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Patent Ductus Arteriosus (PDA) is infrequently reported in cats and represents between 1-
7.3% of left to right shunting cardiac congenital anomalies. The objective of this study was
to report the presenting complaints, clinical examination findings, diagnostic findings,
treatment outcomes and survival times in cats diagnosed with a PDA in the United Kingdom
(UK). Medical records from three major UK referral centres were searched for cats that were
diagnosed with PDA from January 2004 to December 2012. Data obtained for analysis
included: signalment, clinical examination findings including murmur characteristics,
diagnostic imaging findings, treatment outcomes and survival times. Nineteen cats were
included in the analysis. The most common reason for referral was investigation of an
incidentally detected heart murmur without clinical signs (13/19; 68%). Pulmonary arterial
hypertension (PAH) was diagnosed in seven (37%) cats and those cats with PAH were
significantly more likely to present with signs of disease ($P = .004$). Median survival time in
cats that were diagnosed with PDA and died due to cardiac causes was 898 days (IQR 459-
1011 days). The median survival time of those cats that had an additional congenital anomaly
was significantly shorter to those cats without a congenital anomaly ($P = .008$).
Patent Ductus Arteriosus (PDA) is less frequently reported in cats than in dogs (Kittleson and Kienle 1998, Zook 1987). In two case series of cats with congenital left to right shunting cardiac anomalies only seven of 927 (<1%) and seven of 96 (7.3%) were diagnosed with PDA respectively (Kittleson and Kienle 1998, Liu 1977). The course of disease in cats is similar in dogs whereby left sided volume overload leads to congestive heart failure if the PDA is left untreated. In some cases an increase in pulmonary arterial pressure in response to the pulmonary over-circulation secondary to the large volume of left to right shunting may induce a pathological response in the pulmonary vasculature over time. Vascular changes include hypertrophy and intimal proliferation in the small and medium pulmonary vessels leading to a gradual narrowing of the pulmonary vessels and eventual pulmonary arterial hypertension (PAH) (Friedman and Silverman 2001, Kittleson and Kienle 1998, Oswald and Orton 1993). The PAH may become severe enough to reduce left to right shunting of blood through the PDA and in some cases reverse it – the Eisenmenger’s physiology (Friedman and Silverman 2001, Oswald and Orton 1993). Despite a thorough understanding of PDA in dogs and cats, reports of outcomes particularly in cats are infrequent in the veterinary literature. A single multicentre case series has been published recently, which reported 28 cats diagnosed with PDA over a 21 year period (Hutton and others 2015). This retrospective study reported the clinical presentation and outcomes of cats treated surgically and medically at three referral/university practices in the United States. Another case-series of feline PDA describing a cohort of 21 cats from 3 separate referral centres in the United States was presented as a clinical communication at the American College of Veterinary Internal Medicine (ACVIM) congress in 2000 (Hitchcock and others 2000). The rest of the veterinary literature consists of single case reports or small case series (Allen 1982, Aoki and others 2013, Connolly and others 2003, Fiske 1980, Jeraj and others 1978, Jones and Buchanan 1981, Schneider and Hildebrandt 2003, Summerfield and Holt 2005). The purpose of this
Doppler studies were used to determine pulmonary vascular resistance and right ventricular dilatation. Special
sectioned samples from 2D images and recorded as a binary data (yes/no). This included right atrial,
intracardiac shortening (FS%) calculated. Changes of the right atrio-ventricular valves were assessed
and diameter at the end of diastole (LVIDd) and the end of systole (LVIDs) were recorded. After
ventricular的功能 dimensions at choose end-diastolic level included left ventricular internal
(LV:No., end diastole) (Apple and Absolute 2006) measurements were recorded. Left
and right atrial measurements were determined from 2-dimensional (2D) images. From the right atrial
measurement, the left atrial data were retrieved from the clinical record. Each side standard
Post-cardiography data were retrieved from the clinical record. Left side standard
outcome including post-operative echocardiographic findings and survival times.
Echocardiographic findings, clinical (medial or surgical), hospitalization time, admission
findings, including minimum oxygen saturations, echocardiographic findings (including radiographic and
certified cardiologist's Data obtained for analysis included: signalement, clinical examination
(ROC'S, ECHOM or AGIM) cardiologist or a resident under the direct supervision of a board
evaluated. The diagnosis had to be confirmed by a board certified
were diagnosed with PDA from January 2004 to December 2012. For inclusion in the
Medical records from three referral centers (XX, XX and XX) were searched for cases that

Materials and Methods

Kingdom (UK).

Findings, mean/rum outcomes and survival times in cases diagnosed with a PDA in the United
study was to report the presenting complaint, clinical examination findings, diagnosis,

26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
and mitral valves as well as peak velocity of PDA flow. The presence of PAH was recorded as a binary data (yes/no) based on the direction and velocity of PDA flow and tricuspid or pulmonic regurgitation velocities, where present (in cats where concurrent pulmonic stenosis was excluded). The presence of significant PAH was arbitrarily defined as estimated pulmonary arterial systolic pressure of $\geq 50$ mmHg (i.e. moderate or severe) (Kellihan and Stepien 2010). PAH was considered to be present in the following circumstances: (i) right to left or bidirectional PDA flow, (ii) where left to right flow was still present, but the systolic blood pressure to peak PDA flow velocity derived aortic-pulmonary pressure gradient (PG) (calculated using the modified Bernoulli equation; $PG \approx 4 \times (velocity^2)$) was $<50$ mmHg, (iii) in absence of pulmonic stenosis in cases with tricuspid regurgitation (TR), if the TR velocity exceeded $3.5$ m/s (RV-RA PG $>49$ mmHg). Direction of flow in the PDA was recorded as left-to-right, right-to-left, bidirectional and it was timed as continuous or predominantly systolic. For the statistical analysis of flow velocities between different PDA flow directions, right-to-left and bidirectional shunting PDAs were grouped and compared to the left-to-right shunting PDAs. If echocardiographically visible, the diameter of PDA ostium as it entered the main pulmonary artery was measured. Surgical treatment was further assessed for technique (minimally invasive or open surgical occlusion procedure), intra-operative and post-operative complications. Telephone interviews with referring veterinary surgeons and owners were conducted to determine survival, cause of death and ongoing treatments where applicable. Survival time was calculated from the date of presentation to the respective referral centre to the date of death in days. If an exact date of death was not recorded, the 1st of the month was used as the date of death. Study approval was obtained from the clinical research ethical review committees at the respective institutions.
The most common grade was grade 3/6 (n = 4), followed by grades 4/6 (n = 2) and grade 5/6 (n = 1) in a heart murmur.

coded, collected with examination/collection and small sample data. Ultrasound, echocardiography, and additional

was attributed to the PDA including weight, loss, heart failure, cardiomyopathy, and abnormal

cells were referred because of an incidental detected heart murmur in a

case without clinical signs (1/3/9; 89%). The remaining six cells (32%) were referred because

most common reason for referral was investigation of an incidentally detected heart murmur in a

were referred. The age and clinical examination data are presented in Table 1. The most

n = 6 refered), The age and clinical examination data are presented in Table 1. The most

n = 1, 5%) Nonsmokers (n = 2, 16%), Persimmon (n = 2, 11%), and n = 1, 5%) and Spiny

68

67

amylase. The breeds of cats were Domestic Short Hair (n = 8, 42%), Domestic Long Hair (n = 4, 21%), Siamese (n = 2, 11%), and Persimmon (n = 2, 11%), and n = 1, 5%). Nonsmokers (n = 2, 16%), Persimmon (n = 2, 11%), and n = 1, 5%) and Spiny

Results

Values of p < 0.05 were considered significant for all analyses.

d due to low case numbers individual survival times were reported with median (QR).

analyzed using Kaplan-Meier plots and comparison of hazards by log rank (Kaplan-Meier X2).

compared using non-parametric tests (Kaplan-Meier u-test), survival analysis data were

compared using independent two-tailed Student's t-test. Data not meeting the hypothesis for

PDA, aortic diameter and follow up time (were expressed as mean ± standard deviation and

distributed data (body weight, respiratory rate, systolic blood pressure, PDA peak velocity).

variables were tested for normal distribution using the Kolmogorov-Smirnov test. Normally

new York, US and Minneapoli, Minnesota incorporated, Pennsylvania, USA). Continuous

Statistical analyses were performed using commercial software (SPSS Version 21, IBM®).
2/6 (n = 2) and 6/6 (n = 2) respectively. In six (35%) cats a continuous heart murmur was
documented. Thoracic radiographs were performed in 12 cats: four (33%) had generalised
cardiomegaly, three (25%) had right ventricular enlargement and one (8%) had severe left
atrial enlargement. A pulmonary vascular pattern was present in seven (58%) of 12 cats. Only
two cats had a lung pattern that was suggestive of congestive heart failure and both cats were
considered to be in left sided failure. In three cats the pulmonary vascular pattern was the
only radiographic finding with no change to the cardiac silhouette size or shape observed.
Both cats with CHF were alive at the time of the analysis: one cat underwent surgical ligation
of the PDA while the other was managed medically with diuretics.

Echocardiography

Echocardiography findings are summarised in table 2. In the 15 cats where the direction of
flow through the PDA was recorded, the flow was left to right in 12 (80%), right to left in
two (13%) and bidirectional in one (7%) cat. Changes of the right cardiac chambers were
identified in seven (37%) cats, including five (26%) with right atrial dilation, seven (37%)
with right ventricular hypertrophy and five (26%) cats with right ventricular dilation. All the
cats with right sided changes had a combination of atrial and ventricular morphological
changes seen on echocardiography. Left atrial enlargement was present in nine (53%) and left
ventricular dilatation with eccentric hypertrophy documented in the majority of cats during
diastole (81% cats) and systole (71% cats). The cats with increased end-systolic left
ventricular internal diameter (LVIDs) (mean ± SD: 13 ± 4 mm) were inferred to have
impaired left ventricular systolic function. Seven (37%) cats were diagnosed with PAH:
three cats had bidirectional PDA flow and the remaining four cats had left-to-right shunting
PDAs. Peak PDA flow was recorded in 14 cases: in the left-to-right shunting PDAs the mean
peak flow was 4.5 ± 0.9 m/sec while the mean peak flow was 1.7 m/sec in the one cat with a right to left shunting PDA with recorded data. If cats with left to right shunting and PAH were excluded, the peak PDA flow was 4.7 ± 0.9 m/sec. The PDA flow velocity in the cats with left to right shunting and a concurrent PAH was significantly lower at 3.9 ± 0.1 m/sec that those without PAH (P = .05). The cats with PAH were significantly more likely to present with signs of disease (i.e. lethargy) than those cats without PAH (P = .004). Six (32%) cats had one or more additional congenital cardiac abnormalities diagnosed: three had a ventricular septal defect (VSD), one had an atrial septal defect (ASD) and tricuspid valve dysplasia, one had an ASD, and one had mitral valve dysplasia. The presence of an additional congenital defect was not significantly associated with reason for referral (P = .92) but those with an additional congenital defect were presented at a significantly younger age (6 months) compared to 34 months in those cats with PDA only (P = .05). The PDA ostium was visualised in 13 (68%) of the 19 cats and where the diameter was measured (n = 12) the mean diameter was 2.3 ± 0.8 mm.

138

139 Treatment

139 Closure of the PDA was performed in 6 (32%) cats: an open surgical procedure with ligation of the ductus was done in five and transvenous coil embolization was performed in one. In the remaining 13 cats where records were available for review, two cats were not treated as the PDA was considered haemodynamically insignificant, and the cost of treatment was prohibitive for the owner. In another four cats, treatment was not performed due to right to left shunting (n = 2) and bidirectional flow within the PDA (n = 2). Surgery was performed via a left sided intercostal thoracotomy with ligation of the PDA. No intraoperative complications were encountered in the open surgical cases and a minor post-operative
complication was seen in one cat (removed sutures). Transvenous coil embolisation was performed by use of MReye® Flipper® 5 mm 5 loop detachable embolization coil (Cook Medical Europe Ltd) through a femoral venous access.

Outcome

At the time of analysis nine of the 19 cats (47%) were still alive, seven (37%) had died or were euthanased and three (16%) were lost to follow up. Of the seven that died, three cats died of causes unrelated to heart disease: two were hit by a car and one was attacked by dogs. The median follow up time for the cats that were alive at time of analysis was 897 days (IQR 504-2078 days). Post-operative echocardiographic data were available for three of the six cats that had surgical or interventional closure of the PDA: two cats that had surgical ligation and one that had transvenous coil embolisation. Residual ductal flow was not evident in any of the three cats, but one of the three cats was diagnosed with PAH, based on tricuspid regurgitation velocity, which had not been documented pre-operatively. This cat was still alive at the time of analysis after a follow up of 1867 days. Conversely one cat that was diagnosed PAH pre-operatively underwent surgical ligation with resolution of the PAH on follow-up examinations. This cat was still alive at follow up of 843 days.

The median survival time for all cats that died or were euthanased during the study period was 220 days (IQR 15-898 days). If the cats that died or were euthanized for reasons other than cardiac disease were excluded from the analysis, the median survival time was 898 days (IQR 459-1011 days). Of the six cats that had surgical occlusion of the PDA performed, two died or were euthanized (33%), three were still alive (50%) and one was lost to follow up
unrelated to cardiac disease were excluded then a comparison could not be made due only

This difference was not significant (p = 0.74). However, if the cars that died due to causes

1-2-1 II days (10, 3 days) compared to 30 days (10, 9-10 days) for those cars with non-PAH (Figure 2).

199 The median survival times for the group of cars with PAH was 89 days (10R

198 where were at 317.8 days, 2009.247 and 3119 days of follow up respectively (median

197 at 30 days and one after 101 days due to causes related to cardiac disease. In the six that were

196 had died: two died after being hit by a car at 9 and 220 days, one after being attacked by dogs

195 euthanized (23%) of which were alive (50%) and two were lost to follow up (7%), the cars that

194 died (12%). In 12 cars that did not have PAH euthanized at presentation, four had died or had been

193 that were still alive were at 31, 67, 167, 2009.247 and 384 days of follow up respectively (median

192 two died due to causes related to cardiac disease at 89 and 111 days respectively. The three

191 (14%). In the three cars that were euthanized at 15 days after presentation while the other

190 were still alive, three had or been euthanized (14%) and one was lost to follow up

189 (3%) were diagnosed with PAH at the time or analysis three of the seven (43%) had

188 have sufficient occlusion of their PA.

187 (Figure 1). All the cars that died or were euthanized for causes related to heart disease did not

186 due to cardiac disease.

185 The difference between median survival times of 9.5, 101, 898 and 111 days (median 459 days: 15-898

184 study period had survival times of 9, 15, 101, 898 and 111 days respectively. The three cars that did not have sufficient and died of was euthanized during the

183 by dogs with a survival times of 220 and 30 days (median 30 days: 10R 30-220 days)

182 the group of cars that had sufficient occlusion, one was hit by a car and the other was attacked

181 where were still alive (50%) and three were lost to follow up (23%). The two cars that died in

180 (17%). Of the 13 cars did not have occlusion of the ductus, five died or were euthanized (39%).

179
one cat remaining in the group of cats without PAH. One cat with PAH had surgical occlusion of the PDA performed while the remaining six cats did not. The cat with pre-operative PAH died due to causes related to cardiac disease after 1011 days. In the remaining six cats that had PAH and did not have surgical occlusion of the PDA, three had right to left shunting PDAs, one was bidirectional and two had left to right shunting PDAs. The three cats that had left to right shunting PDA’s and did not have surgery: two were hit by car nine and 220 days after presentation respectively while the third cat was alive at a follow up of 2009 days. There were no details in the clinical notes for any of three cats with PAH and left to right shunting PDAs as to why surgery was delayed or not undertaken.

In the seven cats that died or were euthanized, two had other congenital cardiac anomalies (29%). The survival times for those without additional cardiac congenital anomalies were 30, 101, 220, 898 and 1011 days (median 459 days; IQR 220-898 days). Of the two cats with an additional congenital cardiac anomaly one was euthanized due to causes related to cardiac disease 15 days post-operatively and the other was hit by car nine days post-operatively. The median survival time of those cats that had an additional congenital anomaly was therefore 8 days (IQR 8-15 days) and was significantly different to those cats without a congenital anomaly ($P = .008$) (figure 3). Two of the cases that had an additional congenital anomaly had surgical occlusion of the PDA: one cat was still alive at the time of analysis with a follow up of 1867 days and the other lost to follow up.
PD A. This comparison is with those who have been reported with 9% of the cases with 6% of the cases with 7% of the cases with 8% of the cases with 9% of the cases with 10% of the cases with 11% of the cases with 12% of the cases with 13% of the cases with 14% of the cases with 15% of the cases with 16% of the cases with 17% of the cases with 18% of the cases with 19% of the cases with 20% of the cases with 21% of the cases with 22% of the cases with 23% of the cases with 24% of the cases with 25% of the cases with 26% of the cases with 27% of the cases with 28% of the cases with 29% of the cases with 30% of the cases with 31% of the cases with 32% of the cases with 33% of the cases with 34% of the cases with 35% of the cases with 36% of the cases with 37% of the cases with 38% of the cases with 39% of the cases with 40% of the cases with 41% of the cases with 42% of the cases with 43% of the cases with 44% of the cases with 45% of the cases with 46% of the cases with 47% of the cases with 48% of the cases with 49% of the cases with 50% of the cases with 51% of the cases with 52% of the cases with 53% of the cases with 54% of the cases with 55% of the cases with 56% of the cases with 57% of the cases with 58% of the cases with 59% of the cases with 60% of the cases with 61% of the cases with 62% of the cases with 63% of the cases with 64% of the cases with 65% of the cases with 66% of the cases with 67% of the cases with 68% of the cases with 69% of the cases with 70% of the cases with 71% of the cases with 72% of the cases with 73% of the cases with 74% of the cases with 75% of the cases with 76% of the cases with 77% of the cases with 78% of the cases with 79% of the cases with 80% of the cases with 81% of the cases with 82% of the cases with 83% of the cases with 84% of the cases with 85% of the cases with 86% of the cases with 87% of the cases with 88% of the cases with 89% of the cases with 90% of the cases with 91% of the cases with 92% of the cases with 93% of the cases with 94% of the cases with 95% of the cases with 96% of the cases with 97% of the cases with 98% of the cases with 99% of the cases with 100% of the cases with
The present study found that the median survival time for all cats diagnosed with PDA (treated or untreated) that died due to cardiac disease was 898 days. Interestingly, although not statistically significant, the cats that did not have surgical occlusion of the PDA lived longer (459 days) than those that did have their PDA treated surgically (30 days) (figure 1). A more detailed analysis within the group that had surgery was not possible as the cats that died after the PDA was occluded did so due to non-cardiac causes (hit by car or attacked by dogs). Thus after exclusion of these cats from the analysis no cats died within the follow up period due to cardiac causes that had surgery. One may argue that surgery therefore may be a survival benefit but conversely it is possible the cats with a traumatic cause of death suffered this due to reduced activity capacity. This warrants further study. Hutton and others (2015) found that the median survival time for cats that did not have surgery was 45 months (1350 days), which is almost twice of that found in the present study. The median survival time for those cats that did have surgery was not calculable in the Hutton and others’ (2015) study but it was not significantly different ($P = .41$) from the group of cats that were managed without surgery. The survival data in the present and the Hutton and others’ (2015) studies is in stark contrast to what has been reported in dogs where there was a statistically significant difference found between dogs that had their PDA surgically occluded and those that were managed medically (Saunders and others 2014, Van Israel and others 2003). Median survival times ranged from 1800 days for dogs that were managed medically and 753-3030 days for those that had surgical occlusion of their PDA respectively (Saunders and others 2014, Van Israel and others 2003). The distribution of dogs less than a year of age in the Van Israel and others (2003) study was similar to the present report where 45% of dogs were presented older than 1 year of age. This lends to a more direct comparison between the species and from the present study it suggests that cats do not survive as long as dogs.
meaning that the results of the analysis would not be reliable. The analysis was performed on the present study's data due to the relativity low case numbers. Analysis on radiographs at the time of surgery (Bueno and others 2005), Cox regression pre-operative measurement with angiotensin-converting enzyme inhibitors and triple arterial resection of the lung in dogs were aged, weight, pre-operative lethargy, have been found to be negatively associated with probability of survival after surgical resection. Chronic disease (other than a maximum instead than investigation of a minimum risk factors that associated with reason for referral where the cases with PAVH were more likely to present with and conclusions cannot be made respectively. In the present study PAVH was significantly have PAVH died due to cause related to cardiac disease and therefore more detailed analysis PAVH appeared to live longer (figure). However only one cat in the group of cats that did not PAVH and those did not were not significantly different but interestingly the trend with single cat (Novo-Marin and others 2014). Survival times comparisons between the cats that changes on biopsy and resolution on PAVH following PAVH close and one have been reported in another cat consistent with pulmonary vascular changes. Both histopathological lung the pulmonary vascular. Conversely, PAVH was diagnosed suggests close to PAVH close in resolve to the pulmonary over-erection, rather than resolving irreversible remodeling of case undergoing surgical resection of the PAVH. PAVH resolved on follow-up, suggesting it was their population of 21 cats. The difference between the two cat populations is unclear. In one (Hilton and others 2015), Hilton and others (2014) found an incidence of 8% of PAVH in incidence of PAVH was also higher in the present study in comparison to a recent study of cats population studied presented with PAVH secondary to PAVH (Sander and others 2014). The presence of PAVH, this is vastly higher than the incidence in dogs, where only 3% of the pulmonary arterial hypertension was a frequent finding in our population with 37% of cats.
The main limitations of the present study were that it was retrospective in nature: data was reliant on accurate record keeping, inevitable missing data, multiple clinicians involved in performing tests such as echocardiography and a limited number of cases. The present study was a multi-centre collaboration where most of the referral centres within the United Kingdom that had either a board certified surgeon or cardiologist were invited to participate. Only three centres were able to contribute data that was used in the analysis and overall only 19 cases were able to be included. This was a similar finding in a recent study where three centres in the United States were able to contribute 28 cases over a 21-year period. This again highlights the rarity of PDA diagnosed in cats in comparison to dogs. This may reflect in some way selection bias where some cats with low-grade murmurs that are asymptomatic are not referred for investigation. Similarly there may be cats with more balanced or right-to-left shunts that the murmur is not detectable. Therefore the incidence of PDA in cats in the UK may be very different to what is presented here. Due to the retrospective nature of the data collection, there were inevitable gaps in the data set that adds doubt to the statistical conclusions however this study adds more cats to the existing literature.


In the Normal Cat. Veterinary Radiology. 26, 149-158.


Indicators for surgical intervention of left-to-right shunt in patent ductus arteriosus in dogs: 25.


In the Normal Cat. Veterinary Radiology. 26, 149-158.


Indicators for surgical intervention of left-to-right shunt in patent ductus arteriosus in dogs: 25.


In the Normal Cat. Veterinary Radiology. 26, 149-158.


Indicators for surgical intervention of left-to-right shunt in patent ductus arteriosus in dogs: 25.


In the Normal Cat. Veterinary Radiology. 26, 149-158.


Indicators for surgical intervention of left-to-right shunt in patent ductus arteriosus in dogs: 25.


Table 1: Clinical data on cats that were diagnosed with PDA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>N</th>
<th>Median (range) or Mean ± stdev</th>
<th>IQR (Q1-Q3)</th>
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<tbody>
<tr>
<td>Age (months)</td>
<td>19</td>
<td>11 (3-90)</td>
<td>4-37</td>
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<tr>
<td>Weight (kg)</td>
<td>17</td>
<td>2.9 ± 1.1</td>
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<td>Heart rate (beats per minute)</td>
<td>15</td>
<td>169 (120-200)</td>
<td>160-180</td>
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<tr>
<td>Respiratory rate (breaths per minute)</td>
<td>9</td>
<td>42 ± 17</td>
<td>30-50</td>
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<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>5</td>
<td>128 ± 20</td>
<td>111-129</td>
</tr>
</tbody>
</table>

stdev – standard deviation; IQR – interquartile range; Q1 – first quartile; Q3 – third quartile
denotes those values outside reference range

and Dukes-Nicolan (2012)

Reference falling values; Deviation and others (1983); Aboy and Macleod (2006).

ventricular internal dimension in systole. FS = fractional shortening.

ventricular internal dimension in diastole. LVIDD = L

third quartile. LAVMax = maximum left atrial diameter. L/A = L left atrial to aortic

PDA data is in measured or median. IQR = Interquartile range. Q1 – First quartile, Q3 –

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Table 2: Echocardiographic measurements for car diaphragm with PDA where values were