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RETROSPECTIVE STUDY ON PATENT DUCTUS ARTERIOSUS (PDA): SURGICAL LIGATION IN SELECTED DOGS NOT TREATED BY AMPLATZER OCCLUDER

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Abstract

Patent ductus arteriosus (PDA) is the most common congenital heart disease in dogs and can lead to heart failure. The left-to-right PDA can be treated by minimally invasive procedures or open thoracotomic surgery. Intravascular techniques for PDA occlusion in our Hospital involve the use of vascular occluders, a device that expands within the ductus lumen to close the PDA. In small breed dogs, due to the small diameter of the femoral artery or due to the shape of the ductus itself, intravascular access is not achievable. In these patients, open surgery with ductus ligation is the proper approach. The surgical procedure is influenced by the characteristics of the ductus. When the ligature of the ductus appears difficult or too risky because of the presence of multiple adherences and adhesions on the medial part of it or because the extremely reduced size of it, the Jackson-Henderson technique is a valid alternative. The appropriate technique is chosen for each patient after considering the possible complications, the risk of dissection, the surgical timeline and the outcome. Our study aimed to evaluate all the intra- and postoperative complications associated with thoracotomic PDA-ligation in a definite category of affected dogs characterized by higher risk factors than the average of the surgery-treated ones.

Key words: Patent ductus arteriosus, PDA, surgical ligation, PDA complications, dogs.

INTRODUCTION

Patent ductus arteriosus (PDA) is the most common congenital cardiovascular disease in dogs occurring in about 30% of cases (Buchanan, 2001).

In this cardiovascular pathology, the ductus arteriosus fails to close in the immediate post-natal period, due to a reduced percentage of muscle fibers in the ductus wall, especially near the aorta where they may be absent (Buchanan & Patterson, 2003).

Some breeds appear to be highly predisposed to PDA and inheritance has been demonstrated in Poodles and Welsh Corgis (Patterson et al., 1971; Oswald & Orton, 1993). Females appear to be more predisposed to the development of the defect than male dogs (Buchanan, 2001).

The presence of the PDA implies the existence of a shunt between systemic and pulmonary circulation, in which the flow direction is determined by either the size of the ductus or the difference between the systemic vascular resistance (SVR) and the pulmonary vascular resistance (Moïse and Short, 1987).

Under physiological conditions, the resistance in the aorta is greater than that in the pulmonary artery, therefore usually (at least in the initial stages of the disease) the shunt is directed from left to right. If not treated, left-to-right PDA may result in congestive heart failure by 1 year of age (Eyster et al., 1976).

Transcatheter occlusion with an ACDO device is the treatment of choice for the majority of dogs with left-to-right shunting PDA (Singh et al., 2012), but when the dog is too small (<2.5 kg) or the femoral artery is not suitable for the egress of the catheter or when the ductus is characterized by an excessive minimum ductal diameter (MDD) or by a cylindrical morphology with a variation in its diameter <20%, ACDO occlusion is not achievable (Blossom et al., 2010; Wesselowski et al., 2017; Orton, 2017).

In all these circumstances surgical ligation is the only solution to resolve the pathology.

Different approaches for dissection around the ductus and safe passage of the ligature material have been reported, like Standard ligation and Jackson-Henderson techniques (Jackson & Henderson, 1979; Parchman, 1991; Downs et al., 1995).

An appropriate technique is chosen for each patient after considering all the risk factors correlated to the most frequent complications.

It's essential to proceed with surgery as soon as possible, due to the increase in fibrousness of the periductal tissue and the reduction in elasticity and friability of the ductus in relation to the age of the animal (Breznock, 1975; Eyster et al., 1976).

The most serious complication associated with thoracotomic ligation is a potentially fatal hemorrhage (Brockman, 2016).

It's common to deal with large and short ducts, characterized by a greater degree of abnormality of the duct and therefore greater fragility (Buchanan, 2001). Considering also the greater perimeter to be explored with the dissection and the abundance coalescences, the surgical dissection may be quite difficult. To avoid blind dissection medial to the ductus, the Jackson-Henderson technique is a valid alternative but is linked to a higher risk of postoperative residual flow than standard ligation (53% vs 21%) (Stanley et al., 2003).

Another challenge related to the surgical approach is represented by the small size of the patient that imposes a very restricted operating field and requires a skilled surgeon.

Our aim was to evaluate all the intra and postoperative complications associated with thoracotomic PDA-ligation in a selected category of cases in which the execution of minimally invasive procedures was limited, and compare our results with the literature.

MATERIALS AND METHODS

The data for this study were collected from the database of dogs referred at the University Veterinary Teaching Hospital (OVUD) of the University of Perugia between January 2009 and February 2021, for a PDA surgical treatment. All clients were informed of therapeutic options and formally consented to the therapeutic plan.

Eighteen dogs underwent surgical ligation because they were excluded from minimally invasive techniques. Three of them were previously attempted to close with ACDO, with no success, while the others were immediately destined for surgical ligation due to their small size or the morphology of the ductus. All dogs were diagnosed with PDA by correlating physical examination, radiography, and transthoracic echocardiography (TTE). A complete TTE study was performed with echocardiography using electronic sector-scanning transducers (frequency range: 2-11 MHz).

Ductal shape and minimal ductal diameter at the pulmonic ostium were assessed by TTE. All imaging studies were submitted for evaluation to a single cardiologist (FP) who then determined the ductal measurements and ACDO size for each dog.

A complete blood count and biochemical and coagulation profile were performed in all patients.

According to these clinical findings, the patients included in the study represent a heterogeneous population in which 3 were mixed-breed and 15 breed dogs (Pomeranian, Chihuahua, Maltese, German Shepherd, Dachshund, Miniature Poodle, Lagotto, Deutsch Kurzhaar, Deutsche Spitz). Dogs had a bodyweight ranging between 0.8 kg and 15.8 kg, aged between 2 months and 2 years old. Of the 18 dogs evaluated, 13 were females and 5 were males (see Table 1 for demographic data).

All surgical procedures were performed by the same surgeon. Dogs were pre-oxygenated (flow-by; 3 to 5 L/min according to the size of the dog) before induction of general anaesthesia. Dogs were premedicated with intramuscular (im) opioids (such as pethidine 4-5 mg/kg or methadone 0.1 mg/kg) and midazolam 0.2-0.3 mg/kg, induced with lidocaine (Lidocaina 2%, Esteve Spa, Italy) (1.5 mg/kg) and propofol (Proposure, Merial Italia Spa, Italy) intravenous (iv) to effect (Cerasoli *et al*. 2016) and maintained with isoflurane (Isoflo, Esteve Spa, Italy) in 100% oxygen and sufentanil (Disufen, Angenerico Spa, Italy) constant rate infusion (CRI) (Bufalari et al. 2007).

Table 1. Breed, Gender (M - Male; F - Female), Age and Weight of 19 cases of PDA ligation.
Case 13 and 14 were the same dog, which required a second surgery due to the total ductus recanalization

Cases	Breed	Gender	Age (months)	Weight (kg)
1	**Miniature Poodle**	**M**	4	**2,7**
2	**German Shepherd**	**F**	4	**15,8**
3	**Deutsche Kurzhaar**	**F**	2	**3,3**
4	**Lagotto**	**M**	3	**4**
5	**Pomeranian**	**F**	7	**1,5**
6	**Maltese**	**F**	8	**2,1**
7	**Mixed breed**	**F**	2,5	**1,2**
8	**German Shepherd**	**F**	3	**6,8**
9	**Chihuahua**	**F**	3	**0,8**
10	**Deutsche Spitz**	**F**	9	**4,3**
11	**Pomeranian**	**M**	6	**2,3**
12	Mixed breed	M	3	2,6
13	Dachshund	F	12	4,4
14	Dachshund	F	13	3,8
15	Chihuahua	F	12	1,7
16	Pomeranian	F	3	2,8
17	Maltese	M	7	2,6
18	**Mixed breed**	**F**	24	**13**
19	Pomeranian	F	5	1,4

For those who required it, dobutamine or colloidal solution to counteract hypotension and lidocaine to control arrhythmias were used. All dogs received a pre-operative and post-operative intercostal nerve block with bupivacaine, lidocaine or ropivacaine. Carprofen (4 mg/kg iv) (Rimadyl®, Zoetis, Italy) (Bufalari et al. 2012) and buprenorphine (10 µg/kg iv) (Buprenodale, Dechra Veterinary Product Srl, Italy) were administrated as postoperative analgesic drugs.

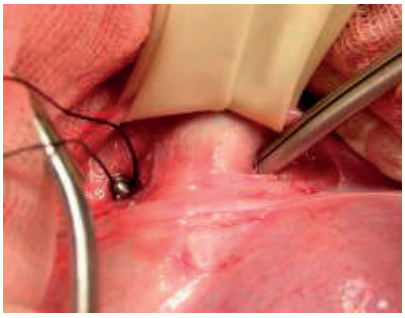
HR (beats/min); electrocardiogram; respiratory frequency; systolic, diastolic and mean non-invasive arterial blood pressures; peripheral capillary oxygen saturation; end-tidal carbon dioxide partial pressure; end-tidal isoflurane and rectal temperature (Multiparameter Monitor HB100; Foschi) were monitored continuously.

The surgical approach to the ductus was through a left, fourth intercostal thoracotomy. Dissections were either intra- or extrapericardial, with identification and careful preservation of the vagus, phrenic and left recurrent laryngeal nerves. We can identify two groups according to the technique used: Group S (Standard Dissection Technique) and Group JH (Jackson and Henderson Dissection Technique).

Group S

After caudal retraction of the cranial lung lobe, the vagus nerve was dissected free from the pericardium and retracted dorsally or ventrally using stay sutures or a silicone vessel loop. The phrenic nerve and recurrent laryngeal nerve were identified and avoided. A right-angled dissection instrument was then used to dissect around the aorta caudal to the ductus but cranial to the first intercostal artery. Therefore, a Penrose drain was placed around the aorta as a noose with its ends secured in a forceps. Slight traction of the loop allowed to open the space caudal to the ductus between the aorta, ductus and pulmonary artery trunk and to extend it medially by gentle dissection under direct visualization (Brockman, 2016). Exposure of the cranial aspect of the ductus was facilitated by cutting the loose connective tissues between the ascending aorta and ductus with blunt-tipped scissors, then a right-angle forceps was passed between the aorta and ductus at a 45° angle to the transverse plane (Orton, 2017). Afterwards, a blind dissection medial to the duct was carried out from caudal to cranial to complete the duct dissection. This step was undertaken with care because of the possible fragility of the medial wall of the ductus and proximity of the right pulmonary

artery. The dissection was performed using blunt-tipped right-angled forceps like Satinsky. Once the passage was created, a loop of ligature was passed from cranial to caudal (Figure 1). The loop was divided to form 2 individual strands. The ligature at the aortic end of the ductus was always tied first (Figure 2).



Figures 1, 2. Standard dissection technique. To the left (1): the right-angled forcep is passed from caudal to cranial, medial to the ductus to grasp the loop of ligature. To the right (2): The ligature at the aortic end of the ductus is tied first

Group JH

After caudal retraction of the cranial lung lobe and preservation of the nerves (as above), the mediastinal pleura dorsal to the aorta was incised with Metzenbaum scissors and delicately blunt dissection of the medial side of the aorta was performed, using both fingers and Satinsky forceps (Figure 3).

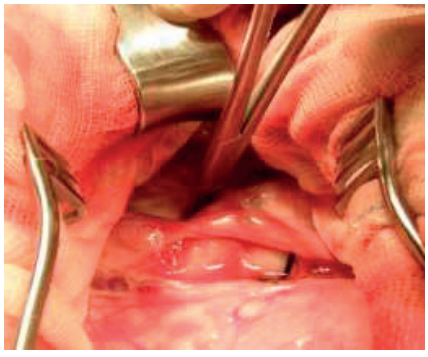


Figure 3. Jackson and Henderson dissection technique. The area dorsal and medial to the aorta has been dissected

A gentle exploration cranial and caudal to the ductus was carried out.

A right-angled forceps was then inserted immediately cranial to the ductus and passed around the aorta from ventral to dorsal while gently elevating the aortic arch with a finger or whit a Penrose drain aortic noose (as above). A loop of ligature was passed from the dorsomedial aspect of the aorta to the cranial aspect of the ductus, ventral to the aorta. The same procedure was repeated around the aorta from ventral to dorsal on the caudal margin of the ductus to pick up the 2 free ends of the ligature. Ventral traction was applied on the ligatures to draw them down slowly from the dorsomedial aspect of the aorta to the medial aspect of the ductus. The loop was divided to obtain two individual strains and the ligature at the aortic end of the ductus was always tied first.

In all dogs, ligations were performed using silk suture. Overall the closure took place in a time ranging from 5 to 7 minutes, in order to reduce the impact of a possible Branham reflex (De Monte et al., 2017). The ductus, aorta, and pulmonary arteries were then palpated for the presence of fremitus and to evaluate the appearance of aortic aneurysm dilation. After repositioning the cranial lung lobe and making sure of its complete reperfusion and physiological re-expansion, the thoracotomy was closed in layers. Negative pressure was delicately and progressively restored by a temporary small thoracic drainage that was removed after closure of the muscle layer. Perioperative antibiotic coverage was provided to all patients. First-generation cephalosporins or amoxicillin associated with clavulanic acid were administered, starting at induction and every 90 minutes during surgery, then continued postoperatively every 12 h for five days.

All dogs were echocardiographically evaluated 24-48 hours after surgery and 15 days after surgery, while the subsequent checks were set according to the clinical conditions of the individual patient.
Complications, either intra- or postoperative, were classified as:

Severe:
- Severe bleeding (Brockman, 2016);
- Suture suppuration;
- Total ductus recanalization (Brockman, 2016);
- Secondary chylothorax (Brockman, 2016);
- Cardiac arrest (Van Israel et al., 2002; Saunders et al., 2014).

Medium:
- Branham sign (De Monte et al., 2017);
- Transient or permanent post ligation aortic aneurysm dilation (Brockman, 2016);
- Iatrogenic pulmonary injury (Brockman, 2016);
- Iatrogenic left recurrent laryngeal nerve injury (Brockman, 2016);
- Partial ductus recanalization (Brockman, 2016);
- Hypertension (Brockman, 2016);
- Minor bleeding (Brockman, 2016).

Mild:
- Slight residual flow (Brockman, 2016);
- Cutaneous suture infection/dehiscence (Alison Moores, 2016);
- Weakness of the left forelimb (Alison Moores, 2016).

Associated risk factors were analyzed for each complication. Initial procedural success was defined as patient survival without need for a second surgery. Dogs that survived the initial procedure but died from an unrelated cause were considered to have a successful procedure.
Procedural mortality was defined as death within 14 days of the procedure.

RESULTS

Ligation was carried out in 95% of cases (n=18/19): in one dog the presence of numerous medial adhesions to the ductus and the aneurysm of the pulmonary artery were considered too high risks to proceed with the ligature. The same dog had already undergone an attempt at occluding with ACDO, whose access was considered impossible.
We considered 19 as denominator as one dog was counted twice since a second surgery was required.
On the other hand, the patient in which the ligation was not completed was not considered in the calculation of the procedure times and intra and postoperative complications rates.
Surgeries lasted from 75 to 275 minutes, with an average of 142 minutes.
Standard ligation was performed in 88% of cases (n = 16), Jackson-Henderson technique in 12% of cases (n = 2).
The silk threads used for the ligature were USP 1 in 7% of cases, USP 0 in 65% of cases, USP 2/0 in 14% of cases and 3/0 in 14% of cases.
A graphic illustration of the complications that occurred is shown in Figure 4.

Severe complications
Severe complications occurred in 11% of dogs (n = 2).
Severe I.O. complications included severe bleeding, that happened in 5.5% of dogs (n = 1): first, a hemorrhage medio-cranial to the ductus occurred, then, at the time of ligating the PDA, severe pulmonary artery bleeding occurred, which resulted in the patient's death.
Severe P.O. complications included total ductus recanalization, which occurred in 5.5% of dogs (n = 1), due to the failure of the silk threads. This dog required a second surgery to close the duct, 1 month later (surgery was postponed due to respiratory infection by *Bordetella bronchispeptica*, not related to the first surgery). At the time of the second surgery, it was possible to verify that the knot was intact, while the thread was totally worn out. The size of the thread used in the first surgery was a 2/0 USP in diameter. Probably, due to the high pressure reached in the postoperative phase, the thread had suffered a fatigue failure.
Medium complications
Medium complications occurred in 89% of dogs (n = 16).
The I.O. ones included Branham reflex that showed in 55.5% of dogs (n = 10) and transient

aortic aneurysm dilation, occurring in 22.5% of dogs (n = 4).
In dogs that exhibited Branham reflex, atropine 20 μg/kg iv was administered with a complete return to baseline values of the heart rate within few seconds.
In these dogs, the average MDD was 3.87 mm and the average Ampulla diameter was 8.56 mm.
Aortic aneurysm dilation is caused by the increase in pressure triggered by the ligation of the ductus. High-pressure blood flow acts on the thin walls of this anatomical structure causing its dilation, which can be transient and reduce with the reestablishment of blood pressure or persist into the postoperative period.
In one dog (5.5%) permanent aortic aneurysm dilation occurred. It led to the formation of a thrombus inside of it, which required low dose

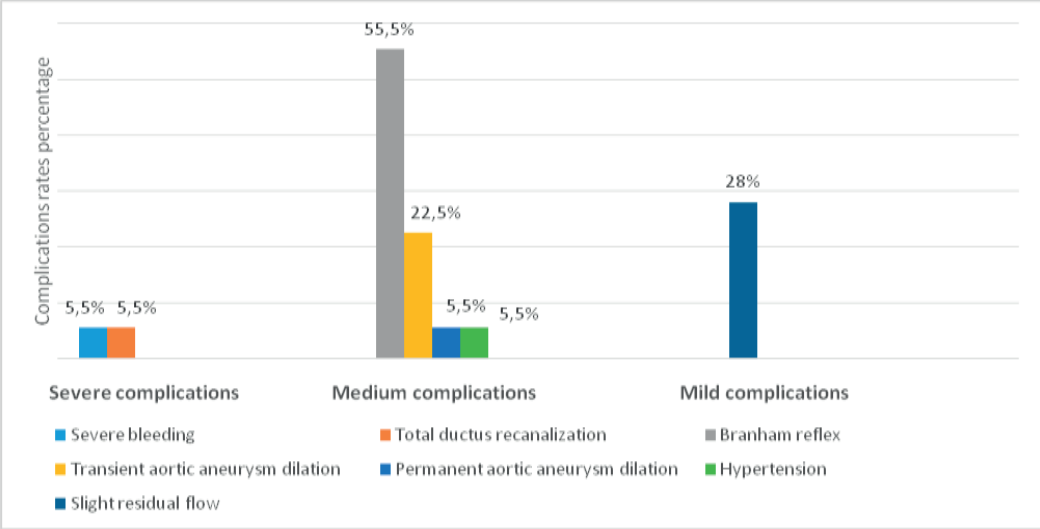


Figure 4. Graphic illustration of the complications, and related rates, we encountered in our study

acetylsalicylic acid treatment until the thrombus disappeared, which was confirmed two months after surgery follow-up.
In dogs that showed aortic aneurysm dilation, the average MDD was 4.3 mm and the average Ampulla diameter was 10.6 mm.
Other P.O. complications included hypertension, presenting in 5.5% of dogs (n=1).
Furosemide (2 mg/kg EV BID) was administered in this dog; the same dog underwent ductal recanalization due to the fatigue failure of both sutures which required a second surgery.

Mild complications
Mild complications occurred in 28% of dogs (n = 5) which presented slight residual flow.
In one of them, the 4 months after surgery echocardiographic control decreed the absence of the flow. In the other patients, subsequent checks confirmed the persistence of a slight but insignificant residual flow with no repercussions on cardiac hemodynamics.
The initial success rate was 94.5% because 17 of 18 dogs didn't require a second surgery.
The procedural mortality rate was 5.5%, due to the only patient who died intraoperatively due to severe arterial bleeding.

DISCUSSIONS

In this study, we evaluated the results of PDA ligation in a group of high-risk patients selected for their particular small size and morphology of the ductus, which limited the execution of minimally invasive procedures. Starting from this assumption, the results obtained were considered good and comparable with those obtained by other authors who had a larger cohort of non-selected patients.

The anatomical features of the ductus influence the choice of surgical technique, as they also influence complications rate. In this regard, the studies of James Buchan (Buchanan 1978, 2001) illustrate the anatomical basis that explains the fragility of the ductus or aorta experienced during dissection in some animals. His studies demonstrated that certain regions of the ductus and the section of the aortic wall through which the ductus courses (which Buchanan termed the "ductus aneurysm") were very thin compared with the normal aorta. In addition, certain anatomic types, which are ever excluded from minimally invasive techniques (like type III ducts according to Miller classification) (Miller, 2006), might be even more challenging to dissect around to the point. In this respect, according to some authors, the best choice may be not the ligation of the ductus; some authors prefer to perform its incision followed by suturing the two ends (Buchanan, 1996; Rodriguez Gomez et al., 2013).

To plan the proper surgery, careful preoperative measurement of the MDD, of the diameter and length of the ampulla is essential. This data can be obtained by magnetic resonance (RMI), angiotomography (Henjes et al., 2001) or transesophageal echocardiography (TEE) which provides more accurate results than TTE (Saunders et al., 2019).

In our study, diagnostic tools for preoperative measurement only included TTE which unfortunately can overestimate the size of the duct (Saunders et al., 2007), often leading us to understand the real conformation of the duct only in the intraoperative setting.

The major complication we encountered, was severe bleeding which led the dog to sudden death. The patient was a 3 months old Chihuahua, with a weight of 800 grams. Its duct had a MDD of 2.8 mm and the ampulla was 4.1 mm long. The dog experienced severe ductal bleeding during the dissection of the duct; at first, the bleeding was controlled and stopped. Unfortunately, during the following duct ligature, an unrecoverable hemorrhage of the pulmonary trunk caused the animal death. The ligation, in consideration of the small size of the dog, was attempted with a USP 3/0 silk thread; we may speculate that the size of the thread was too small and contributed to tearing the tissue apart, which was already very fragile in itself. The choice of suture material and size may be very important. Unfortunately, since there are no specifics about it, the choice of the size of the thread depends on the surgeon's experience. Silk is a great option as it is a braided suture that has greater strength and allows a higher knot tightness than a monofilament one, although it's more prone to bacterial nesting. A smaller USP suture allows to tighten the knot better but has a more relevant abrasive action that can lead to a progressive laceration of the vessel; moreover, it's less resistant and can break. On the other hand, a higher USP suture has greater resistance, less abrasive effect but can untie easily and its thickness could create difficulties in the complete closure of the duct and could increase the risk of the permanence of a residual flow.

When ductal hemorrhage is minimal, a change in the direction of dissection may lead to the completion of dissection (Brockman, 2016). Other authors like Hunt (2001) have described the clinical use of the temporary total cardiac outflow occlusion, as advocated by Eyster (1985). This technique would either allow further dissection or facilitates accurate clamp placement in the event of ductal hemorrhage (Hunt et al., 2001). To realize it, pericardium must be incised and vascular clamps are placed simultaneously across the aortic and pulmonary roots. In addition, making traction on the aortic noose (method described above) will limit backflow of blood down the aorta and allow to expose the caudal ductus further to facilitate clamp placement. In our study, extrapericardial access was used for most of the subjects as the duct was outside the pericardial membrane and clearly visible. According to some authors (Selmic et al., 2013), intrapericardial access would allow also to deal with a smaller amount of tissue and reduce the dissection times.

Based on previous studies, severe bleeding during PDA ligation has been estimated at 6-10% in dogs (Eyster et al., 1976; Ackerman et al., 1978; Hunt et al., 2001; Birchard et al., 1990) leading to a 1.6-11% mortality risk (Van Israel et al., 2002; Hunt et al., 2001; Eyster et al., 1976; Bureau et al., 2005; Birchard et al., 1990); that means our results fall within the incidence ranges described in the literature. The

most important risk factor linked to intraoperative bleeding is the blind dissection medial to the duct, principally required in the Standard technique: care must be taken not to execute a shallow dissection in relation to the ductus because this could lead the instrument directly into the medial ductus wall and, at the same time, it's imperative not to continue dissection too deeply because the right pulmonary arterial branch is vulnerable in this position. In addition, the risk is increased by the type of instrument used and the age at the time of the procedure. Very small curved forceps are often required (Figure 5) (especially when the patient is small), the ends of which are pointed, increasing the risk of perforation of the vessel walls. While in older subjects, especially in those over two years of age (Rodriguez et al., 2013), the risk increases due to the greater fibrousness of the periductal tissue (Breznock, 1975) and the friability and the lower elasticity of the duct (Eyster et al., 1976). For this reason, it is important to proceed with surgery as soon as possible. In our series, the average age of the operated subjects was 6.4 months, with 61% ≤ 6 months and 21% ≥ 12 months.

Figure 5. Several types of Satinsky hemostats were used in our study for the dissection of the patent ductus arteriososus

Jackson & Henderson technique (Jackson & Henderson, 1979) was specially designed to avoid blind dissection medial to the duct and thus reduce the risk of hemorrhage. A randomized, prospective study on 35 dogs revealed that the risk of residual postoperative ductal flow is higher for this technique (53%) than for the Standard one (21%), due to greater inclusion of periductal tissue in the ligature (Stanley et al., 2003). We noted a similar slight residual flow (mild complication) in group S (19%, n = 3/16) but a higher incidence in group JH (100%, n = 2); it must be considered that in our study the JH technique was performed only in 2 patients, therefore the number of subjects included is small in order to be able to compare this data with other reports. To avoid residual ductal flow, authors like Brockman (2016), propose a third ligation with polypropropylene suture, transfixed to the duct and positioned between the two traditional ones.

If the residual flow is evaluated as insignificant from a haemodynamic point of view, not only it is not necessary to perform a second surgery but it is even not recommended (Brockman, 2016). Surgical revisions are inherently risky due to the development of adhesions between the duct and surrounding structures that make dissection difficult and ligation dangerous as they increase the risk of vascular laceration. Sometimes the risk is so high that division of the duct and pulmonary lobectomies may be required (Eyster et al., 1975).

The major cause for concern with residual shunting is apparent recanalization of the ductus, which is reported to occur in approximately 1%-2% of cases (Eyster et al., 1975; Birchard et al., 1990), whose risk increases according to the extent of the residual flow and in case of hypertension (Brockman, 2016).

In our study, 1 dog (5.5%) had postoperative hypertension (due to the initial closure of the duct) that caused the breakage or failure of the suture. It led to duct recanalization and so to a second surgery. In the first surgery, ligation was realized with a 2/0 USP silk suture; during the revision surgery, we opted for a 0 USP for the reasons described above. The same dog also required a partial pulmonary lobectomy of the left cranial lobe which was severed during the access to the thoracic cavity due to a complete adhesion with the left rib wall.

Speaking of Branham reflex, it consists in the lowering of the heart rate (by at least 5-6 bpm) (Muir, 2007) as a consequence of an increase in mean and diastolic arterial pressure, following the closure of the duct, both by surgical ligation and by catheter occlusion (Hellyer, 1992).

According to the study by De Monte et al. (2017), the only variable capable of predicting the haemodynamic reactions following the ligation of the duct would be the diastolic velocity of blood flow in the duct, as it has a moderate inverse correlation with the increase in mean arterial pressure.

The entity of a flow through a duct is directly proportional to the pressure gradient existing at its ends and inversely proportional to the resistance encountered. In small ducts, the resistance is highs, as is the flow velocity, but the volume of blood passing through them is modest. For this reason, a less pronounced Branham reflex should be expected following the occlusion of smaller diameter ducts.

In the dogs which exhibited Branham reflex in our study, ducts were characterized by a medium to large MDD and a large ampulla. One of them is the one who developed hypertension and total ductal recanalization (MDD = 4.2 mm; Ampulla diameter = 10 mm).

Many factors related to anesthesia and surgery can lead to changes in heart rate and blood pressure. In our case, sufentanil, isoflurane, as well as pain, surgical manipulation and hypothermia may have played a role in influencing these parameters (Bufalari et al., 2007).

Finally, post ligation aortic aneurysm dilation: in our series, we have found that dilation is very common, especially in dogs with large ducts, in which the increase in pressure following the ligation of the ductus is greater.

We have more frequently noticed a transient intraoperative dilation, which however retains a high risk of rupture, described by some authors in the postoperative period. Unfortunately, is not possible to avoid its rupture (Brockman, 2016), but perhaps it could be possible to predict its formation based on the characteristics of the duct.

CONCLUSIONS

Reducing the risks associated with surgical ligation is possible thanks to a multimodal approach which consists in planning the surgery as soon as possible in young animals, in the use of diagnostic imaging tools like RMI, angio-TC or TTE that give precise and reproducible results and allow to know the characteristics of the ductus before surgery, in order to choose the most suitable technique, as well as the most suitable dissection forceps and suture for ligation. Last but not least, the surgeon's skill and experience on dissection and familiarity with the techniques usedare of the utmost importance

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