and thoracic radiographs, be able to determine which congenital heart defect is present, i.e., a 4-month-old female Maltese dog with a continuous murmur, bounding pulses, electrocardiographic and radiographic evidence of left ventricular enlargement and left atrial enlargement, and radiographic evidence of pulmonary overcirculation is likely to have a patent ductus arteriosus.

MINOR OBJECTIVES

1. Know the relative frequencies of specific congenital heart defects in the dog, cat, horse, cow and swine.
2. Be familiar with which canine breeds are predisposed to specific congenital heart defects.
3. Be familiar with the potential modalities of therapy for each of the congenital heart defects.
4. Be able to interpret cardiac catheterization data, including intracardiac pressure measurements and oximetry data.

CONGENITAL HEART DISEASE

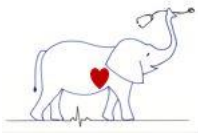
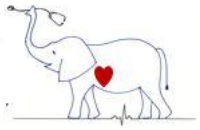
GENERAL CONSIDERATIONS

A. Definition of congenital heart disease: cardiovascular malformation present at birth

1. Etiology
   a. Genetic or hereditary factors: polygenic mode of transmission proposed in many defects studied by breeding experiments.
   b. Environmental causes: exposure during fetal life to environmental agents such as drugs, toxins, infectious diseases (esp. viral, protozoal), or poorly defined "stressors" **may cause cardiac malformation.**

B. Incidence reported in dogs (5-10 per 1000 births) is similar to the incidence in humans but less than the reported incidence in other species: true incidence unknown. In one study from Italy, up to 19% of Boxer dogs screened for heart disease had a congenital malformation.

Most common defects:
- Canine: PDA, PRAA, VSD, PS, AS
- Feline: Mitral valves malformation, tricuspid dysplasia, VSD, AS
- Equine: VSD; Tetralogy of Fallot

- Bovine: VSD; Ovine: VSD
- Porcine: subvalvular aortic stenosis
- Complex defects (i.e. Transpositions and Pseudotruncus arteriosus) are more common in large animal species.

C. Importance of accurate diagnosis

1. Often young, asymptomatic animal on first exam
   a. Owner: purchase return, emotional attachment
   b. Prognosis, breeding potential, potential for surgical correction or medical care
   c. Other associated congenital lesions

D. Methods useful in differentiating congenital heart defects

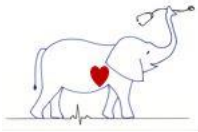
1. Murmurs: timing, location, intensity, quality, radiation
2. Transients (S_1, S_2, S_3, S_4)
3. Pulse character -- increased or decreased pulse pressure
4. Cyanotic or acyanotic ($\geq$ 5gm/100ml of reduced hemoglobin)
5. Right heart and/or left heart enlargement (EKG, radiographs, etc.)
6. Pulmonary blood flow -- increased (over-circulated), decreased (under-circulated), normal
7. Volume load = eccentric hypertrophy (mitral and tricuspid dysplasia, septal defects, PDA) or pressure load = concentric hypertrophy (AS, PS)
8. Need to differentiate from innocent, functional (anemia, fever, pregnancy) murmurs (generally early systolic, decrescendo, variable; mid-pitched blowing, rough or vibratory).

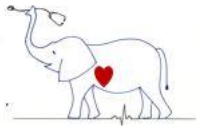
E. Embryologic Structures and Cardiovascular Defects (see Appendix)

1. Useful in understanding the cause of the defect and resulting pathophysiology.

F. Review of fetal circulation

1. Cardiac output is 2-4 time adult; placenta has low resistance - lungs high resistance.
2. Response to decreased pO2 is bradycardia
3. Foramen ovale, ductus arteriosus, umbilical arteries, umbilical vein, ductus venous
4. Please review notes and diagrams from your earlier Embryology lectures. Concentrate on:
   a. Umbilical artery and vein
   b. Ductus venosus
   c. Foramen ovale
   d. Ductus arteriosus
   e. Pulmonary flow in utero





SPECIFIC LESIONS

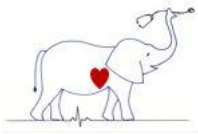
The earliest indication of cardiac congenital defect is usually auscultation of a cardiac murmur. Loud murmurs of long duration are usually the result of cardiac malformation and should be investigated. Murmurs of softer intensity may be physiologic in origin (innocent murmurs) or they may result from anemia or congenital cardiac defect. Characterization of murmurs with respect to timing, location on the chest wall, intensity, quality, radiation, and presence or absence of abnormalities in transient sounds (S1, S2, S3, or S4) is important in differentiation of congenital heart defects. In addition to cardiac and pulmonary auscultation, the physical examination should include palpation of the precordium to find the site of the apex beat and palpate for thrills, palpation of femoral arterial pulse quality, observation of the jugular veins for distention or pulsation, abdominal palpation for hepatomegaly or ascites, and the mucous membrane color and capillary refill time should be carefully evaluated for pallor, cyanosis, or poor capillary refill time. Animals with congenital heart defects may be stunted in size when compared to littermates.

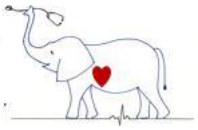
Innocent murmurs in small animals are typically systolic, of short duration, and of low intensity (grade III or less). Some innocent murmurs may be described as having a musical character. The localization of innocent murmurs may be over the aortic or pulmonic valve in dogs and cats, although localization and timing in horses and other large animals are less predictable. These murmurs frequently change in character or disappear completely with changes in the animal's body position (i.e., lie them on their back and auscultate). Innocent murmurs in large animals may be diastolic. Innocent murmurs become softer as the animal ages and usually disappear by 12 months of age.

The cardiovascular work-up for congenital heart disease may include thoracic radiographs, an electrocardiogram, an echocardiogram, non-selective angiography, selective cardiac catheterization, or other specialized tests to determine the severity of the defect and the specific diagnosis. Selective cardiac catheterization is used to perform selective angiography or to obtain direct measurement of intracardiac pressures and blood oximetry. Selective angiography is indicated to document cardiac defects and localize the lesion. Measurement of intracardiac pressures allows documentation of the hemodynamic severity of the lesion (i.e. gradients across stenotic valves). This hemodynamic information can be used to formulate a more accurate prognosis and determine the need for therapeutic interventions. Measurement of blood oxygen content (oximetry) allows identification of left-to-right or right-to-left shunting defects and provides a quantitative assessment of the degree of shunting and the need for surgery (i.e., there is twice as much blood flowing through the lungs than through the systemic circulation).

Patent Ductus Arteriosus - Dogs, Cats, Horses, Llamas

In the fetus, blood returning to the heart either passes through the foramen ovale to the left atrium or is pumped through the right ventricle to the pulmonary artery. The pressure in the pulmonary vessels is high during fetal life so blood pumped into the pulmonary artery is shunted through the ductus arteriosus to the aorta, preventing unneeded pulmonary circulation. At birth, expansion of the lungs causes a drop in pulmonary vascular resistance and the pressure in the systemic circuit rises. This results in a reversal of blood flow through the ductus arteriosus (blood now flows from the aorta to the pulmonary artery). This reversal in blood flow, inhibition of prostaglandin synthesis, and local increase in PO2 results in vasoconstriction of the ductus with functional closure by 72 hours postpartum in dogs and cats.





Failure of ductal closure results in patency (patent ductus arteriosus - PDA) and results in the permanent connection from the aorta to the pulmonary artery.

PDA is most common in female pure bred dogs; a polygenic mode of inheritance has been proven in the poodle but several other breeds of dogs including Pomeranians, collies, Chihuahuas, Maltese, Shetland sheep dogs, German shepherds, cocker spaniels, and Irish setters are predisposed. Siamese cats may be predisposed to PDA.

Although animals with PDA may be presented for evaluation of poor growth, exercise intolerance, and/or respiratory distress (tachypnea, dyspnea), only about 25-35% of dogs will be presented with signs of congestive heart failure.

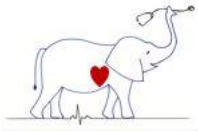
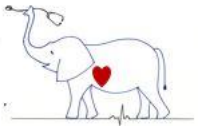
In most animals with PDA blood flows continuously from the aorta to the pulmonary artery through the ductus arteriosus. This continuous, turbulent blood flow produces a continuous cardiac murmur (usually with a thrill) at the left base of the heart up under the axilla. The murmur peaks in intensity at the second heart sound. The systolic component of the murmur radiates well and may be ausculted over the entire thorax. However, the diastolic component may be missed in some animals if one fails to listen carefully at the left base. This left-to-right shunt increases blood flow through the proximal aorta, pulmonary vasculature, left atrium, and left ventricle, producing enlargement of the left atrium and ventricle as well as pulmonary overcirculation (volume overload = eccentric hypertrophy). Mitral valve regurgitation (and the accompanying systolic, regurgitant quality murmur) frequently develops, probably secondary to left ventricular dilation and stretching of the mitral valve annulus. Volume overloading of the left heart results in increased filling pressures to the left atrium and left ventricle and pulmonary edema (with pulmonary crackles on auscultation) may occur as a result of left ventricular failure. Right ventricular enlargement may develop with large shunts.

PDA causes unusually wide arterial pulse pressures (the pulse character is strong and sharp, then rapidly drops off) as the peak systolic arterial pressure is normal or elevated due to an increased stroke volume (blood entering the pulmonary artery courses through the lungs and re-enters the left heart), but the arterial diastolic blood pressure rapidly drops as blood "runs off" into the low pressure pulmonary artery. This causes the bounding pulse, often described as waterhammer or bounding.

Thoracic radiographs demonstrate marked left ventricular and atrial enlargement, with an elongated heart most evident on the VD view. Pulmonary overcirculation is indicated by enlargement of the pulmonary arteries and veins in addition to an increased interstitial pattern throughout the lungs. The ventrodorsal radiographic view variably demonstrates three "bumps" at the left cranial aspect of the heart. The bumps represent dilation of the descending aorta (ductus bump) at the 1 o'clock position, enlargement of the main pulmonary artery (2 o'clock), and left auricular enlargement (3 o'clock). If heart failure is present, interstitial or alveolar pulmonary edema may be present.

The ECG frequently shows a left ventricular enlargement pattern and p-mitrale (LAE). Sinus tachycardia is common, ventricular or supraventricular arrhythmias may be observed, and atrial fibrillation may be present in dogs with marked left atrial enlargement.

Echocardiographic findings supportive of the diagnosis include left atrial and ventricular enlargement and prominent aortic root motion, the ductus is visualized in some cases, with continuous flow in the main pulmonary artery documented on color-flow Doppler. Cardiac

catheterization is performed on those animals whose findings suggest pulmonary hypertension or other concomitant congenital cardiac defects and is performed to allow coil occlusion of the ductus.

The treatment of choice for animals with PDA is early coil occlusion, Amplatzer ductal occlusion or surgical ligation of the ductus, preferably before 4-6 months of age. The natural history of dogs with uncorrected PDA is poor, with up to a 40 to 70% mortality rate in the first year of life. Animals with congestive heart failure are stabilized (medical therapy) prior to surgery. Surgical ligation or coil occlusion of the PDA in young animals who have not yet developed CHF is usually curative. Mitral insufficiency from mitral valve annulus stretching may resolve as young animals "grow into" their mitral valve. Animals with arrhythmias or longstanding congestive heart failure prior to surgery, or surgical correction after 1 year of age often require long-term medical therapy and may succumb to heart failure.

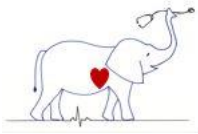
Pulmonic Stenosis - Dogs

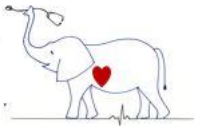
Pulmonic stenosis (PS) may be due to valvular dysplasia, subvalvular stenosis, or rarely supravalvular stenosis. Valvular stenosis is most common in dogs and is recognized by the finding of thickened, malformed valves, often fused at the commissures. Bicuspid or single dome-shaped valves with a small orifice are also recognized. The valve annulus may be hypoplastic. Subvalvular stenosis, which may accompany valvular stenosis or occur as an isolated lesion, is manifested as a thick fibrous ridge of tissue below the valve in the right ventricular outflow tract. Both valvular and subvalvular PS can be exacerbated by ventricular myocardial hypertrophy in the infundibular region of the right ventricular outflow tract. Isolated PS is rare in the cat and the horse.

Pulmonic stenosis causes obstruction to ejection of blood from the right ventricle. The right ventricle must hypertrophy to generate pressures greater than normal to maintain cardiac output across the narrowed pulmonary outflow tract (pressure overload = concentric hypertrophy). Excessive infundibular hypertrophy may result in an additional dynamic obstruction. Secondary right atrial enlargement may develop.
Several breeds of dogs are recognized as being predisposed to PS, including the English bulldog, schnauzer, beagle, Chihuahua, terriers, cocker spaniel, and Samoyeds.

Clinical signs may result from forward heart failure (syncope, muscular weakness) or backward right-sided heart failure (ascites, jugular venous distention or pulsation, etc.) Forward heart failure occurs when the right ventricle is unable to pump a sufficient volume of blood through the lungs to the left ventricle. The left ventricle is deprived of adequate preload and is unable to increase cardiac output in response to exercise or excitement. Right ventricular myocardial failure, tricuspid regurgitation, or pulmonic valve insufficiency may contribute to the development of right heart failure. In symptomatic dogs, signs typically develop during the first three to five years of life.

Physical examination reveals a prominent systolic murmur with a point of maximal intensity at the left cardiac base (second or third intercostal space). The murmur is typically a loud, harsh, ejection quality (crescendo-decrescendo) murmur and frequently has a thrill. A second murmur of regurgitant quality may be ausculted on the right hemithorax in dogs with tricuspid insufficiency. The cardiac apex beat may be strongest on the right hemithorax. Mucous membrane color and pulse quality at rest are normal in dogs with mild to moderate stenosis, however, those with critical stenosis may have pallor and weak pulse quality, especially after





exercise. Signs of right ventricular failure include hepatomegaly, ascites, pleural effusion, and jugular venous distention and/or pulsation.

Thoracic radiographs frequently demonstrate right ventricular enlargement with a post-stenotic dilation of the main pulmonary artery evident on the ventrodorsal radiographic projection at the 2 o'clock position. Right atrial enlargement is variably noted, and the caudal vena cava is enlarged if right heart failure is present or imminent. Pulmonary vasculature is usually otherwise normal, although in some cases apparent hypo-vascularity is noted.

The electrocardiogram is often normal with mild stenosis, but right ventricular enlargement and/or a right axis shift are usually present with moderate or severe pulmonic stenosis. P-pulmonale is less frequently recorded. Ventricular arrhythmias may occur; supraventricular arrhythmias are more common in dogs with significant right atrial enlargement.

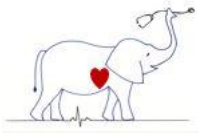
The echocardiogram reliably identifies compensatory right ventricular hypertrophy, and the post-stenotic dilation of the pulmonary artery can frequently be appreciated. The pulmonary outflow tract may appear narrowed, thickened valve leaflets and/or abnormal valve excursions are found with valvular stenosis. The interventricular septum is hypertrophied and may move toward the right ventricle during systole (paradoxical septal motion). Doppler echocardiography can be used to document turbulent blood flow in the main pulmonary artery and in many cases will provide an accurate estimate the pressure gradient across the pulmonic valve.

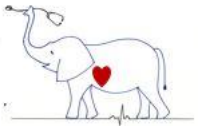
Both selective and nonselective angiography are useful for documentation of right ventricular hypertrophy and post-stenotic dilatation, but selective right ventricular angiography is frequently required to differentiate between valvular and subvalvular pulmonic stenosis. The severity of the defect (pressure gradient) cannot be documented without catheterization or Doppler echocardiography. These procedures allow for grading of the severity of disease based on the pressure gradient across the stenosis. Mild pulmonic stenosis in dogs is defined as a gradient of 10 to 50 mmHg, moderate gradients are between 50 and 100 mmHg, and severe gradients for pulmonic stenosis are those in excess of 100 mmHg (some people use > 80 mm Hg as severe).

Dogs with mild PS usually remain asymptomatic and do not require therapy. Untreated dogs with severe stenosis and clinical signs often do not live beyond 4 years of age. Animals that have clinical signs and those with moderate to severe stenosis are candidates for balloon valvuloplasty or surgery. Medical therapy is limited to antiarrhythmic drugs and judicious use of diuretics and low-salt diet to control signs of congestive heart failure.

Several surgical procedures have been developed, including bistoury and valvotomy techniques to surgically enlarge the pulmonic valve. Patch graft techniques, using either the pericardium or a synthetic patch material, can be used to enlarge the entire pulmonic outflow region. The appropriate technique is selected for each animal based on the type and location of the stenosis (valvular, subvalvular, or both). Effective surgery results in a significant decrease in the gradient across the pulmonic valve. The efficacy of surgery and the incidence of complications is, in part, dependent on operator skill. In general, balloon valvuloplasty is associated with a lower mortality than surgery, and is more effective in dos with isolated valvular disease and is usually the first intervention of choice.

Aortic Stenosis - Dogs, Cats, Pigs





Aortic stenosis may result from narrowing at the subvalvular, valvular, or rarely supravalvular locations in the aortic outflow tract. Subvalvular aortic stenosis (SAS), present in over 90% of affected dogs, is evident as deposition of a thick band or ridge of fibrous connective tissue in the aortic outflow tract just below the valve. Valvular stenosis results from valvular dysplasia with thickened or fused leaflets. All forms of aortic stenosis have been observed in the cat, although the defect is less commonly encountered in this species. Aortic stenosis has been proven to be transmitted genetically in the Newfoundland breed, and several breeds such as German shepherd dogs, boxers, golden retrievers, Rottweilers, and German shorthair pointers are predisposed to aortic stenosis.

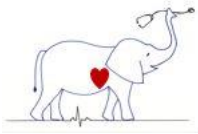
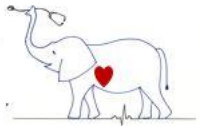
Because aortic stenosis causes obstruction to ventricular outflow, the left ventricle must hypertrophy to develop a greater than normal systolic pressure to maintain normal stroke volume (pressure overload = concentric hypertrophy). Turbulent blood flow, generated by the stenosis, causes a murmur and post-stenotic dilation distal to the site of obstruction. Advanced disease and left ventricular failure leads to left atrial enlargement and eventually pulmonary edema. Mitral or aortic insufficiency may accompany and complicate aortic stenosis. Cats may be more likely than dogs to develop pulmonary edema.

Dogs with SAS usually develop syncope or sudden death before congestive heart failure. This results from a combination of an inability to increase cardiac output in response to exercise and compromised myocardial perfusion. SAS limits the ability of the left ventricle to increase stroke volume in response to increased tissue demands, so increases in cardiac output result largely from increases in heart rate. Ventricular hypertrophy, combined with increased heart rate, results in an increased myocardial oxygen demand. Unfortunately, elevated intraventricular pressures limit the coronary arterial blood flow during systole and tachycardia shortens diastole, therefore myocardial oxygen demand increases while coronary artery perfusion decreases leading to left ventricular endocardial ischemia. Myocardial ischemia leads to myocardial depression, decreased myocardial compliance, myocardial necrosis and fibrosis, and increased risk for arrhythmia. All of these factors may contribute to sudden death which is often observed in dogs with aortic stenosis.

Many dogs are asymptomatic at the time of presentation, but some are presented for syncope, weakness, stunted growth, exercise intolerance, dyspnea, or cough. The first clinical sign of SAS in dogs can be sudden death during a period of physical exertion or excitement, most likely caused by an arrhythmia, resulting from sub-endocardial ischemia.

Physical examination reveals the presence of a systolic, ejection quality (crescendo-decrescendo) murmur. The point of maximal intensity is typically at the left heart base, usually at the 3rd or 4th intercostal space. The murmur may be equally loud at the right heart base, and may radiate to the thoracic inlet and up the carotid arteries. A thrill often accompanies loud murmurs, and a prominent left apical impulse may be noted on precordial palpation. Femoral pulses are weak and are described as slow rising. Arrhythmias and pulse deficits are noted in some animals.

Thoracic radiographs may demonstrate left ventricular enlargement, but the concentric nature of the hypertrophy can be difficult to detect radiographically. The post-stenotic dilation of the aorta appears as an increased density cranial to the heart on both lateral and ventrodorsal projections. In advanced cases, left atrial enlargement and evidence of congestive heart failure may be observed.

Electrocardiographic findings with SAS vary with the severity of the stenosis and the ECG is normal in mild cases. Increased QRS amplitude and/or duration reflect left ventricular enlargement. Abnormalities in the ST segment or T wave may be noted, with significant ST segment depression suggestive of myocardial ischemia, necrosis or fibrosis. An ECG that demonstrates ST segment depression or ventricular arrhythmias after exercise is compatible with exertional myocardial ischemia.

The echocardiogram is useful in demonstration of both valvular and subvalvular aortic stenosis. Post-stenotic dilation of the aorta, left ventricular hypertrophy, and a small left ventricular end systolic cavity are supportive of the diagnosis. Two-dimensional echocardiography may demonstrate an echodense ridge or band of tissue in the left ventricular outflow tract in dogs with subvalvular stenosis, or abnormal valvular anatomy or motion in the case of valvular stenosis. Doppler echocardiography can be used to demonstrate turbulent blood flow in the ascending aorta and to estimate the gradient across the aortic valve.

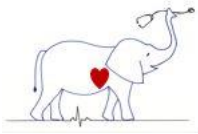
Cardiac catheterization or Doppler echocardiography is used to measurement of the pressure gradient across the aortic valve. Mild stenosis is defined by a gradient of 10 to 40 mmHg; moderate stenosis by a 40 to 80 mmHg gradient; and severe stenosis by a gradient in excess of 80 mmHg. Dogs with mild aortic stenosis (gradient < 40 mmHg) usually remain asymptomatic and do not require therapy. Dogs with moderate stenosis may live for several years and/or die suddenly. Selective angiography documents the valvular and subvalvular anatomy, left ventricular hypertrophy, the post-stenotic dilation, and the presence or absence of aortic insufficiency.

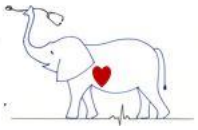
Due to the high incidence of complications, a high surgical mortality, and the need for cardiopulmonary bypass techniques, surgical correction of subaortic stenosis is infrequently attempted. Animals who are candidates for surgical therapy are those with remarkable clinical signs, severe arrhythmias, ECG evidence of ischemia, and those with gradients in excess of 80 mmHg, who are thought to be at risk for sudden death.

Balloon valvuloplasty is of questionable value in dogs with SAS as the balloon appears to be incapable of consistently stretching the fibrous tissue ring. This technique is most useful in animals with valvular aortic stenosis. Some veterinarians are investigating the role of cutting balloons or high-pressure balloons for management of SAS.

Atenolol or other beta-adrenergic blocking drugs have been used to reduce the myocardial oxygen demand and diminish the risk of arrhythmic death, and although not proven to be effective their use is probably indicated in dogs with severe stenosis or ventricular arrhythmias. A recent clinical retrospective study failed to show any benefit from the use of beta-blockers in dogs with SAS. Positive inotropes (i.e. digitalis, dobutamine) may exacerbate dysfunction associated with subvalvular stenosis and increase myocardial oxygen demand and vasodilators may cause hypotension, therefore both types of drugs are generally contraindicated. Aortic stenosis may predispose dogs to aortic valve endocarditis, therefore prophylactic antibiotics (i.e., penicillin for dental procedures, ampicillin and gentamicin for genitourinary or gastrointestinal surgery) are indicated for procedures associated with bacteremia. Cats with aortic stenosis frequently develop heart failure or sudden death, and many die before one year of age.

Ventricular Septal Defect - Cats, Horses, Cattle, Alpaca, Sheep, Goats, Dogs, pocket pets





A ventricular septal defect (VSD) results from malformation of the interventricular septum and allows communication between the left and right ventricles. The VSD may occur anywhere in the interventricular septum, although the most common site is high, in the membranous portion of the septum below the aortic valve, under the septal tricuspid leaflet. VSD may occur alone or in combination with other congenital defects, such as tetralogy of Fallot or the endocardial cushion defect.

In most circumstances, the left ventricular systolic pressure exceeds that of the right, producing a left-to-right shunt. Because most VSDs are located high in the ventricular septum, the shunted blood is ejected directly into the right ventricular outflow tract. This results in overcirculation of blood in the pulmonary vasculature, left atrium, and left ventricle with minimal hypertrophy of the right ventricle. The left ventricle hypertrophies eccentrically to accommodate the volume overload. Dogs with large VSDs and heart failure usually develop pulmonary edema, while cats are more prone to the development of biventricular failure with pulmonary edema, pleural effusion, and less frequently ascites. In some animals, the missing septal tissue may include the supporting structure for one of the aortic valve leaflets, leading to aortic insufficiency and deleterious additional volume overload to the left ventricle.

Ventricular septal defect is one of the most common congenital heart defects in cats, occurring either as an isolated defect or as a component of the endocardial cushion defect. While VSD is also a common canine congenital cardiac defect, the only breeds thought to be at increased risk are keeshonds and English bulldogs. VSD may be seen in association with microphthalmia in dogs and calves. VSD is the most common congenital cardiac defect in horse, cattle, and sheep. Small VSDs usually result in minimal hemodynamic changes and animals remain asymptomatic, therefore clinical signs are usually observed only in animals with large defects. Presenting complaints with left-to-right VSD include weakness, coughing, and respiratory distress.

The typical cardiac murmur is a harsh, holosystolic murmur ausculted loudest at the right cranial sternal border. The murmur is quite variable in character and may be described as plateau, crescendo, or crescendo-decrescendo. Other murmurs may be present, including a flow murmur of relative pulmonic stenosis. Animals with endocardial cushion defect may also have murmurs of mitral or tricuspid insufficiency, and if VSD is complicated by aortic insufficiency, a diastolic murmur may be ausculted. Arterial pulses are usually normal, but tend to be brisk with large defects and weak with congestive heart failure. Jugular venous distention or pulsation are usually absent unless VSD is complicated by pulmonary hypertension or biventricular failure.

Thoracic radiographs are often normal or may demonstrate left atrial and ventricular enlargement, pulmonary overcirculation or edema, and variable right ventricular enlargement. The ECG is normal with small VSDs, while animals with larger defects may have ECG evidence of left atrial or ventricular enlargement, conduction disturbances such as right bundle branch block, or ventricular or supraventricular arrhythmias.

Typical echocardiographic findings include left atrial enlargement and a hyperdynamic, dilated left ventricle. When the VSD is large enough (usually 0.5-1 cm or greater) it can be visualized as an echolucent region in the ventricular septum, usually just below the aortic valve. Color-flow Doppler studies can easily identify blood flow through the defect and can be used to confirm and identify the direction of blood flow through the defect.

Selective cardiac catheterization is useful to confirm the diagnosis, demonstrate the direction of shunting, and to establish the functional integrity of the aortic valve. Oximetry data, obtained

during cardiac catheterization, can be used to calculate the magnitude of the shunt. The size of the shunt is usually expressed as a ratio of the blood flowing through the pulmonary and systemic circulations. If the flow through the pulmonary circuit is greater than or equal to 2.5 times the systemic circulation, the animal is at risk of developing pulmonary vascular disease (hypertension) or heart failure, and surgical therapy is recommended.

Animals who are asymptomatic, have minimal cardiomegaly and no evidence of congestive heart failure, or who have pulmonary blood flow less than 2 times the systemic flow, probably do not require surgical therapy. Those that have clinical signs of failure may respond well to medical therapy. Surgical therapy should be considered if clinical signs are present or if shunt flow is great. Anatomic closure of a VSD requires open-heart-surgery which is possible at Tufts but is not feasible at most institutions because of the cost of maintaining needed equipment and personnel. Pulmonary artery banding, a palliative technique, increases pulmonary vascular resistance, decreasing the magnitude of the left-to-right shunt. If the pulmonary artery band is applied too tightly, or if the animal outgrows the band, then right-to-left shunting may result. There may be a new catheter-based device that can be used to occlude VSD in the future – the current devices "trap open" the aortic or tricuspid valve for most animals with VSD.

Dogs and cats with small defects remain asymptomatic and spontaneous closure of the defect may occur during the first 2 years of life. Animals with large defects often develop signs of congestive heart failure during the first 18 months of life. Affected and related animals should be restrained from breeding.

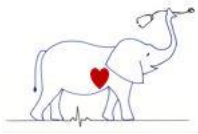
Atrial Septal Defect - Cats, Dogs, Horses, Cattle, Llama, Alpaca

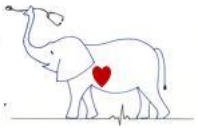
Malformation of the atrial septum permits abnormal blood flow between the left and right atria. The ostium primum defect results from failure of formation of atrial tissue low in the atrial septum (low ASD). Ostium primum defects are limited ventrally by the ventricular septum or annulus of the atrioventricular valves. The ostium secundum defect (high ASD) is located in the middle of the atrial septum and results from failure of normal septation at the site of the fossa ovalis. Isolated atrial septal defects are uncommon in dogs and cats, but may be observed more frequently in association with other congenital heart defects such as endocardial cushion defect, pulmonic stenosis, and tricuspid dysplasia.

The ostium primum and the ostium secundum defects have similar pathophysiologic consequences. Normally, left atrial pressures exceed right atrial pressures and blood is shunted from the left atrium, through the defect, to the right atrium. Blood flow is increased through the circuit formed by the right atrium, right ventricle, pulmonary vasculature, and left atrium. Animals with small defects are unlikely to develop clinical signs. The magnitude of the shunt depends on the size of the defect and the diastolic compliance of each ventricle. Because ASD places a volume overload on the right heart, large defects result in right atrial and ventricular dilation. Accompanying pulmonic stenosis, tricuspid dysplasia, or right ventricular failure may produce elevation of the right atrial pressure and cause reverse shunting through the defect. ASD is also observed as a component of the endocardial cushion defect.

Predisposed breeds boxers, Samoyeds, Doberman pinschers, and old English sheep dogs. Large defects may result in exercise intolerance, respiratory distress, or syncope and may predispose animals to lower respiratory tract infections.

There is no murmur generated by the flow of blood through an atrial septal defect. Abnormal auscultatory findings can include a systolic murmur of relative pulmonic stenosis, relative tricuspid stenosis (a low intensity, rumbling diastolic murmur) and fixed splitting of the second heart sound.





Thoracic radiographs are usually normal with small, isolated ASD, while larger defects are associated with enlargement of the right atrium and ventricle, pulmonary overcirculation, and variable degrees of left atrial enlargement. The electrocardiogram is usually normal, although a right ventricular enlargement pattern may occur in large shunts. The most useful non-invasive diagnostic technique for ASD is echocardiography. If the defect is sufficiently large, an echolucent space will be visualized in the atrial septum. Contrast or Doppler echocardiography may be useful in documenting right-to-left or bidirectional blood flow across the atrial septum.

Cardiac catheterization (oximetry data) will document the presence, direction, and magnitude of shunt flow, while selective angiographic studies from pulmonary arterial injections or after passage of the catheter through the defect will also demonstrate the ASD and the direction of blood flow. Most dogs with ASD remain asymptomatic and, due to the lack of a loud murmur, some probably go unrecognized. Animals with very large defects may develop heart failure within the first few years of life and can be managed with medical therapy. Surgical correction of the ASD usually requires cardiopulmonary bypass techniques. There is a catheter-based technique available to close an ASD (Amplatz ASD device). When ASD is present in association with other defects, the degree of hemodynamic disturbance caused by the combination of the two defects will determine the clinical course.

Atrioventricular Valve Malformations - Cats, Dogs, Horses

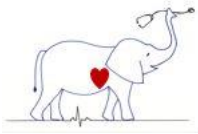
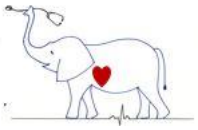
Congenital mitral and tricuspid malformations may result in insufficiency, stenosis, or both. Atrioventricular valvular insufficiency is the most common sequela to malformation. Valve leaflets may be thickened or fused and abnormal (short and thick or long and thin) chordae tendineae may be observed. In addition the papillary muscles may be malpositioned, incompletely developed, or absent, and malpositioning of the papillary muscles or valves on the ventricular wall has been frequently described.

Atrioventricular valvular insufficiency places a volume overload (with resulting eccentric hypertrophy) on the affected ventricle. With each beat, the ventricle must eject blood forward through the semilunar valve in addition to the volume of blood ejected backwards through the malformed atrioventricular valve. In mitral valve malformation, left ventricle and left atrial enlargement occur and left ventricular failure (pulmonary edema) may result. Tricuspid dysplasia causes right ventricular eccentric hypertrophy, often dramatic increases in right atrial size, and can result in right heart failure (ascites and/or pleural effusion, etc.).

Animals with atrioventricular valve stenosis have impaired ventricular filling, with the potential for elevations in atrial pressures and congestive heart failure. Severe atrial dilation can result from either valvular insufficiency or stenosis, predisposing to atrial arrhythmias. Atrial tachyarrhythmias, which shorten diastole and the time available for ventricular filling, are particularly detrimental to animals with atrioventricular valve stenosis.

Mitral and tricuspid valve dysplasia have been suggested as the most common congenital cardiac defect in the cat. Large breed dogs, especially the Great Dane, German shepherd, Labrador retriever and Weimaraner may be predisposed to atrioventricular valve dysplasia. The defect is genetically determined in the Labrador retriever.

Dogs with atrioventricular valve dysplasia often develop clinical signs at an early age, including weight loss, exercise intolerance, dyspnea, or coughing. Tricuspid dysplasia may lead to abdominal distention from ascites or dyspnea from pleural effusion. Episodic weakness or syncope may result from cardiac arrhythmias with disease of either valve. While some cats are severely affected at a young age, a few cats live for many years with no evidence of cardiac

dysfunction. These cats likely have less severe malformations, and it is likely that some adult cats with mitral valve murmurs actually have congenital mitral valve malformation. Cats with mitral valve malformation may develop pulmonary edema or bi-ventricular failure as well as systemic arterial embolism.

Physical examination usually reveals a pansystolic murmur over the affected valve. Animals with mitral dysplasia have typical left apical regurgitant quality murmurs that may radiate dorsally toward the mitral valve. Dyspnea, tachypnea, and pulmonary crackles are present in animals with congestive heart failure. In dogs with tricuspid dysplasia, the murmur is loudest on the right hemithorax over the third to fifth intercostal space. Jugular distention and/or pulsations, as well as hepatomegaly and/or ascites, are frequently observed.

Animals with mitral insufficiency have radiographic evidence of left atrial and ventricular enlargement, and when heart failure occurs pulmonary venous distention and pulmonary edema in dogs; cats tend to develop biventricular failure. Electrocardiographic findings may include P-mitrale, left ventricular enlargement pattern, and supraventricular arrhythmias. The abnormal morphology of the mitral valve leaflets, chordae tendineae, papillary muscles, or left atrial and ventricular enlargement may be appreciated with echocardiography. Cardiac angiography or Doppler studies are employed to document AV valvular regurgitation.

Tricuspid dysplasia results in right ventricular enlargement and may cause severe right atrial enlargement, enlarged caudal vena cava, hepatomegaly, ascites, and pleural effusion. The ECG frequently demonstrates right ventricular and/or right atrial enlargement patterns in dogs. The abnormal tricuspid valve apparatus as well as right atrial and right ventricular enlargement can often be visualized by 2-dimensional echocardiography. Cardiac catheterization will reveal normal oximetry, elevated right atrial pressures, and tricuspid regurgitation on selective right ventricular angiography.

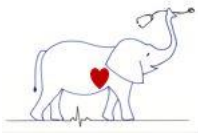
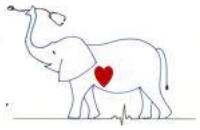
Animals with atrioventricular valve malformations are usually managed with medical therapy alone. Arterial vasodilators may be particularly helpful in mitral dysplasia where they are thought to reduce the degree of mitral regurgitation and increase forward blood flow. Digitalis is usually employed in animals that are refractory to diuretics and vasodilators, who appear to have diminished myocardial function by echocardiography, or who have atrial tachyarrhythmias. Additional antiarrhythmics should be employed as needed. In selected cases, mitral or tricuspid valve replacement can be performed but this requires the use of cardiopulmonary bypass.

The prognosis for animals with congestive failure is very guarded, although some animals can be effectively managed with medical therapy. In spite of this, the disease is usually progressive and survival greater than a few years in uncommon unless surgery is performed

RIGHT-TO-LEFT SHUNTING LESIONS, USUALLY ASSOCIATED WITH CYANOSIS

Tetralogy Of Fallot - Cats, Dogs, Horses

Tetralogy of Fallot (TF) is defined as a cardiac defect with four pathologic findings: 1) pulmonic stenosis, 2) a high ventricular septal defect, 3) dextroposition of the aorta such that it overrides the interventricular septum, and 4) secondary right ventricular hypertrophy. A genetic predisposition for a spectrum of conotruncal abnormalities, including tetralogy of Fallot, has been documented in the keeshond breed. The English bulldog is also predisposed. Tetralogy of Fallot is also a relatively common defect in the cat and the horse.

The obstruction to pulmonary outflow forces the right ventricle to develop increased systolic pressures. Blood typically shunts from right-to-left at the level of the ventricular septal defect and in addition, the overriding aorta receives blood from both ventricles. Resultant arterial oxygen desaturation leads to cyanosis and increases in red blood cell mass.
Clinical signs usually result from arrhythmias, systemic hypoxemia, and/or complications of polycythemia. Hypoxemia results in exercise intolerance, dyspnea, syncope, and can cause stunting. Most animals are cyanotic at the time of examination, and the cyanosis may worsen with exercise or excitement. Polycythemia can produce hyperviscosity and red blood cell sludging in small vessels and may lead to cerebrovascular accident. An additional sequela of tetralogy of Fallot is systemic embolism because thrombi, normally filtered by the lungs, freely cross the VSD to the systemic circulation. Congestive heart failure is uncommon.

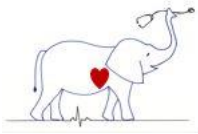
A murmur of pulmonic stenosis is heard best at the left base, and a second murmur (ventricular septal defect), is loudest at the right cranial sternal border. The murmurs may be attenuated in animals with polycythemia, severe pulmonic stenosis, or minimal blood flow through the VSD.

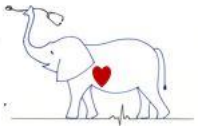
Thoracic radiographs may demonstrate right ventricular hypertrophy, but it is stressed that some animals with tetralogy of Fallot have nearly normal cardiac size radiographically. Pulmonary under-circulation, evident by decreased vascular markings and a post-stenotic dilatation of main pulmonary artery may be observed. In other animals, the main pulmonary artery remains small, compatible with pulmonary under-circulation. Evidence of right ventricular failure (pleural effusion, ascites) is typically absent. Most cyanotic animals with TF have ECG evidence of right ventricular enlargement. Polycythemia is a common finding in animals with TF and the hematocrit may rise above 75% in some animals. Blood gas analysis or pulse oximetry documents hypoxemia.

The echocardiogram can be very useful in documenting tetralogy of Fallot. The ventricular septal defect is typically evident high on the septum, just below the aortic valve; right ventricular hypertrophy and abnormalities in the pulmonic valve or pulmonary outflow tract may also be imaged. Dextroposition of the aorta can be clearly appreciated in some cases. Contrast echocardiography will demonstrate right-to-left blood flow across the VSD with the appearance of microbubbles in the ascending aorta. Cardiac catheterization is required in some animals to rule out Eisenmenger's syndrome (pulmonary hypertension) and other complex cardiovascular malformations. Cardiac catheterization is definitely indicated if surgical therapy is contemplated.

Animals who are not cyanotic and who have mild pulmonic stenosis may be managed conservatively with low-dose aspirin therapy to reduce the likelihood of venous-to-arterial thromboembolism. Periodic phlebotomy or hydroxyurea can be used in polycythemic animals to maintain a hematocrit near 60%. Non-selective beta-blocking drugs (i.e., propranolol) are advocated to decrease heart rate and myocardial contractility. The latter may diminish additional pulmonary outflow obstruction posed by infundibular hypertrophy. These drugs also increase systemic vascular resistance which decreases right-to-left shunting.

Surgical therapy is indicated in most cyanotic animals. Complete surgical correction is difficult and requires cardiopulmonary bypass. However, several palliative surgical procedures appear to be useful, and involve anastomosis of a systemic artery (either aorta {Pott's procedure} or subclavian artery {Blalock-Taussig procedure}) to the pulmonary artery thereby increasing pulmonary blood flow. Animals undergoing successful surgical palliative procedures may remain comfortable for several years. Cyanotic animals with clinical signs of disease who do not have surgery have a very guarded to poor prognosis, with most dying by 2-4 years of age.





VSD with pulmonary hypertension (Right-to-left VSD) – Dogs

If the VSD is very large, the ventricular systolic pressures tend to equilibrate, right ventricular hypertrophy ensues, and the pulmonary vasculature is subjected to high pressures and increased blood volume which may contribute to the development of pulmonary hypertension. If the right ventricular pressure equals or exceeds the pressure in the left ventricle, then bi-directional blood flow or right-to-left shunting will occur. Pulmonary hypertension with a right-to-left shunting VSD is called Eisenmenger's syndrome and is an example of Eisenmenger's physiology. Blood flowing from right-to-left results in systemic arterial oxygen desaturation, cyanosis, and polycythemia.

Clinical signs are similar to those with Tetralogy of Fallot and include cyanosis, exercise intolerance, weakness, syncope, and neurologic abnormalities (i.e. depression, focal neurologic deficits, or seizures) may result from cerebrovascular accidents or brain abscess caused by paradoxical embolism (venous thrombi or bacteria not filtered by the lung), or from severe polycythemia.

In animals with a right-to-left or bidirectional shunting VSD, the murmur may be soft or absent and the second heart sound may be loud and/or split. Cyanosis is usually present in cases of right-to-left shunting and may be exacerbated with exercise.

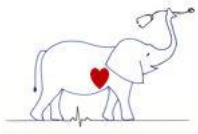
Right ventricular enlargement with enlarged, tortuous pulmonary arteries is a common radiographic finding in animals with pulmonary hypertension and right-to-left shunting. ECG criteria for right ventricular enlargement are usually present. Contrast echocardiography (bubble study) can be performed, using intravenous saline injection, to demonstrate bi-direction or right-to-left shunting.

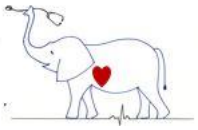
Therapeutic options in animals with right-to-left shunts are limited to exercise restriction, periodic phlebotomy to keep the hematocrit below 60% if neurologic signs are manifested, and antithrombotic therapy (clopidogrel, aspirin) to reduce the risk of systemic thromboembolism. Surgical therapy is not indicated for dogs with pulmonary hypertension and right-to-left shunting. Those patients with pulmonary hypertension and right-to-left shunting have a poor prognosis for long-term survival. Sildenafil has been used with success in selected cases to reduce pulmonary hypertension and limit right-to-left shunting.

PDA with pulmonary hypertension (Right-to-Left PDA) – Dogs

If the high pulmonary vascular resistance present in the fetus fails to regress, or if pulmonary arteries develop muscular hypertrophy in response to voluminous, high pressure blood flow through the pulmonary vasculature, pulmonary hypertension will result, leading to bi-directional or right-to-left shunting through the ductus. Right-to-left PDA often causes differential cyanosis; the head is supplied with oxygenated blood but the aorta, distal to the site of the ductus, carries oxygen desaturated venous blood. Pulmonary hypertension stresses the right ventricle (pressure overload = concentric hypertrophy) and may cause right heart failure.

The murmur is attenuated and the diastolic component of the murmur is absent. A loud second heart sound may be heard at the left base. The ECG often demonstrates a right ventricular enlargement pattern and thoracic radiographs document biventricular enlargement. The triad of bumps may be replaced by an aneurysmal dilation in the descending aorta and





dilated or tortuous pulmonary arteries. The lung fields appear hypovascular and right ventricular hypertrophy is evident on echocardiographic examination.

Surgical ligation of the ductus in right-to-left shunting PDA is contraindicated. The ductus provides a "pop-off valve" and ligation of the ductus may lead to fatal increases in pulmonary arterial pressure.

Animals with right-to-left PDA may live comfortably for several months to a few years before developing clinical signs of weakness, right heart failure, respiratory difficulties, or arterial thromboembolism. Sildenafil has been used with success in selected cases to reduce pulmonary hypertension and limit right-to-left shunting.

ASD with pulmonary hypertension (Right-to-left ASD)

ASD in combination with pulmonic stenosis, tricuspid dysplasia, or right ventricular failure may produce elevation of the right atrial pressure and lead to reversal of the direction of the shunt. As deoxygenated blood flows from the right atrium to the left atrium, systemic arterial oxygen desaturation results. In contrast to VSD and PDA, atrial septal defects rarely result in obstructive pulmonary vascular disease and pulmonary hypertension in dogs and cats. When ASD is present in combination with conditions that produce right-to-left shunting, cyanosis, weakness, and arterial thromboembolism may be observed.

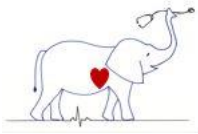
ADDITIONAL CARDIOVASCULAR DEFECTS

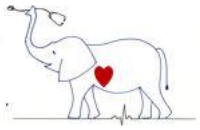
Many other congenital defects have been reported in domestic animals. Some of these defects are combinations or variations of the above described cardiovascular malformations, others involve malposition of the great vessels or failure in development of cardiac chambers. These defects are frequently referred to as complex congenital defects. It is likely that many complex congenital cardiac defects in animals are lethal within the first few hours of life and go unrecognized. In addition to combinations of the above defects, a few other malformations of the heart and great vessels are observed.

A large number of vascular ring anomalies have been reported in dogs and cats. Vascular ring anomalies result from abnormal embryologic development of the aortic arches. Persistent right fourth aortic arch is the most common in the dog and is seen most frequently in German shepherds and Irish setters. The esophagus becomes trapped by the base of the heart, the abnormally formed aorta (from the right 4th arch instead of the left), the pulmonary artery, and the ductus arteriosus, which can be patent in some cases. Associated clinical signs are referable to the gastrointestinal tract and include regurgitation, usually in 3 to 8 week old dogs as the start to eat solid foods. Surgery is indicated and may be curative if the esophagus is not markedly enlarged at the time of surgery.

Peritoneopericardial diaphragmatic hernias are reported in dogs and cats. Abdominal organs herniated into the pericardial sac include the stomach, liver, gall bladder, spleen, omentum, and small intestines. Animals can present for gastrointestinal disturbances, collapse, or respiratory signs. CHF is uncommon. Surgical therapy is usually curative.

Additional infrequently observed defects include coarctation of the aorta and ectopic cordis (calf), Cor Triatriatum Sinister in the cat and Cor Triatriatum Dexter in the dog.





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