Diagnosis of Cardiac Disease in Avian Species

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Antemortem diagnosis of cardiac disease in avian patients pose a challenge for the clinician. A number of anatomical and physiological features unique to birds can impede assessment of the cardiovascular system. A paucity of reference data for the majority of bird species further complicates diagnosis of cardiac dysfunction. This paper discusses the detection and assessment of cardiac disease in birds, highlighting the uses and limitations of diagnostic tests in the clinical situation.

The avian heart is anatomically similar to mammals, although birds have a proportionally larger heart size relative to a comparably sized mammal (King and McLelland, 1984). Heart size in mammals remains equivalent to body mass, while larger birds have a proportionally smaller hearts in relation to body size than smaller birds (Smith et al., 2000). The size of the heart in birds can vary according to activity levels, with an increase in heart mass associated with migration in barnacle geese (Smith et al., 2000). The apex of the heart is enclosed between the right and left hepatic lobes and lies along the sternum and parallel to the thoracic spine in the cranioventral coelom. Unlike mammals, the ascending aorta in birds curves to the right (King and McLelland, 1984).

The avian cardiovascular system is highly adapted to the high aerobic requirements for flight, running or swimming (Butler et al., 2000). Efficient oxygen transfer to the tissues is facilitated by a lower total peripheral resistance, higher heart rate, higher arterial blood pressure and more rapid myocardial depolarisation (Smith et al., 2000). Improved electrical conduction in the avian heart is achieved by an increased surface area from a smaller myocyte diameter and a lack of M band and transverse tubules (Smith et al., 2000).

The clinical signs seen in birds afflicted with cardiac disease can be vague and non-specific, mimicking many other conditions. Similar to mammals, birds may present with lethargy, weakness, exercise intolerance, syncope, dyspnoea, coughing and even sudden death (Lumeij et al., 1994; Rosenthal et al., 1997; Strunk and Wilson, 2003). On physical examination cardiac disease may be suspected based on the presence of arrhythmia, murmur, muffled cardiac sounds, poor peripheral pulses, cyanosis and coelomic distension ((Lumeij et al., 1994; Rosenthal et al., 1997; Strunk and Wilson, 2003). Pulmonary oedema, hepatomegaly, ascites and enlarged jugular veins with pulsation may be seen in cases of congestive cardiac failure ((Lumeij et al., 1994; Oglesbee and Lehmkul, 2001; Strunk and Wilson, 2003; Pees et al., 2006a; Pees et al., 2006b; Knafo et al., 2011). Central neurological signs have been described in cases of cardiovascular disease due to reduced cerebral perfusion (Rosenthal et al., 1997; Bavelaar and Beynen, 2004). Intermittent paresis secondary to hindlimb hypoperfusion has been documented in an Amazon Parrot with atherosclerosis (Beaufrere et al., 2001).

Pericarditis can occur with primary infectious agents or secondary to disease occurring in adjacent tissues, such as mycotic pulmonary granulomas (Lumeij et al., 1994; Pees et al., 2006a). Visceral gout due to hyperuricaemia may also affect the pericardium (Lumeij et al., 1994; Pees et al., 2006a).

Congestive heart failure and systemic manifestations of disease, such as hypoproteinaemia, may result in effusions within the pericardium (Lumeij et al., 1994; Pees et al., 2006a). Haemopericardium has been documented following trauma (Lumeij et al., 1994).

Cardiomyopathies arise from similar mechanisms to those that occur in mammals. Myocardial ventricular hypertrophy can occur with any condition that results in an elevated preload on the heart, including pulmonary hypertension and atherosclerosis. The myocardium may also be directly affected by infectious agents, toxins, nutrition, drugs, neoplasia and degenerative processes (Lumeij et al., 1994; Strunk and Wilson, 2003; Pees et al., 2006a). Myocarditis has been observed in cases of chlamydiosis (Lumeij et al., 1994), polyomavirus infection(Lumeij et al., 1994) and proventricular dilatation disease (PDD) from bornavirus (Vice, 1992; Rinder wet al., 2009). Heavy metal toxicosis has been associated with cardiac neural dysfunction and myocardial infarction (Lumeij et al., 1994). Myocardial dilation and dysfunction can be idiopathic or follow valvular insufficiency of any aetiology (Rosenthal and Stamoulis, 1993; Lumeij et al., 1994; Oglesbee and Lehmkul, 2001). Vegetative endocarditis and resultant valvular insufficiency can occur with bacteraemia from chronic bacterial infections involving other organ systems (Isaza et al., 1992; Pees et al., 2006a). Other primary cardiac diseases that have been documented in birds include congenital defects, such as ventricular septal defect(VSD) (Harari and Miler, 1983; Bailey and Kinne, 2001; Evans et al., 2001). Cardiac dysfunction can occur secondarily to hypovolaemic, septic and neurogenic shock (Pees et al, 2006a).

Antemortem diagnosis of cardiac disease in avian patients can be challenging and one of the greatest limitations with the majority of diagnostic tests is the lack of available reference ranges for many species. Accurate diagnosis is important in order to define prognosis and treatment plans. Studies in canine and feline cardiac patients have shown that owner's perceive the quality of life of their pet to be a higher priority than longevity (Reynolds et al., 2010). Adequate palliative care in cases of terminal cardiac disease is therefore important and should be considered a high priority in avian patients.

Physical Examination

Indications

- All patients!
- Suspected cardiac disease based on signalment, history and clinical signs.
- Amazon parrots, African grey parrots, macaws and cockatoos in particular appear predisposed to the development of atherosclerosis (Bavelaar and Beynen, 2004; Pees et al., 2006b).

Method

- The physical exam should be performed in a quiet room and in a calm manner.
- The patient should be examined at rest initially, particularly for evidence of dyspnoea or weakness.
- Birds with cardiac disease can decompensate dramatically and rapidly during handling.
- A full examination may not be possible at one time but should include all organ systems to help detect a primary aetiology.
- Specific examination of the cardiovascular system must include:
    - Thoracic auscultation from the lateral and ventral aspects of the sternum

        - Murmurs
        - Arrhythmias
        - Tachycardia, bradycardia
        - Muffled cardiac sounds
        - Pulmonary rales
    - Peripheral pulse palpation
        - Femoral artery
        - Brachial artery
    - Coelomic palpation
        - Ascites
        - Hepatomegaly
    - Assessment of venous return
        - Jugular distention
        - Jugular pulsation
        - Poor CRT (using the ulnar or jugular vein)
    - Peripheral perfusion
        - Cyanosis of the feet, mucous membranes and facial skin (in species with this feature)
        - Pallor suggesting anaemia

Limitations

- The patient's level of debility is often a limiting factor.
- Identification of clinical features consistent with cardiac dysfunction ultimately requires further investigation in order to achieve an accurate cardiac evaluation.

Ancillary Tests - Haematology, Biochemistry, Virology, Chlamydia

Indications

- Detect infectious or inflammatory causes through haematology and specific infectious disease screening (Chlamydia, virology).
- Supportive evidence for cardiac disease (Strunk and Wilson, 2003):
    - Cardiac myocyte damage can result in elevations in plasma creatine kinase (CK).
    - Hypercholesterolaemia may be detected concurrently in cases of atherosclerosis.
    - Elevations in hepatic enzymes may occur secondary to hepatic congestion with heart failure.
    - Hypoproteinaemia secondary to effusions.
    - Hyperuricaemia may be seen with visceral gout.

Method

- Venipuncture should be performed with caution in birds with cardiac dysfunction.
- The jugular vein should be avoided if evidence of distention and/or pulsation are seen.

Limitations

- While the primary cause may be identified, the exact mechanism of cardiac dysfunction can only be assumed. Further diagnostic testing is required.
- Restraint or anaesthesia for venipuncture may be contra-indicated in unstable, debilitated patients.

Abdominocentesis

Indications

- Coelomic effusion

Method (Campbell, 1998)

- The skin is prepared aseptically as per surgical preparation.
- Needle enters the coelom in the midline, caudal to the sternum. Care must be taken to avoid the air sacs. Abdominocentesis may be guided by ultrasound.
- Evaluation and categorisation of the effusion with standard techniques.

Limitations

- A transudate may support a diagnosis of cardiac failure, although transudates from cardiac origin will be indistinguishable from those caused by hepatic failure or disease processes resulting in systemic hypoproteinaemia (Campbell, 1998).

Blood Pressure Measurement

Indications

- Adjunctive assessment of the cardiovascular system in cardiac disease
- Diagnosis of hypovolaemic shock
- Monitoring during anaesthesia

Method

- Catheterisation of the arterial system and connection to an electronic transducer is the gold standard in blood pressure measurement.
- Indirect methods that have been utilised in avian medicine include doppler ultrasonic flow detector and ultrasound.

Limitations

- Recent studies have shown poor reproducibility of results with indirect methods (Johnston et al., 2011).
- Direct arterial measurement is unlikely to be achievable in the clinical setting.

Radiography

Indications

- Detection of:
  - Cardiomegaly
  - Pulmonary oedema or congestion
  - Ascites
  - Atherosclerosis of the great vessels
  - Hepatomegally
- The presence of concurrent or primary diseases may be detected during radiographic examination. This may include evidence of:
  - Heavy metal toxicosis
  - Organomegaly
  - Neoplastic masses
  - Granuloma (mycotic, bacterial or mycobacterial organisms)

Method

- While not pathognomonic, radiopaque particles can be detected in a minimally restrained, conscious patient to support a diagnosis of heavy metal toxicosis. The absence of radio-opacities in the gastrointestinal tract does not exclude a diagnosis of heavy metal toxicosis.
- In order to accurately assess the cardiovascular system via radiography, a well-positioned, anaesthetised patient is advisable. Performing radiography at a standard stage of anaesthesia can minimise any changes that may occur with anaesthesia.
- A ventrodorsal and both lateral projections should be obtained.
- Cardiac measurement (Hanley et al., 1997; Pees et al., 2006a; Rettmer et al., 2011):
  - The level of the greatest cardiac width is compared with the maximum thoracic width on a ventrodorsal projection.
  - Normal cardiac silhouette widths have been reported as 51-61% of the thorax.

Limitations

- An enlarged cardiac silhouette may be seen radiographically, although pericardial effusion may be difficult to distinguish from true cardiomegaly.
- When assessing cardiac size, the length of the heart is often difficult to measure due to superimposition with the hepatic silhouette (Pees et al., 2006a).
- The presence of ascites limits assessment of the coelomic cavity and in severe cases, also the cardiac silhouette and pulmonary regions.
- Reference ranges for normal radiographic cardiac size do not exist for the vast majority of avian species. Recent studies have been reported in the Spix's Macaw (Rettmer et al., 2011), Harris' Hawks, peregrine falcon, saker falcon, and lanner falcon (Barbon et al., 2010) , and screech owls , red-tailed hawks and Canada geese (Hanley et al., 1997).
- Accurate radiographic evaluation requires a properly positioned patient. Restraint devices are possible to use in small or severely debilitated birds, although anaesthesia is required in most cases. Patients with cardiac disease are undesirable

anaesthetic candidates and stabilisation of debilitated animals must be considered prior to anaesthesia.

Ultrasonography

Indications

- Cardiac evaluation:
  - Pericardium and pericardial fluid; assistance with pericardiocentesis
  - Valve morphology and function
  - Myocardial thickness and function
  - Atherosclerosis
  - Pulmonary hypertension
  - Congenital malformations, such as ventricular septal defects, pulmonary and aortic stenosis
- Coelomic effusion; assistance with abdominocentesis
- Hepatomegaly
- Coelomic masses

Method

- The patient may be conscious or anaesthetised and ideally held in a vertical position
- Features required for avian echocardiography (Strunk and Wilson, 2003; Pees et al., 2006a):
  - Small footprint probe and possible use of a standoff pad
  - High frequency transducer with a minimum frequency of 7.5 MHz
  - Minimum 100 frames/second
  - Doppler function, which is useful in assessing arterial flow, peripheral perfusion and indirect blood pressure measurement
- Approaches to the heart:
  - Ventromedial and caudal to the sternum, via the homogenous texture of the liver (Krautwald-Junghanns et al., 1994, 1995);
  - Right lateral parasternal region, caudal to the last rib (Strunk and Wilson, 2003)
  - Transoesophageal (Beaufrere et al., 2010).
- Visualisation of the heart
  - Two dimensional images can only be achieved from the standard ventromedian approach (Pees et al., 2006a).
- Measurements
  - Left ventricular length has been correlated with body mass and sternal length (LVL = 0.5 + 0.33 x sternal length). Sternal length can be measured with calipers or from radiographs (Pees et al., 2006a).
  - Fractional shortening (FS% = (diastole - systole)/diastole x 100)

Limitations

- The sternal bone significantly limits ultrasound access to the thoracic structures and can also create image artefacts

- Reverberation artefacts occur when gas is encountered by ultrasound waves (Doust, 2002). This is important to consider in avian species where the air sacs surround the internal organs within the coelom.
- Interference of the image with the gastrointestinal tract can occur. Fasting prior to ultrasound has been recommended
- Measurement of the atrial and right ventricular size are considered inaccurate (Pees et al., 2006a).
- Reference ranges exist for the domestic pigeon, some psittacine birds and some raptors (Pees et al., 2004; Pees et al., 2006a).

Electrocardiography (ECG)

Indications

- Diagnosis of primary cardiac disease
- Assessment of arrhythmias and abnormal rates (tachycardia, bradycardia) detected on auscultation
- Monitoring during anaesthesia

Method (Lumeij et al., 1994)

- Birds may be anaesthetised or conscious.
- Contact of lead to skin is achieved with alcohol or gel, using alligator clips or a combination of hypodermic needle and alligator clips.
- Various protocols for lead placement exist with the most commonly utilised being the right wing (RA), left wing (LA) and left leg (LL) (Lumeij et al., 1994).
- The paper speed should be at least 100mm/s to facilitate accurate recording of the rapid heart rates of birds.
- The mean electrical axis (MEA) is negative in birds, which contrasts with the positive MEA in mammals
- Recordings are primarily taken from the standard Lead II, as in mammals.

Limitations

- Lead placement can be difficult and artefacts in the tracing are possible, especially in conscious animals.
- Stressed animals with increased heart rates can make evaluation of the ECG difficult.
- While isoflurane anaesthesia can slow the heart rate and therefore make detection of abnormalities easier, it may also lead to an increased QT interval.
- Reference ranges exist for many raptors (Burtnick and Degernes, 2003; Talavera et al., 2008; Hassanpour et al., 2010), psittacine birds (Nap et al., 1992; Casares et al., 2000; Oglesbee et al., 2001), the pekin duck (Cinar et al., 1996), free living birds (Machida and Aohagi, 2001) and the domestic fowl (Sturkje, 1949).

Advanced Imaging - CT, MRI

Indications

- Advanced imaging has some merit in diagnosis of vascular disorders, such as atherosclerosis, which may be difficult to detect with more conventional methods, such as radiography and echocardiography (Beaufrere et al., 2010).
- May be useful in detecting structural defects and abnormalities of the heart, not visible in radiography or echocardiography.
- Functional assessment of the heart is limited, unless fluoroscopic MRI or CT are utilised.

Method

- Anaesthesia is vital to achieve adequate images.
- Standard algorithm in helical scan mode has been reported when using CT: 1.25mm slice thickness, 1.375 pitch, 100 kilovolt and 150 mA (Beaufrere et al., 2010).
- Angiography can be performed with CT using contrast agents, although thinner slices should be used.

Limitations

- The cost of these procedures can be limiting in the clinical situation and the value is questionable when other modalities are readily and more economically available.
- The availability of facilities with adequate resolution for avian patients.
- Anaesthesia is required for both imaging techniques and this can be particularly protracted during MRI. Birds with cardiac disease are undesirable anaesthetic candidates.
- Motion artefacts with MRI and the size of the patient limits the value of this method.
- Rapid circulatory rates in birds will mean contrast media used in angiography will be peak very quickly and may be missed during CT or MRI.
- References ranges are limited

Cardiac Biomarkers

Indications

- Cardiac assessment in human medicine relies heavily on biomarkers for diagnostic and prognostic purposes (Archer, 2003).
- The use of cardiac biomarkers in small mammal medicine is advancing and a number of commercial assays are readily available for canine and feline patients (Roland et al., 2009; Connolly, 2010; Fonfara et al., 2010).

Method

- Troponin I (cTnI) is part of a complex found within myocardial cells and is released following myocardial cell damage. In dogs cTnI levels begin to rise after 2 hours and peak in 12-24 hours (Fonfara et al., 2010). The severity of cardiac disease has been correlated with cTnI levels, while persistent elevations suggest irreversible myocardial damage (Fonfara et al., 2010).

- Brain natriuretic peptide (BNP) is a neuroendocrine hormone with a primary role in fluid homeostasis by increasing the glomerular filtration rate and inhibition of the renin-angiotensin-aldosterone system (Roland et al., 2009). It is found in myocardial tissue and released in response to atrial muscle stretch or injury. NT-proBNP is the metabolically inactive precursor to BNP and appears to be more suitable for analysis due to a longer half life in plasma (Roland et al., 2009).

Limitations

- There are no commercial avian biomarkers available, although they have been researched in laboratory settings (Hastings et al., 1991; Mifune et al., 1996).
- Troponin has been measured with mammalian assays in a case of congestive heart failure in a red-tailed hawk, although the significance of the results could not be determined (Knafo et al., 2011).
- NT-proBNP relies on renal excretion and may be elevated in non-cardiac disease, such as renal failure (Roland et al., 2009).

Angiography

Indications

- Detection and assessment of atherosclerosis
- Abnormalities of the vessels, including aneurysm, stenosis and congenital malformations
- Evaluation of cardiac lumen size and valve function

Method

- An anaesthetised patient receives intravenous iodinated contrast agent and serial radiographs, MRI, CT or fluoroscopy performed.
- Dose rates for nonionic iodinated contrast 2mg/kg IV given 1-2ml/kg/sec (Beaufrere et al., 2010).

Limitations

- The rapid heart rate of birds can make detection of abnormalities difficult.
- There are limited reports of normal reference ranges for avian species with regional vascular anatomy investigation with CT angiography in Hispaniolan Amazon parrots (Beaufrere et al., 2011) and flamingos (Holliday et al., 2006).
- This methodology has been used to identify an aneurysm in an umbrella cockatoo (Vink-Nooteboom et al., 1998) and ventricular dilation in a severe macaw (van Essen et al., 2012).

Endoscopy

Indications

- Detection of pericardial diseases, cardiac masses and assessment of the great vessels
- Primary or concurrent disease diagnosis
- Guided pericardiocentesis or cardiac muscle biopsy
- Guided pericardial biopsy and creation of a pericardial window

Method

- Interclavicular (thoracic inlet) approach has been described to visualise the heart base and great vessels (Beaufrere et al., 2010).
- Routine coelomic endoscopy via caudal thoracic air sac.

Limitations

- The requirement for anaesthesia will be contraindicated in many patients with cardiac disease.
- Perforation of the air sacs in the presence of ascites can lead to aspiration and death.
- Visualisation can be impaired using the interclavicular approach in overweight animals due to intracoelomic fat (Beaufrere et al., 2010).

Biopsy

Indications

- Diseases that may be diagnosed through cardiac biopsy include myocarditis and neoplasia. It is also used in human medicine to diagnosis cardiac transplant rejection (Wu et al., 2001).

Method

- Endoscopic cardiac biopsy via routine approaches may be possible.
- Endomyocardial biopsy via jugular, femoral or subclavian veins are commonly utilised in human medicine and have been reported in dogs and cats (van Essen et al., 2012). The small size of most avian patients is likely to limit the use of this technique.
- Transabdominal ultrasound guided serial cardiac biopsies has been recorded in feline medicine with no mortality (van Essen et al., 2012). Minor pericardial bleeding was observed in 50% of cases (van Essen et al., 2012).

Limitations

- There are no literature reports of cardiac biopsy in avian patients.

REFERENCES

Archer J. 2003. Cardiac biomarkers: a review. Comparative Clinical Pathology 12, 121-128.

Bailey T, Kinne J. 2001. Ventricular septal defect in a houbara bustard (*Chlamydotis undulata macqueenii*). Avian Diseases 45, 229-233.

Barbon AR, Smith SS, Forbes N. 2010. Radiographic evaluation of cardiac size in four Falconiform species. Journal of Avian Medicine and Surgery 24, 222-226.

Bavelaar FJ, Beynen AC. 2004. Atherosclerosis in parrots. A review. Veterinary Quarterly 26, 50-60.

Beaufrere H, Holder KA, Bauer R, Schnellbacher R, Pariaut R, Tully Jr TN, Wakamatsu N. 2001. Intermittent Claudication-like syndrome secondary to atherosclerosis in a yellow-naped amazon parrot (Amazona ochrocephala auropalliata). Journal of Avian Medicine and Surgery 25, 266-276.

Beaufrere H, Pariaut R, Rodriguez D, Tully TN. 2010. Avian vascular imaging: A review. Journal of Avian Medicine and Surgery 24, 174-184.

Beaufrère H, Rodriguez D, Pariaut R, Gaschen L, Schnellbacher R, Nevarez JG, Tully TN. 2011. Estimation of intrathoracic arterial diameter by means of computed tomographic angiography in Hispaniolan Amazon parrots. American Journal of Veterinary Research 72, 210-218.

Burtnick NL, Degernes LA. 2003. Electrocardiography on fifty-nine anaesthetised convalescing raptors. In: Redig PT, Cooper JE, Remple JB, Hunter DB, editors. *Raptor biomedicine.* Minneapolis, Minnesota, University of Minnesota Press. pp. 111-121.

Butler PJ, Bishop CM. 2000. Flight. In: Whittow GC, editor. *Sturkie's Avian Physiology*. 5th edition. San Diego: Academic Press; pp 391-435.

Campbell TW. 1998. Cytology of abdominal effusions. In: Campbell TW, editor. Avian hematology and cytology. Ames, Iowa: Iowa State University Press. pp. 41-44.

Casares M, Enders F, Montoya J. 2000. Comparative electrocardiography in four species of macaws (genera Anodorhynchus and Ara). Journal of Veterinary Medicine. A, Physiology, Pathology, Clinical Medicine 47,277-281.

Cinar A, Bagci C, Belge F, Uzun M. 1996. The electrocardiogram of the pekin duck. Avian Diseases 40, 919-923.

Connolly DJ. 2010. Natriuretic peptides: the feline experience. Veterinary Clinics of North America: Small Animal Practice 40, 559-570.

Doust WT. 2002. Basic Ultrasound Physics. In: Thrall DE, editor. *Veterinary Diagnostic Radiology*. 4th edition. Philadelphia: W.B Saunders, pp 20-27.

Evans DE, Tully TN, Strickland KN, Williams JF, Rich GA. 2001. Congenital cardiovascular anomalies, including ventricular septal defects in 2 cockatoos. Journal of Avian Medicine and Surgery 15, 101-106.

Fonfara S, Loureiro J, Swift S, James R, Cripps P, Dukes-McEwan J. 2010. Cardiac troponin I as a marker for severity and prognosis of cardiac disease in dogs. Veterinary Journal 184, 334-339.

Hanley CS, Murray HG, Torrey S, Pokras MA. 1997. Establishing cardiac measurement standards in three avian species. Journal of Avian Medicine and Surgery 11, 15-19.

Harari J, Miler D. 1983. Ventricular septal defect and bacterial endocarditis in a whistling swan. Journal of the American Veterinary Medical Association 183, 1296-1297.

Hassanpour H, Moghaddam AKZ, Bashi MC. 2000. The normal electrocardiogram of conscious golden eagles (Aquila chrysaetos). Journal of Zoo and Wildlife Medicine 41, 426-431.

Hastings KEM, Koppe RI, Marmor E, Bader D, Shimada Y, Toyota N. 1991. Structure and developmental expression of troponin I isoforms.The Journal of Biological Chemistry 266, 19659-19665.

Holliday CM, Ridgely RC, Balanoff AM, Witmer 2006. LM. Cephalic vascular anatomy in flamingos (Phoenicopterus ruber) based on novel vascular injection and computed tomographic imaging analyses. Anatomical Record Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology 288, 1031-1041.

Isaza R, Buergelt C, Kollias GV. 1992. Bacteriemia an vegetative endocarditis associated with a heart murmur in a blue and gold macaw. Avian Diseases; 36, 1112-1116.

Johnston MS, Davidowski LA, Rao S, Hill AE. 2011. Precision of repeated, doppler-derived indirect blood pressure measurements in conscious psittacine birds. Journal of Avian Medicine and Surgery 25, 83-90.

King AS, McLelland J. 1984. Cardiovascular system. In: *Birds-their Structure and Function*.2nd edition. East Sussex: Baillie`re Tindall. pp 214-228.

Knafo SM, Rapoport G, Williams J, Brainard B, Driskell E, Uhl E, Crochik S, Divers SJ. 2011. Cardiomyopathy and right-sided congestive heart failure in a red-tailed hawk (Buteo jamaicensis). Journal of Avian Medicine and Surgery 25: 32-39.

Krautwald-Junghanns ME, Enders F. 1994. Ultrasonography in birds. Seminars in Avian and Exotic Pet Medicine 3, 140-146.

Krautwald-Junghanns ME, Schulz M, Hagner D, Failing K, Redman Tl. Transcoelomic two-dimensional echocardiography in the avian patient. Journal of Avian Medicine and Surgery 1995; 9: 19-31.

Lichtenberger M. 2004. Principles of shock and fluid therapy in special species. Seminars in Avian and Exotic Pet Medicine 13, 142-153.

Lumeij J Ritchie B. Cardiology. 1994. In: Ritchie B, Harrison G, Harrison L, editors. *Avian medicine: Principles and applications.* Lake Worth, Florida; Wingers Publishing. pp 695-722.

Machida N, Aohagi Y. 2001. Electrocardiography, heart rates and heart weights of free-living birds. Journal of Zoo and Wildlife Medicine 32, 47-54.

Mifune H, Suzuki S, Nokihara K, Noda Y. 1996. Distribution of immunoreactive atrial and brain natriuretic peptides in the heart of the chicken, quail, snake and frog. Experimental Animals 45, 125-33.

Nap A, Lumeij, Stokhof. 1992. Electrocardiogram of the African grey (*Psittacus erithacus*) and Amazon (*Amazona* spp.) parrot. Avian Pathology 21, 45-53.

Oglesbee BL, Lehmkul L. 2001. Congestive heart failure associated with myxomatous degeneration of the left atrioventricular valve in a parakeet. Journal of Avian Medicine and Surgery 218, 376-380

Oglesbee B, Hamlin R, Klingaman H, Cianciola J, Hartman SP. 2001. Electrocardiographic reference values for Macaws (Ara species) and Cockatoos (Cacatua species). Journal of Avian Medicine and Surgery 15, 17-22.

Pees M, Straub J, Krautwald-Junghanns ME. 2004. Electrocardiographic examination of 60 African grey parrots and 30 other psittacine birds. Veterinary Record 155, 73-76.

Pees M, Krautwald-Junghanns ME, Straub J. 2006a. Evaluating and treating the cardiovascular system. In: Harrison GJ, Lightfoot TL, editors. *Clinical Avian Medicine.* Palm Beach, Florida; Spix Publishing. pp 379-394.

Pees M, Schmidt V, Coles B, Krautwald-Junghanns ME. 2006b. Diagnosis and long-term therapy of right-sided heart failure in a yellow crowned Amazon (Amazona ochrocephala). Veterinary Record 15, 445-447.

Phalen DN, Hays HB, Filippich LJ, Silverman S, Walker M. 1996. Heart failure in a macae with atherosclerosis of the aorta and brachiocephalic arteries. Journal of the American Veterinary Medical Association 209, 1435-1440.

Rettmer H, Deb A, Watson R, Hatt JM, Hammer S. 2011. Radiographic measurement of internal organs in Spix's macaws (Cyanopsitta spixii). Journal of Avian Medicine and Surgery 25, 254-258.

Reynolds CA, Oyama MA Rush JE, Rozanski EA, Singltary GE, Brown DC, Cunningham SM, Fox PR, Bond B, Adin DB, Williams RM, MacDonald KA, Malakoff R, Leeper MM, Scober KE, Petrie JP, Hogan DF. 2010. Perceptions of quality of life and priorities of owners of cats with heart disease. Journal of Veterinary Internal Medicine 24, 1421-1426.

Rinder M, Ackermann A, Kempf H, Kaspers B, Korbel R, Staeheli P. 2009. Broad tissue and cell trophism of avian bornavirus in parrots with proventricular dilatation disease. Journal of Virology 83, 5401-5407.

Roland RJ, van Kimmenade MD, Januzzi Jr, JL. 2009. The evolution of the natriuretic peptides - current applications in human and animal medicine. Journal of Veterinary Cardiology 11, 9-21.

Rosenthal K, Miller M, Orosz S, et al. 1997. Cardiovascular system. In: Altman RB, Clubb SL, Dorrestein GM, et al, editors. *Avian Medicine and Surgery*. 1st edition. Philadelphia: W.B Saunders. pp 489-500.

Rosenthal K, Stamoulis M. 1993. Diagnosis of congestive heart failure in an Indian Hill Mynah Bird (Gracula religiosa). Journal of Avian Medicine and Surgery 7, 27-30.

Smith FM, West NH, Jones DR. 2000. The cardiovascular system. In: Whittow GC, editor. Sturkie's avian physiology. 5th edition. San Diego: Academic Press. pp 41-231.

Strunk A, Wilson GH. 2003. Avian Cardiology. Veterinary Clinics of North America: Exotic Animal Practice 6, 1-28.

Sturkie PD. 1949. The electrocardiogram of the chicken. American Journal of Veterinary Research 10, 168-175.

Talavera J,Guzman MJ, Fernaandez de Palacio MJ, Albert AP, Bayon A. 2008. The normal electrocardiogram of four species of conscious raptors. Research in Veterinary Science 84, 119-125.

van Essen VJ, Uilenreef JJ, Szatmari V, Kroeze EJBV, Kuiper RV, Rothuizen J, de Bruin A. 2012. Ultrasound-guided serial transabdominal cardiac biopsies in cats. Veterinary Journal 191, 341-346.

Vice CA. 1992. Myocarditis as a component of Psittacine Proventricular Dilatation syndrome in a Patagonian conure. Avian Diseases 36, 1117-1119.

Vink-Nooteboom M, Schoemaker NJ, Kik MJ et al. 1998 Clinical diagnosis of a aneurysm of the right coronary artery in a white cockatoo (Cacatua alba). Journal of Small Animal Practice 39, 533-537.

Wu LA, Lapeyre Jr AC, Cooper LT. 2001. Current role of endomyocardial biopsy in the management of dilated cardiomyopathy and myocarditis. Mayo Clinic Proceedings 76, 1030-1038.