# Long-term follow-up of dogs with patent ductus arteriosus

**Postocclusion survival data from dogs with left-to-right shunting patent ductus arteriosus (PDA) was available from 80 dogs, diagnosed from 1990 to 2000. Of these, 37 had undergone a procedure to close the ductus and were re-evaluated at the time of this study; clinical data from the follow-up examination was compared with that from the original examination. Radiographically, the right ventricle remained apparently enlarged, and the aortic bulge associated with dilation of the descending aorta did not disappear after closure. On M-mode echocardiography, left ventricular chamber diameter in diastole and systole and left ventricular posterior wall in systole decreased significantly. Mitral endocardiosis was a common feature. Residual flow was evident in 46 per cent of the animals. Late closure occurred in 8 per cent of the dogs, and trivial recanalisation in 19 per cent. The maximum survival time postclosure was 168 months and, after non-occlusion, 114 months, suggesting that dogs with PDA follow an unpredictable course. However, there was a significant difference in survival times between the corrected and non-corrected group.**

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## INTRODUCTION

The ductus arteriosus is a normal fetal structure which shunts blood from the pulmonary artery to the aorta. In puppies, the ductus arteriosus functionally closes a few days after birth (King 1999). Patent ductus arteriosus (PDA) is caused by the failure of the duct to close, and is one of the most commonly recognised congenital cardiac lesions found in dogs (Patterson 1968, Tidholm 1997, Kittleson 1998). Currently, accepted therapies for PDA are surgical ligation (requiring thoracotomy) and transcatheter coil embolisation (via femoral artery/vein) (Buchanan 2001).

Although several large studies evaluating the surgical outcome of dogs following surgical ligation have been published (Eyster and others 1975, Birchard and others 1990, Hunt and others 2001), none has evaluated the long-term echocardiographic findings (ie, over a period of more than nine months). Only short-term studies of limited case numbers are available for the electrocardiographic (eight dogs with a follow-up time of two days to nine months, Ackerman and others 1978) and radiographic changes (case numbers and follow-up times undetermined, Buchanan 1972; five dogs with follow-up times ranging from one to 20 weeks, Ackerman and others 1978) after PDA occlusion. A retrospective evaluation of PDA occlusion using haemoclips in 20 dogs has also been published, based on radiographic and echocardiographic changes (Corti and others 2000).

Myocardial failure and residual shunting are well recognised findings after PDA closure (Kittleson 1998, Corti and others 2000, Van Israël and others 2002), but the long-term clinical significance of these findings remains unknown. The main objective of this study was, therefore, to evaluate the long-term echocardiographic features of PDA following closure of the ductus, with special emphasis on left ventricular systolic and diastolic function. An additional aim was to compare three different closure techniques: standard ductal dissection and double ligation (Buchanan 1994), dissection using the Jackson-Henderson technique (Jackson and Henderson 1979), and transcatheter closure using Cook detachable coils (Stokhof and others 2000, Schneider and others 2001), based on residual shunting, recanalisation and late spontaneous closure. The survival time after PDA occlusion was also assessed.

## MATERIALS AND METHODS

### Survival study

The owners of 90 dogs with PDA as an isolated lesion, described in a previously published retrospective study (Van Israël and others 2002), were contacted by telephone or by post to obtain follow-up data.

If the dog had undergone ductal closure, the owner's permission was gained for participation in a long-term follow-up study (n=37).

## Long-term follow-up study

Six-lead electrocardiograms pre- and postclosure were available from 35 dogs. Radiographs pre- and postclosure were available for 18 animals which were fully grown at the time of initial presentation. Thirty-seven animals were re-presented to the cardiology clinic for full repeat assessment, including history, physical examination, electrocardiography, radiography and echocardiography.

### History

An extensive general history of each dog was obtained. The date of birth, sex, breed and weight were all recorded.

### Physical examination

A detailed clinical examination of the cardiorespiratory system of each dog was made. Each dog was carefully auscultated at rest in a quiet environment, using a Littmann Cardiology II stethoscope (3M, USA). Heart murmurs which were detected were localised and graded (I to VI), according to the classification of Perloff and Braunwald (1998), with a note made of the character, radiation, duration and location in the cardiac cycle.

### Electrocardiography

The six-lead electrocardiographic strips (ECGs) (ECG Schiller, Cardiovit 60, Switzerland) were assessed for the presence of rhythm disturbances. Complex sizes (P and QRS amplitude and duration, P-Q/Q-T interval, Q-T segment) were measured according to the recommendations of Tilley (1992), and compared with the ECG findings at initial presentation, measured in a similar way by the same author (NVI) (Van Israël and others 2002).

### Radiography

Couplets of right lateral and dorsoventral radiographs pre- and postclosure were blinded and assessed independently of each other by NVI, following the recommendations of Suter and Lord (1977). The presence of individual chamber or vessel enlargement was recorded. Cardiomegaly was assessed using the vertebral heart size (VHS) scale (Buchanan and Buchler 1995). Pulmonary perfusion was assessed in the dorsoventral view by comparing the width of the pulmonary artery with that of the ninth rib, at the point of intersection (Stickle and Anderson 1978). Pulmonary parenchyma was assessed for the presence of interstitial, mixed or alveolar patterns.

Animals which were fully grown at initial presentation (eight months of age for the small breeds, 12 and 18 months for large and giant breeds, respectively) were compared at the time of follow-up, for VHS, pulmonary overperfusion and chamber or vessel enlargement.

### Echocardiographic examination/ colour flow Doppler examination

The follow-up ultrasound examinations were all performed using a Vingmed CFM 800 machine (BMS, UK). Echopac (Vingmed Sound; Horten) was used to analyse the data (average of five consecutive heart cycles) and videotapes (Super VHS 180, JVC) were reviewed for the presence of flow across the ductus. Studies were performed in accordance with recommendations for standardised transthoracic imaging planes (Thomas and others 1993), and Doppler echocardiographic views were orientated to permit optimal alignment with blood flow (Darke and others 1993).

Left atrial size was assessed using a combination of two-dimensional findings (left atrial diameter parallel to the mitral valve annulus before opening of the mitral valve in right parasternal long-axis view and right parasternal short-axis two-dimensional left atrium:aorta ratio by planimetry) (Häggström and others 1994, O'Grady and others 1986, Boon 1998b), and right parasternal short-axis M-mode findings (left atrium:aorta ratio) (Boon 1998c).

From the short-axis view, the left ventricular M-mode study was measured using the leading edge to leading edge technique (Sahn and others 1978). Diastole was measured at the start of the QRS complex on the ECG. Systole was determined as the nadir of septal posterior motion. The values for left ventricular diameter, left ventricular posterior wall, and interventricular septum in diastole and systole were compared with previously recorded normal values for the appropriate breed and bodyweight (Boon 1998b). Maximal aortic outflow velocities were obtained via the subcostal view (Lehmkuhl and Bonagura 1994) and the aortic valve was screened for insufficiency using colour flow Doppler ultrasound.

Pulmonary artery flow was assessed by using the right parasternal short-axis view, and the left cranial parasternal short-axis view for outflow velocity, presence of insufficiency and ductal flow. Left ventricular systolic function was interpreted as being compromised if one or more of the following were identified: fractional shortening (FS) less than 25 per cent (Luis-Fuentes and others 2000), ejection fraction calculated by Simpson's rule (EF) less than 40 per cent (Boon 1998c), and systolic time intervals (pre-ejection period/ejection time [PEP:ET] ratio more than 0·44 seconds, measured using spectral Doppler analysis of aortic flow) (Boon 1998b). Left ventricular diastolic dysfunction was assessed via the combination of mitral inflow patterns (abnormal if E:A is less than 1), isovolumetric relaxation time (IVRT) (abnormal if IVRT is over 0·08 seconds), pulmonary venous flow patterns (normal wave velocities: S, 0·25 to 0·53 m/second; D, 0·42 to 0·70 m/second; Ar, 0·12 to 0·28 m/second) and mitral E-wave deceleration time EDT (abnormal if EDT is more than 0·098 seconds) (Schober and others 1998).

Ductal flow was assessed from the right and left parasternal short-axis views at the level of the pulmonary artery bifurcation with the aid of colour flow Doppler ultrasound, continuous and pulsed Doppler

**Table 1. Breeds of dog with PDA represented in the survival study (n=80)**

| Number of dogs | Breed |
|---|---|
| 16 | German shepherd dog |
| 8 | Cavalier King Charles spaniel |
| 6 | English springer spaniel |
| 5 | Crossbreed, Border collie |
| 4 | West Highland white terrier, Jack Russell terrier |
| 3 | Bichon frise, Labrador |
| 2 | Papillon, Yorkshire terrier, Welsh corgi, English cocker spaniel, Brittany spaniel |
| 1 | Shetland sheepdog, weimaraner, flat coated retriever, bearded collie, Tibetan spaniel, miniature dachshund, Tibetan terrier, Newfoundland, Border terrier, Dandie Dinmont terrier, terrier, Italian greyhound, chihuahua, old English sheepdog, Irish setter, rottweiler |

signals. The amount was graded as none, trace, mild, moderate and severe, based on the jet area and its width at origin, simplifying methods described by a number of authors (Helmcke and others 1987, Keren and Lejemtel 1989, Perry 1989).

The shunt ratio was calculated from the following formula, where $Q_p$ is the pulmonary flow and $Q_s$ the systemic flow; PAsv the stroke volume through the pulmonary artery, and $AO_{sv}$ the aortic stroke volume (Boon 1998a):

$$Q_p/Q_s = AO_{sv}/PA_{sv}$$

Both stroke volumes were calculated by multiplying the velocity time integral (obtained by tracing the Doppler outflow profile of the aorta and pulmonary artery, respectively) by the area of the vessel ($\pi r^2$). The diameter (radius [r] $\times 2$) of the aorta was measured from the left apical two-chamber view at the level of the sinotubular junction. The diameter of the pulmonary artery was measured from the right parasternal short-axis view at the level of the valve leaflets.

Only left ventricular M-mode indices (divided by the body surface area to accommodate differences in body size) were compared pre- and postocclusion in dogs which were adults at initial presentation. Data from the initial colour flow Doppler echocardiographic studies obtained by multiple experienced cardiologists with similar training were retrieved from the case records (Van Israël and others 2002).

### Statistical analysis

Statistical analysis of the comparative data was performed using Sigmastat software (2.03, SPSS). Survival data analysis was done using a Minitab (13.2, Minitab) statistical package. Electrocardiographic, radiographic and echocardiographic data pre- and postclosure were compared using a paired *t*-test (if the data was normally distributed) or Wilcoxon test (if the data was not normally distributed or if variance was unequal), after a normality test was performed. The Mann-Whitney Rank Sum test was used to see if there was a correlation between age at presentation and the occurrence of aortic, pulmonary or auricular bulges on thoracic radiographs (comparing zero/one bulge with two/three bulges).

The comparison of residual shunting, late closure and recanalisation between groups was done using the Chi-squared or Fisher's exact test. Recanalisation was considered to have occurred if the colour flow Doppler study at the time of discharge did not show any residual shunting, but this was present at follow-up examination. Late closure was considered to have occurred if the colour flow Doppler study at the time of discharge showed residual shunting and that this was absent at follow-up examination.

Initially, all the animals which underwent PDA closure were compared with the non-occluded animals. For further survival analysis, all animals (including the re-evaluated dogs and the cases followed up by telephone) that did not receive surgical or transcatheter closure and all animals with concurrent defects were excluded. Data were excluded if animals were still alive, or the time of most recent information if they were lost to follow-up. Kaplan-Meier curves were drawn and the log rank test was used to detect any statistically significant differences between independent groups of survival times. The significance level for all tests was $P<0.05$.

## RESULTS

### Survival study

#### Epidemiology

Survival data were obtained from 80 dogs and 10 dogs were lost to follow-up. There were 35 breeds represented (n=80); German shepherd dogs (20 per cent), Cavalier King Charles spaniels (10 per cent), springer spaniels (8 per cent), mongrels (6 per cent) and Border collies (6 per cent) were the most common breeds (Table 1). There were 68 females and 12 males. The age range at the time of diagnosis was two to 120 months (mean 18·4, median 7·5 months). Forty-five percent of the dogs were one year or older at initial presentation.

#### Survival

Since four dogs died during the perioperative period, only 76 dogs were included in the analysis for survival time. Of these, 19 animals had died. Ten died secondarily to congestive heart failure (five were surgically ligated [age at death ranged from 46 to 120 months, mean 73 months, median 60 months], and five had been managed medically [age of death ranged from 26 to 114 months, mean 88 months, median 101 months], and seven from non-cardiac related causes (age at death ranged from six to 168 months, mean 93 months and median 96 months). In two animals, the cause of death was unknown. The maximum survival time was 168 months after ductal closure, and 114 months in the

**Table 2. Survival time, cause of death and continuous murmur grading in the non-occluded dogs (n=8)**

| Case number | Breed | Murmur (grade) | Status | Cause of death | Survival time (months) |
|---|---|---|---|---|---|
| 1 | Cavalier King Charles spaniel | IV | D | Cardiac | 107 |
| 2 | Cavalier King Charles spaniel | II | D | Cardiac | 90 |
| 33 | German shepherd dog | – | D | Cardiac | 101 |
| 46 | Brittany spaniel | V | D | Cardiac | 26 |
| 49 | Border collie | V | D | Cardiac | 114 |
| 51 | Dandie Dinmont terrier | I | A | Non-cardiac | 63 |
| 68 | Cavalier King Charles spaniel | III | A | Non-cardiac | 84 |
| 82 | West Highland white terrier | V | A | Non-cardiac | 72 |

D Dead, A Alive

**Table 3. Breeds with occluded PDA included in the follow-up study (n=37)**

| Number of dogs | Breed |
|---|---|
| 6 | German shepherd dog |
| 4 | Cavalier King Charles spaniel |
| 3 | English springer spaniel, crossbreed |
| 2 | Border collie, Labrador, West Highland white terrier, Welsh corgi, English cocker spaniel |
| 1 | Bichon frise, Brittany spaniel, Jack Russell terrier, old English sheepdog, Italian greyhound, Shetland sheepdog, dachshund, Tibetan terrier, rottweiler, Tibetan spaniel, Newfoundland |

non-occluded group. Of the group of dogs which did not undergo ductal closure (n=8), five died (age 26 to 114 months, mean 88 months, median 101 months), and three were still alive (at least 63 months of age). Of these eight animals, three had a continuous murmur graded less than or equal to III/VI, one had a grade IV/VI murmur, and three had a grade V/VI murmur (Table 2).

There was a statistical difference in survival time between the treated and non-treated groups (P=0·026) (Fig 1). There was no statistical difference in survival time between animals which had the PDA occluded before or after 12 months of age, or between any of the following age groups: 0 to six months of age, six to 12 months, 12 to 24 months and over 24 months of age. No statistically significant difference between genders was found.

There was no significant influence on survival times between the presence or absence of residual shunting at the time of discharge, and the suggestion of systolic dysfunction by having FS less than or equal to 30 per cent before PDA occlusion. However, a decrease in survival time coincident with echocardiographic evidence of mitral regurgitation at initial presentation was suggested, although was not statistically significant (P=0·052) (Fig 2).

Heart failure at initial presentation, diagnosed on the basis of clinical signs and/or radiographic signs consistent with pulmonary oedema, did not appear to influence long-term survival significantly in this study population.

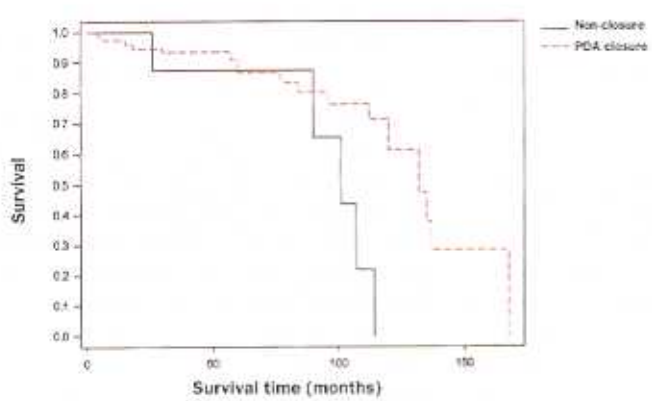



FIG 1. Kaplan-Meier survival curve comparing survival time for dogs which underwent occlusion of the ductus (n=66) with conservative or no treatment (n=8). Log rank test, P<0·05 (P=0·026)

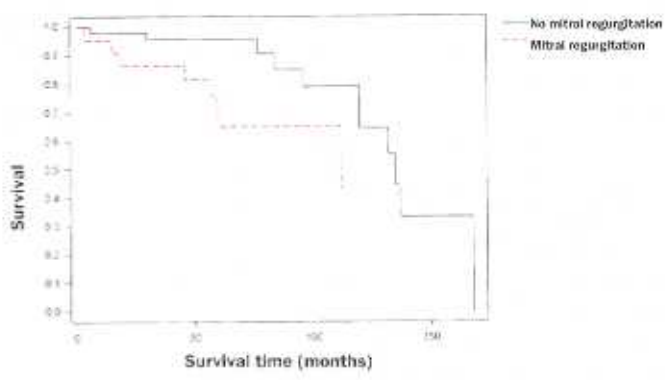



FIG 2. Kaplan-Meier survival curve comparing dogs which had echocardiographic evidence of mitral regurgitation (n=19) at initial presentation with those with no mitral regurgitation (n=49). Non-occluded animals were excluded. Log rank test, P=0·052

**Table 4. Vertebral heart size (VHS) (vertebrae) pre- and postductal occlusion**

| Case number | VHS pre-occlusion | VHS post-occlusion |
|---|---|---|
| 7 | 12·3 | 12·3 |
| 16 | 13·5 | 13·3 |
| 19 | 13·3 | 12·5 |
| 20 | 11·3 | 11·3 |
| 27 | 13·5 | 11·7 |
| 32 | 9·5 | 9·5 |
| 50 | 12·5 | 11·3 |
| 54 | 14·3 | 12·0 |
| 62 | 10·7 | 11·0 |
| 63 | 10·0 | 11·25 |
| 66 | 9·7 | 10·0 |
| 73 | 14·3 | 14·0 |
| 75 | 11·0 | 10·8 |
| 77 | 9·7 | 9·7 |
| 80 | 10·0 | 9·5 |
| 86 | 12·3 | 12·0 |
| 92 | 10·5 | 10·5 |
| 102 | 12·5 | 12·0 |

## Long-term follow-up study

### Epidemiology

There were 20 breeds (n=37) represented, with German shepherd dogs (six), Cavalier King Charles spaniels (four), springer spaniels (three) and crossbreeds (three) being the most common (Table 3). Females outnumbered males by 32 to 5. The age range at the time of re-presentation was 13 to 132 months (mean 65·5, median 60 months). Fourteen dogs were one year or older at initial presentation.

### Clinical findings at follow-up

Thirty-one dogs had no clinical signs; the remaining six dogs showed typical signs of cardiac decompensation (cough and exercise intolerance). One dog was in severe cardiac failure, warranting euthanasia, and three dogs were being treated for heart failure. A left basal continuous murmur was auscultated in six of 37 (16 per cent) dogs, but four of these dogs remained completely without clinical signs (one coughed occasionally and one experienced exercise-induced dyspnoea). The majority of these continuous murmurs were grade II/VI or lower (grade I/VI [three], grade II/VI [two]). Only one dog had a grade III/VI murmur after transcatheter closure of the PDA. Additional systolic murmurs were audible in 13 of 37 animals, and the majority (11 of 13) were mitral in origin. One dog had a murmur with the point of maximum intensity over the tricuspid valve, and another had a left systolic heart base murmur, confirmed later as pulmonic stenosis.

### Electrocardiography findings

Postocclusion ECG strips were available for 40 dogs (37 presented for the study and three as part of their care); however, only 35 animals had electrocardiographic data available pre- and postocclusion. The follow-up time ranged from five to 116 months (mean 45, median 36 months). Most animals had a normal cardiac rhythm at follow-up (21 of 40 had regular sinus rhythm and 15 of 40 had sinus arrhythmia), but four dogs were in atrial fibrillation (AF) (two presented as part of the study and two at an earlier time as part of their care). Of those four dogs, two had been in AF and one had shown a sinus tachycardia at initial presentation.

Complex sizes and duration were assessed pre- and postclosure. The P-wave duration and amplitude were not significantly different between the two time points. There was a statistically significant reduction in R-amplitude ($P<0.001$) and $Q_{II}$-amplitude ($P=0.008$).

### Radiography findings

Radiographic data pre- and postclosure was available from 18 animals which were fully grown at initial presentation. The follow-up time ranged from 2·5 to 107 months (mean 37, median 25·5 months).

There was no significant statistical correlation between the age of the animals at initial presentation and the occurrence of an aortic and/or pulmonary artery, and/or auricular bulge. An aortic bulge was present on 14 of 18 of the initial radiographs, and disappeared in one animal. A pulmonary artery bulge was present in 13 animals initially, and disappeared in six of these after ductal occlusion. An auricular bulge was seen initially in four animals and disappeared in one.

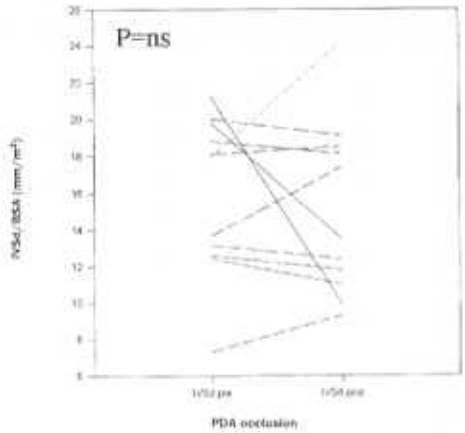
The radiographic signs of pulmonary overperfusion disappeared in all but one dog. The apparent right ventricular enlargement seen on all initial radiographs disappeared in three animals. The VHS pre- and postocclusion was not significantly different (Table 4).

### Colour flow Doppler echocardiography findings

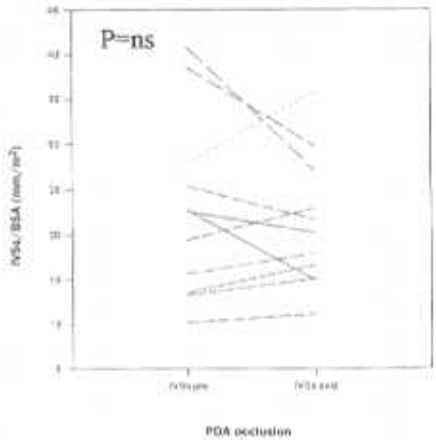
Echocardiographic data pre- and postclosure was available for 37 animals (Table 5). The follow-up times ranged from nine to 121 months (mean 48, median 37 months). At follow-up, the left atrium was enlarged in 12 of 37 dogs and was severely enlarged in one. All these animals except one had mitral regurgitation and/or residual shunting. The mitral valve appeared normal in 27 dogs. The valve was mildly thickened in six dogs, moderately in two and severely in another two. Mitral regurgitation was seen in 14 animals, with six showing a trace, six mild, one moderate and one severe valvular insufficiency. Nine animals with mitral regurgitation had concurrent residual shunting.

Systolic function (Table 5), assessed by a combination of FS, EF and PEP:ET ratio, showed that all indices were normal in 17 of 37 (46 per cent) animals. Nine animals had one abnormal index, another nine had two abnormal indices, and in two animals all three indices were abnormal. When all the animals with mitral regurgitation and/or residual shunting were excluded, seven of 16 (44 per cent) had all indices within normal range, five of 16 animals had one abnormal index and four of 16 had two abnormal indices. Of the 12 dogs with FS less than 30 per cent at initial presentation, subsequent systolic function describing all indices as normal occurred in six dogs (50 per cent). The other six dogs had one (one) or two (four) abnormal indices, indicating persistent systolic dysfunction. However, three of these had developed endocardiosis. When considering the systolic left ventricular volume

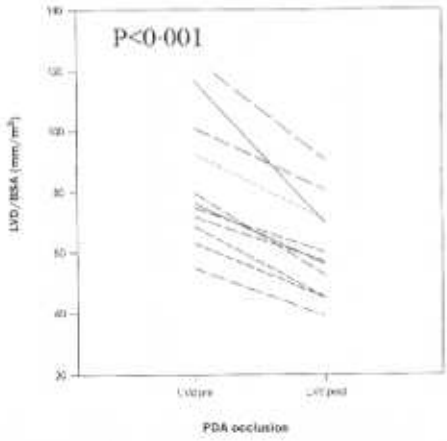
Interventricular septum in diastole indexed to body surface area



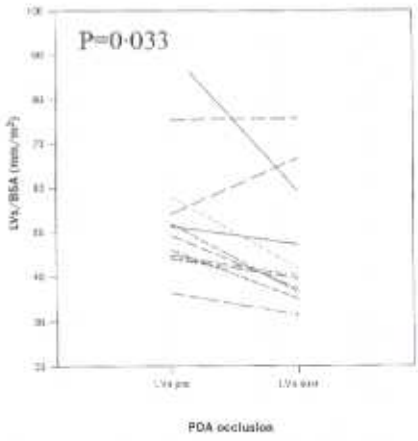

Interventricular septum in systole indexed to body surface area



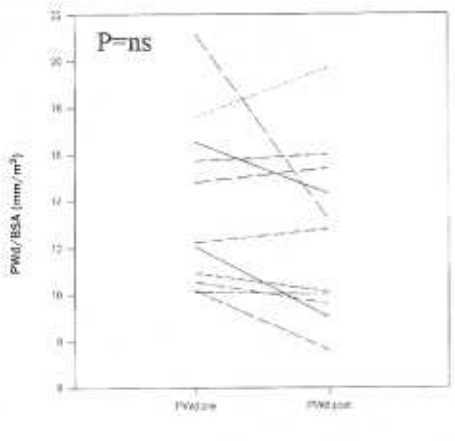

Left ventricular diameter in diastole indexed to body surface area




Left ventricular diameter in systole indexed to body surface area




Left ventricular posterior wall in diastole indexed to body surface area




Posterior wall in systole indexed to body surface area

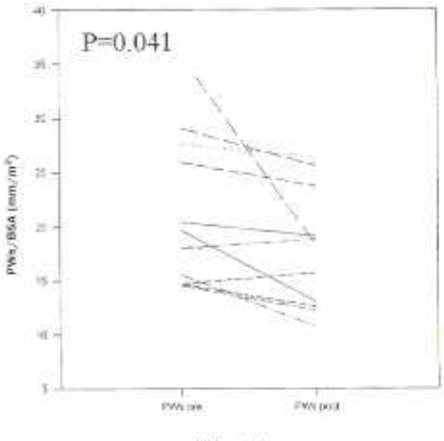



FIG 3. M-mode echocardiographic left ventricular indices in diastole and systole indexed by body surface area (mm/m$^2$) at initial presentation (fully grown animals only) and at long-term follow-up (n=11). P=ns Not significant

**Table 5. Echocardiography findings at initial presentation and at follow-up**

| Case number | Initial presentation | | | | At follow-up | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FS | LA | MR | DF | LA | FS | EF | PEP/ET | AI | PI | MR | MV | DF |
| 12 | 25 | + | – | – | N | 37·9 | 65 | 0·36 | + | N | ++ | T | N |
| 20 | 27 | – | – | N | + | 33·7 | 51 | 0·33 | N | N | ++ | TTT | N |
| 24 | – | – | – | N | N | 26·9 | 54 | 0·53 | N | N | N | N | N |
| 27 | 22 | ++ | +++ | Y | + | 15·2 | 27 | 0·29 | N | N | N | N | N |
| 32 | 31 | – | – | N | N | 21·7 | 47 | 0·35 | ++ | + | N | N | N |
| 34 | 45 | ++ | + | N | N | 31·2 | 63 | 0·33 | – | + | N | N | N |
| 40 | 22 | – | +++ | Y | ++ | 25·9 | 38 | 0·50 | ++ | + | +++ | T | + |
| 44 | 25 | – | N | N | N | 25·8 | 40 | 0·40 | N | N | N | N | N |
| 45 | 34 | ++ | + | N | N | 27·1 | 62 | 0·28 | + | + | + | T | N |
| 48 | 40 | | + | N | N | 43·1 | 54 | 0·40 | N | N | N | N | N |
| 54 | 47 | N | – | Y | + | 16·7 | 29 | 0·73 | ++ | + | ++ | TT | ++ |
| 56 | 25 | N | N | Y | N | 27·6 | 64 | 0·40 | + | N | N | N | N |
| 58 | 26 | N | + | – | N | 27·6 | 58 | 0·30 | ++ | + | + | N | N |
| 59 | 38 | ++ | ++ | N | + | 29·8 | 47 | 0·29 | + | + | + | N | + |
| 62 | 40 | – | – | Y | N | 22·0 | 38 | 0·44 | + | ++ | N | N | + |
| 63 | 39 | N | N | N | N | 32·7 | 64 | 0·30 | + | + | N | N | N |
| 65 | 34 | N | N | N | N | 39·6 | 49 | 0·25 | + | + | N | N | + |
| 66 | 43 | – | N | – | N | 30·3 | 61 | 0·26 | N | + | N | N | N |
| 67 | 40 | N | N | Y | + | 30·4 | 40 | 0·30 | N | N | ++ | T | ++ |
| 71 | 21 | – | ++ | Y | + | 18·3 | 43 | 0·57 | + | ++ | ++ | TT | ++ |
| 72 | 43 | ++ | – | N | + | 24·7 | 46 | 0·46 | + | + | N | N | + |
| 73 | 38 | +++ | ++ | N | +++ | 33·9 | 51 | 0·60 | + | ++ | ++++ | TTT | + |
| 75 | 27 | ++ | – | N | N | 22·1 | 29 | 0·43 | ++ | + | N | N | N |
| 77 | 37 | N | – | N | N | 40·9 | 49 | 0·37 | N | + | N | N | N |
| 78 | 38 | ++ | – | N | N | 28·9 | 53 | 0·38 | N | + | N | N | + |
| 79 | 49 | N | N | Y | + | 22·2 | 54 | 0·29 | + | + | N | N | ++ |
| 80 | 34 | N | – | Y | N | 19·1 | 38 | 0·42 | N | + | + | T | + |
| 81 | 26 | N | N | N | N | 22·8 | 51 | 0·30 | N | ++ | N | N | + |
| 83 | 27 | N | – | N | N | 34·5 | 65 | 0·26 | + | + | N | N | N |
| 85 | 32 | ++ | N | N | N | 15·8 | 48 | 0·42 | + | ++ | N | N | N |
| 86 | 39 | + | N | N | N | 16·4 | 37 | 0·40 | + | + | N | N | N |
| 87 | 38 | + | – | Y | + | 29·3 | 48 | 0·37 | ++ | N | N | N | +++ |
| 91 | – | – | – | Y | + | 17·2 | 50 | 0·30 | + | + | + | N | N |
| 92 | 36 | N | N | N | N | 18·0 | 51 | 0·38 | + | + | + | N | + |
| 94 | 40 | N | N | N | N | 24·5 | 67 | 0·66 | + | + | N | N | N |
| 97 | 39 | N | N | N | N | 23·7 | 29 | 0·40 | + | + | N | N | N |
| 102 | 24 | ++ | ++ | Y | N | 19·2 | 36 | 0·64 | N | + | ++ | T | ++ |

LA Left atrial size (N Normal, + Mildly, ++ Moderately and +++ Severely enlarged), FS Fractional shortening (per cent), DF Ductal flow (N None, + Trival, ++ Mild, +++ Moderate, ++++ Severe), EF Ejection fraction (per cent), PEP:ET Systolic time intervals represented by pre-ejection period/ejection time ratio, MR Mitral regurgitation on colour flow Doppler echocardiography, MV Mitral valve appearance (N Normal, T Mildly, TT Moderately and TTT Severely thickened), AI Aortic insufficiency (N None, + Mild, ++ Moderate, +++ Severe), PI Pulmonic insufficiency (N None, + Mild, ++ Moderate, +++ Severe), AF Atrial fibrillation, – Results not obtained or not available

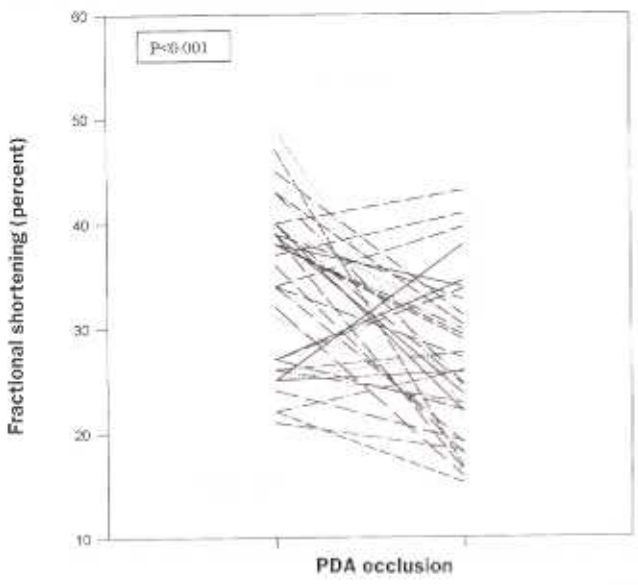



**FIG 4. Fractional shortening at initial presentation and at long-term follow-up (n=37)**

index (LVSI; LVSI = left ventricular volume in systole/body surface area) in this group of 12 dogs with FS less than 30 per cent at initial presentation as a further index of left ventricular systolic performance, eight of 12 animals had a LVSI over 50 ml/m$^2$, but five of these had mitral regurgitation.

Mitral E:A wave reversal occurred in 11 dogs. Linear regression analysis between age and E:A ratio in this population did not show a statistically significant inverse correlation. Furthermore, two dogs had abnormal pulmonary venous flow patterns, two dogs had increased IVRT and three dogs had EDT in excess of 0·098 seconds.

The changes (compared with the initial echocardiograms) in myocardial wall

**Table 6. Occurrences of residual shunting for three different closure techniques**

| Technique | | Residual shunting | | | |
|---|---|---|---|---|---|
| | | None | Mild | Moderate | Severe |
| Standard ligation | n=22 | 11 | 8 | 3 | 0 |
| Jackson technique | n=7 | 5 | 1 | 1 | 0 |
| Coil embolisation | n=11 | 5 | 3 | 2 | 1 |

**Table 7. Occurrences of late closure and recanalisation for three different closure techniques**

| Technique | | Late closure | Recanalisation |
|---|---|---|---|
| Standard ligation | n=20 | 1 | 4 |
| Jackson technique | n=6 | 1 | 1 |
| Coil embolisation | n=11 | 1 | 2 |

thicknesses and left ventricular diameters (normalised to body surface area), as assessed by M-mode echocardiography, in those animals that were over 12 months of age at initial presentation are seen in Fig 3. There was a significant difference in the left ventricular diastolic ($P<0.001$) and systolic ($P=0.033$) diameters indexed to body surface area, and left ventricular posterior wall in systole ($P=0.041$). FS changed significantly after closure (Fig 4). All remaining indices were found not to change significantly (Fig 3). Velocities across the aortic valve were less than 1·7 m/second in all animals. Aortic insufficiency was present in 25 of 37 dogs and this was considered mild in 19 and moderate in six.

The right parasternal short-axis view was found to give the highest quality image of the main pulmonary artery and ductus arteriosus. There was no statistically significant difference in maximum and mean velocity of flow across the pulmonary artery from the right parasternal or left cranial short-axis view. Colour Doppler echocardiography revealed mild pulmonary branch stenosis in two animals (one treated by coil, one surgically ligated). Neither of these dogs had echocardiographic evidence of pulmonary outflow tract obstruction prior to closure of the PDA. Pulmonic insufficiency was present in 28 of 37 dogs, which was considered mild in 23 and moderate in five.

Flow across the ductus was seen in 16 of 37 (43 per cent) animals. This was considered trivial in 10, mild in five and moderate in one; none were considered to have severe flow. The ratio of pulmonic to systemic flow, the Qp/Qs ratio, was above 2 (2·2 and 2·3) in only two of this group of animals.

### Treatment and outcome

Closure of the ductus was attempted via surgical ligation in 29 dogs (standard technique [22], Jackson technique [seven]), and transcatheter embolisation (Cook detachable coil[s]) in 11 dogs. Three dogs with failure of surgical closure (two with haemorrhage and one with ligature slip) underwent an embolisation procedure. There was no significant difference in occurrence of residual shunting between the different closure techniques (Table 6). Late closure of the ductus occurred with all techniques (8 per cent) as well as recanalisation (19 per cent) (Table 7), although there was no significant statistical difference between the techniques.

## DISCUSSION

### Long-term follow-up study

The breed distribution, which included a high prevalence of Cavalier King Charles spaniels, was slightly different from that reported previously (Eyster and others 1976, Buchanan 1994). However, it was a representative sample of the dog population with PDA (Van Israël and others 2002). The gender ratio was similar to that in previous reports (Eyster and others 1976). The high number of adult dogs seen at initial presentation was a valuable inclusion as one of the aims of this study was to evaluate the persistence of myocardial failure after ductal occlusion.

A fairly high proportion of dogs (19 per cent) had clinical signs of heart failure when they were re-evaluated, and this was radiographically and echocardiographically confirmed to be due to decompensating mitral valve endocardiosis. The auscultatory evidence of residual shunting (16 per cent) is much higher than reported previously (3 per cent) (Buchanan 1994), but it should be noted that three different closure techniques were used in the current study population. Mitral valve murmurs, attributed to mitral valvular dilation and stretch (Goodwin and Lombard 1992), and papillary muscle displacement (Kono and others 1992) secondary to left ventricular volume overload, normally disappear within two weeks of PDA occlusion (Buchanan 2001), when the heart returns to its normal size. Therefore, it is most likely that the mitral murmurs audible in this study were acquired murmurs, consistent with degenerative changes of the mitral valve in the older dog. The median age of dogs with echocardiographic characteristics of mitral endocardiosis was 78 months.

The electrocardiographic changes in this study (R and $Q_{II}$ amplitude reduction) were indicative of a reduction of the left and right ventricular masses after ductal closure. This was more prominent than in previous studies (Ackerman and others 1978) and the difference might be attributed to follow-up data at a later stage in life, with more time for reversibility of the cardiac changes. However, ECG voltage criteria used to infer cardiomegaly have inherent limitations (Tilley 1992). Atrial fibrillation at initial presentation has previously been associated with a grave prognos-

sation. This contrasts with the reports of Jackson and Henderson (1979), Buchanan (1994) and Miller (2000). Late closure has been associated with surgical closure (Buchanan 2001) as well as coiling (Stokhof and others 2000, Van Israël and French 2002), but no exact percentages have been published from which to make comparisons. This means that if mild residual shunting is present, complete closure is still possible, and that early attempts to achieve complete closure should perhaps be postponed if the animal is not cardiovascularly compromised by the quantity of residual flow.

## Survival study

Closure of the ductus has been established as a mandatory procedure in veterinary cardiology and the difference in survival times between animals which have undergone the procedure and those which have not support this, although some animals in this study survived for many years without PDA closure. Although some dogs had low-grade PDA murmurs (implying a small ductus), explaining their long survival time, in others there was no explanation for their long survival. This suggests that some animals with PDAs follow an unpredictable course. Interestingly, the time of closure and presence of heart failure at initial presentation do not appear to influence the outcome, and this contrasts with previous reports (DeHoff 1972, Buchanan 2001). One explanation might be the fact that most previous studies described mainly short-term surgical survival. Secondly, in the authors' institution, dogs in heart failure at initial presentation were treated aggressively before attempting to close the ductus, and are monitored long-term after occlusion, probably improving overall survival times. The very long survival times of animals which appear to have had decreased systolic function for years implies that it is not clinically significant. However, FS is a poor and variable measurement of myocardial function when evaluated as a single measurement. Unfortunately, due to the retrospective nature of this part of the study, no other systolic function indices were available.

The persistence of a small amount of flow also appears not to affect survival times. Since there was a trend towards reduced survival (P=0·052) in the presence of echocardiographic evidence of mitral regurgitation at initial presentation, and considering the high rate of occurrence of mitral endocardiosis in this study population, the development of mitral endocardiosis, and not myocardial failure or residual shunting, is probably the most compromising factor in the outcome of animals with PDA.

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