Open heart surgery with deep hypothermic cardiopulmonary bypass and more than 90 minutes of aortic cross clamp time in 10 small dogs

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Abstract

No previous reports have described cardiopulmonary bypass (CPB) techniques involving long aortic cross clamp (ACC) times in small-breed dogs. We previously described open heart surgery under deep hypothermic CPB in small and toy dogs with an approximate ACC time limit of 1 hour, given the low success rate beyond 90 minutes of ACC time. Herein, we describe improvements in cardiac anesthesia, CPB, and cardioplegia that led to a high success rate of open heart surgery with a long ACC time in small dogs. Ten small-breed dogs with severe mitral regurgitation were subjected to mitral valve plasty that necessitated cardiopulmonary bypass (CPB) beyond 90 minutes of ACC time. In the present study, all dogs survived surgery; 7 survived to discharge. In other words, we achieved a high success rate of 70% with mitral valve plasty beyond 90 minutes of ACC time (mean, 105.1 minutes: range, 90-117 minutes). For small dogs, successful open heart surgery with a long ACC time may require cardiac balanced anesthesia, CPB with increased drainage and, importantly, thorough cardioplegia without hemodilution.

Introduction

Cardiopulmonary bypass (CPB) in humans or non-human animals with low body weights is associated with challenging factors such as hemodilution, cardioplegia, and anesthesia.[1,2] However, few reports have described CPB techniques in small- or toy-breed dogs,[3,4] despite some reports of CPB techniques in larger dogs.[5-8] In addition, no reports have described the use of CPB techniques involving long aortic cross clamp (ACC) times in small dogs, even though the complete repair of complex intracardiac lesions requires a long ACC time and extensive CPB techniques.[9] Ideally, however, in dogs the ACC time should not exceed 90 minutes; longer times have been associated with a low success rate.[10] In our previous report, we described open heart surgery under deep hypothermic CPB in small and toy dogs, with a limit of approximately 1 hour of ACC time.[3] At that time, our success rate was low with regard to open heart surgery beyond 90 minutes of ACC time in small dogs. However, in this paper, we describe more recent improvements in our cardiac anesthesia, CPB, and cardioplegic techniques that have allowed us to achieve a high success rate for open heart surgery beyond 90 minutes of ACC time in small dogs.

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Materials and Methods

Between September 2013 and May 2014, 10 small dogs (3 Shih Tzus, 2 Chihuahuas, 2 miniature Schnauzers, 1 Maltese, 1 Pomeranian, and 1 Cavalier King Charles Spaniel) were subjected to mitral valve plasty (MVP) for severe (American College of Veterinary Internal Medicine stage C–D) mitral regurgitation (MR) that necessitated CPB with an ACC time >90 minutes. The dogs had a mean age of 9.3 years (range, 7.3-10.8 years) and a mean body weight at surgery of 5.1 kg (range, 2.9-8.7 kg; Table 1). Basic MVP techniques comprised chordal reconstruction (CR) using expanded polytetrafluoroethylene (ePTFE) sutures in both mitral valve leaflets, and semicircular suture annuloplasty (AP) using polypropylene (Proline) sutures in the posterior valve ring. Additional MVP techniques were used in all cases with valvuloplasty (VP) via a method involving direct suture of cusps in the posterior leaflet.[11] The basic CPB techniques were reported in a previous study;[3] however, some techniques were improved as described below.

Anesthesia

Dogs were premedicated with atropine sulfate (25 μg/kg intramuscularly [IM]), ketamine hydrochloride (2.5 mg/kg intravenously [IV]), fentanyl hydrochloride (5 μg/kg IV), and midazolam hydrochloride (0.2 μg/kg IV) before inducing anesthesia with thiamylal sodium (12.5 mg/kg IV to effect) or alfaxalone (2 mg/kg IV to effect). Anesthesia depth was maintained with 0.5-1.5% isoflurane in oxygen, fentanyl hydrochloride (10 μg/kg/h continuous rate infusion [CRI]), and/or alfaxalone (0.02 mg/kg/min CRI) with intermittent pancronium bromide (0.06 mg/kg IV) or rocuronium (0.5 mg/kg IV, followed by 6 μg/kg/min CRI) according to the anesthetic effect. Hypothermia was slowly induced to an esophageal temperature (ET) of 20-25°C via blood cooling with a heat-exchanger. Immediately before ACC release, blood rewarming was initiated slowly at a rate of 5°C to an ET of 37°C with a heat-exchanger.

Cardiopulmonary bypass

A venous drainage cannula (Toyobo TWN8-12, Toyobo Co., Tokyo, Japan) modified to include 4-5 side holes at the tip (Figure 1) and an arterial cannula were inserted into the right atrium via the left jugular vein and left carotid artery, respectively. These instruments were connected to the CPB open circuit (total priming volume, 188 mL), which comprised a hard reservoir and membrane oxygenator (Terumo Baby RX-05; Terumo Co., Tokyo, Japan) combined with a heat-exchanger (Figure 2).

Unoxygenated blood was drained by gravity through the venous cannula into the reservoir.

A roller pump returned oxygenated blood to the carotid arterial cannula through the membrane oxygenator and heat-exchanger. The priming solution comprised acetated Ringer solution (200 mL), 7% sodium bicarbonate (15 mL), mannitol (15 mL), cefazolin (200 mg), and cross-matched donor blood (60-100 mL) added to maintain a hematocrit (Ht) of approximately 20%.

Cardioplegia

After ACC, cold (4°C) St. Thomas' II cardioplegic solution (Miotector, Mochida Pharmaceutical Co, Tokyo, Japan), which was initially added with KCL to increase the K+ concentration from 16 mEq to 20 mEq, was immediately injected in an antegrade manner at 100-120 mmHg of pressure through an aortic root cannula via syringe; this was repeated every 20 minutes or when an action potential occurred on the electrocardiogram (ECG). The initial dose was 20 ml/kg; all subsequent doses were 10 ml/kg, and all were ultrafiltered at the reservoir to approximately the same volume using a hemoconcentrator (MAQUET BC 20 plus, Maquet Japan Co., Tokyo, Japan) parallel to the CPB circuit (Figure 2).

Results

Open heart surgeries were performed with a mean ACC time of 105.1 minutes (range, 90-117 minutes), mean lowest ET of 22°C (range, 20.3-25.2°C), and mean total pump time of 147.5 minutes (range, 117-190 minutes). During ACC, the mean pump flow was 64.3 mL/kg/min (range, 46.9-80.9 mL/kg/min), mean aortic pressure was 63.5 mmHg (range, 51.7-75.8 mmHg), and mean urine volume was 5.8 mL/kg/h (1.8-16.6 mL/kg/h; Table 2). The mean Ht before CPB was 31.4% (range, 16.9-47.6%); this was reduced via hemodilution during CPB to a mean value of 22% (range, 18.4-27.9%). The mean Ht after CPB was 28.1% (21.6-33.5%). The mean elapsed time from the beginning of blood cooling to an ET of 22°C was 44.2 minutes (range, 30-55 minutes), and the mean elapsed time for rewarming to an ET of 37°C was 41.2 minutes (range, 25-65 minutes). The mean time from the end of the operation to extubation was 197.1 minutes (range, 62–385 minutes; Table 3). All dogs survived surgery, and 7 survived to discharge (success rate,

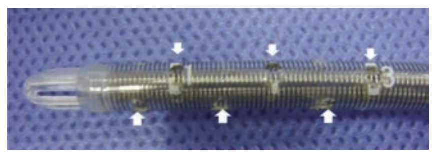

Figure 1. A venous drainage cannula (Toyobo TWN8-12, Toyobo Co. Tokyo, Japan), altered by the addition of 4-5 hand-made side holes at the tip.

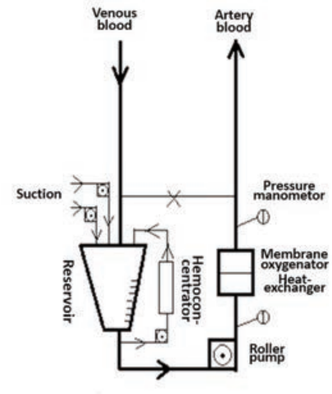

Figure 2. Cardiopulmonary bypass (CPB) open circuit (total priming volume, 188 ml), comprising a hard reservoir, a roller pump, and a membrane oxygenator (Terumo Baby RX-05; Terumo Co., Tokyo, Japan) combined with a heat-exchanger. Left jugular vein blood is drained by gravity through the venous cannula into the reservoir. A roller pump returns oxygenated blood to the carotid arterial cannula through the membrane oxygenator and heat-exchanger. In addition, the hemoconcentrator (Maquet BC 20 plus, Maquet Japan Co., Tokyo, Japan) is parallel to the CPB circuit at the reservoir.

Table 1. Cases, intracardiac surgeries, and results.

Case	Breed	BW, kg	Age, y	Sex	Diagnosis	Operation	Result	Cause
1	KC Cavalier	6	10.2	♀	MR	MVP	Alive	-
2	Pomeranian	4.26	8	♂	MR	MVP	Alive	-
3	M schnauzer	4.1	9	♀	MR	MVP	Alive	-
4	Shih Tzu	8.7	10.3	♂	MR	MVP	Dead (2 d later)	PE
5	Chihuahua	3	9.2	♀	MR	MVP	Alive	-
6	Chihuahua	3	7.3	♀	MR	MVP	Dead (14 h later)	ARF
7	Shih Tzu	8.5	10	♂	MR	MVP	Dead (23 h later)	ARF
8	Shih Tzu	5.2	10	♂	MR	MVP	Alive	-
9	M schnauzer	5.3	8	♀	MR	MVP	Alive	-
10	Maltese	2.9	10.8	♂	MR	MVP	Alive	-
Mean		5.1	9.3					

MR, mitral regurgitation; MVP, mitral valve plasty PE, pulmonary edema

Table 2. Cardiopulmonary bypass parameters.

Case	ACC time, min	Lowest ET, °C	Pump time (min)	MPF during ACC (mL/kg/min)	MAP during ACC (mmHg)	UV during ACC (mL/kg/h)
1	105	20.3	145	47.9	75.8	7.2
2	99	23.8	120	46.9	66.2	3.2
3	92	20.8	117	69.7	73.5	16.6
4	113	23.9	163	60.5	65.1	2.6
5	108	25.2	152	80.9	69.1	2.4
6	106	21	140	77.4	58.6	1.8
7	110	20.5	190	55.4	51.7	3.7
8	90	22.5	122	80	66.4	9
9	117	20.5	190	49.7	54.6	5.7
10	111	21	136	74.9	54.1	5.8
Mean	105.1	22	147.5	64.3	63.5	5.8

CPB: cardiopulmonary bypass, ACC: aortic cross clamp, ET: esophageal temperature, MPF: mean pump flow, MAP: mean aortic pressure, UV: urine volume

Table 3. Other cardiopulmonary bypass parameters.

Case	HT % Before CPB	HT % During CPB	HT % After CPB	Cooling time (min)	Rewarming time (min)	Extubation time (min)
1	21.2	19.1	29.6	44	42	240
2	16.9	19.8	?	(25)	(15)	218
3	24.8	18.4	32	36	25	62
4	?	?	?	(35)	(40)	340
5	47.6	22.9	28.2	(28)	(30)	130
6	34.4	22.6	25.6	45	50	×
7	42.6	27.9	33.5	55	35	×
8	35.9	20.9	26.5	(35)	(30)	70
9	21.9	22.6	21.6	55	65	385
10	37	23.4	?	30	30	132
Mean	31.4	22	28.1	44.2	41.2	197.1

CPB: cardiopulmonary bypass, Ht: hematocrit, ET: esophageal temperature. Cooling time: elapsed time from beginning of CPB to ET of 22°C. Rewarming time: time required for rewarming to ET of 37°C. Extubation time: elapsed time from the end of surgery to extubation. ?: unclear, ( ): inaccurate, ×: immeasurable.

70%). Dog No. 4 died 2 days after surgery because of pulmonary edema. Dogs No. 6 and 7 were euthanized 14 and 23 hours after surgery, respectively, because of acute renal failure (ARF; Table 1).

Discussion

A long ACC time and improved CPB techniques are needed to ensure the complete repair of complex intracardiac lesions.[9] In our cases, which were affected by severe MR lesions involving both valve leaflets, MVP surgery required an ACC time >90 minutes and a long CPB time. In addition, techniques that combined MVP with multiple (4–8) CR, semicircular suture AP, and VP of multiple (2-4) valve cusp direct sutures were required.[11] As a result, the MVP surgeries in our study required a mean ACC time of 105 minutes. However, our overall success rate was 70%.

During heart transplantation with severe congestive cardiac failure, anesthesia is carefully administered to ensure hemodynamic stability.[12] Anesthesia in cases of severe MR with congestive cardiac failure also requires the same level of attention.[13] Therefore, premedication, induction, and maintenance were recently changed from a deep state to a milder state of anesthesia using balanced anesthesia to ensure good hemodynamic maintenance (*e.g.*, aortic pressure, urine volume). Improvements in anesthesia may have led to delayed CPB initiation with a relatively shorter CPB time compared to our previous study, regardless of the longer ACC time (mean pump time, 147.5 minutes with a mean ACC time of 105.1 minutes).[3] Increased drainage flow is required to increase the pump flow.[14] In the present study, an improvement made to the venous drainage cannula, involving the addition of 4-5 side holes at the tip to increase the efficiency and drainage flow, led to an increase in pump flow during ACC from a low to moderate flow.[15] In addition, the location of the drain tube tip was adjusted at the middle site in the right atrium via transesophageal or transthoracic echocardiography. Moreover, excessive slinging of the pericardial hammock was avoided to prevent kinking of the posterior vena cava. In the present study, we found that with mild anesthesia, the mean pump flow during ACC increased, and the aortic pressure and urine volume during ACC both increased interdependently in comparison to the previous study.[3] Furthermore, in this study, the dose of cold St. Thomas' II solution[16] was increased 2-fold relative to our previously reported volume,[3] and was repeated every 20 minutes[17] or when an action potential occurred on the ECG monitor. Accordingly, the recovery of myocardial contractile strength and weaning from CPB occurred more rapidly, regardless of the long ACC. The hemoconcentrator coped well with excessive hemodilution due to an increase in cardioplegic solution,[18] and a post-procedural increase was observed in the mean Ht relative to the level during CPB. In the future, bloodless CPB, involving blood or hot-shot cardioplegia and a small circuit, may be more useful in small and toy dogs. We lost 3 dogs during the present study, all of which were among the 5 dogs (No. 4-8) that underwent surgery at a satellite hospital, which was managed by an inexperienced intensive care unit staff. Dog No. 4 died of pulmonary edema with an unknown etiology 2 days after surgery. As this dog had been successfully extubated at 340 minutes after surgery, CPB did not appear to be the primary cause of pulmonary edema. For dog No. 6, which died of ARF, re-thoracotomy was performed at 5 hours, 20 minutes after surgery because of sustained blood leakage in the chest cavity, which might have led to oliguria and anuria consequent to low output syndrome (LOS). Despite the large urine volume during ACC (3.7 mL/kg/h) and reduced bleeding in the thoracic cavity after chest closure relative to dog No. 6, dog No. 7, which also died of ARF, appeared to develop LOS as a result of poor cardioplegia and/or postoperative management. We note that in contrast to a report involving human conditions, our 2 cases did not appear to be related to hemodilution during CPB.[19]

Conclusions

Cardiac balanced anesthesia for hemodynamic stability, CPB with increased drainage to ensure moderate pump flow during ACC and, especially, thorough cardioplegia without hemodilution appear to be essential to a high success rate following open heart surgery with a long ACC time in small dogs.

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