Mitral valve repair in dogs

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Abstract
Prognosis for dogs with severe mitral regurgitation is poor with medical therapy alone. Open surgical mitral valve repair consisting of circumferential mitral annuloplasty and artificial chordal replacement confers durability and improved long-term clinical outcome without a need for long-term antithrombotic therapies. This approach has been successfully used in canine patients, including small-breed dogs. Methods for mitral valve repair applicable to small dogs are described.

Introduction

Dogs with severe mitral regurgitation have a poor prognosis despite recent medical advances for the management of heart failure. While pimobendan improves the clinical condition and prognosis in affected dogs, 80% of these patients are likely to worsen or die within 2 years of diagnosis. Because medical management of secondary heart failure is incapable of correcting disorders of the mitral valve complex, surgical intervention is required to improve clinical condition and prognosis.

Surgical treatments for mitral regurgitation include valve replacement and valve repair. While these are standard therapies in humans, mitral valve surgery has been reported in comparatively few veterinary patients. Open heart surgery is
more commonly attempted in larger breeds, as it is difficult to perform cardiopulmonary bypass (CPB) in small dogs using traditional methods. Recent improvements in CPB techniques have facilitated its effective use in small-breed dogs and even in a cat. These advances have enabled successful mitral valve surgery in a wider range of dog sizes. Faulty mitral valves can be replaced with a mechanical valve or a bioprosthetic valve. In the case of prosthetic valves, long-term survival is promoted by carefully matching the size of a prosthetic heart valve to the dog and strong efforts to avoid thrombosis. One advantage of bioprosthetic valves is that they are less thrombogenic than mechanical valves. Bioprosthetic valve replacement may be particularly useful in cases of mitral valve dysplasia, in which the original mitral valve is difficult to repair. One potential drawback of bioprosthetic valves is their tendency to calcify or degenerate over time, thus reducing long-term survival. Dogs receiving bioprosthetic valves have been known to survive >17 months, with no reports to date of calcification bioprosthetic heart valves in dogs.

In both human and veterinary medicine, properly performed mitral valve repair, including both circumferential mitral annuloplasty and artificial chordal replacement, confers excellent durability and improved long-term clinical outcomes without the need for long-term antithrombotic therapy. Thus, mitral valve repair may become an important treatment for mitral regurgitation in dogs. This report describes methods for mitral valve repair in dogs.

Cardiopulmonary bypass

Mitral valve surgery requires stopping the heart and support of cardiac and pulmonary function by CPB. This is accomplished by a heart-lung machine with an extracorporeal circuit, oxygenator, and heat exchanger. The CPB circuit is filled with a priming solution consisting of 20% mannitol, 7% sodium bicarbonate, and heparin sodium in acetate Ringer’s solution. In dogs weighing <4 kg, priming solution should be replaced with 20–50 mL of whole blood in order to avoid excess hemodilution. Induction of hypothermia during CPB reduces demand for O2 and preserves peripheral tissues. This is achieved by combination of body-surface cooling and use of a heat exchanger within the CPB circuit. Use of both techniques simultaneously maximizes control of the body temperature. When used in conjunction with anesthesia, hypothermia limits damage during CPB by maintaining low blood circulation.

Cannulation for CPB

In preparation for CPB, the left carotid artery and the jugular vein are surgically isolated and the thoracic cavity is opened at the left 4th or 5th intercostal space. Heparin (400 U/kg) is administered intravenously. Once the activated clotting time has exceeded 300 s, an arterial cannula is inserted into the carotid artery. In dogs weighing <5 kg, arterial cannulation to the carotid artery requires a 6-Fr cannula, whereas an 8-Fr cannula is needed for dogs weighing 5–10 kg. A single venous cannula is inserted into the left jugular vein. An 8 to 10-Fr cannula in dogs weighing <5 kg or a 10 to 14-Fr cannula in dogs weighing 5–10 kg is appropriate. Cannulation of peripheral vessels is preferred over direct cannulation of aorta and right atrium in small dogs in order to avoid obstructing visualization of the surgical field by the cannulae. The CPB circuit is connected to both the arterial and venous cannulae. Air is carefully removed from the arterial side of the circuit. The artery and vein lines are de-clamped and CPB is commenced at a flow rate of 90–120 mL/kg/min. The body temperature is held between 25 and 30 °C. The pump flow is carefully monitored to match venous return (Fig. 1). During CPB, anesthesia is switched from inhalation of isoflurane to intravenous fentanyl and propofol infusion. During CPB, arterial and central venous blood pressure, oxygen saturation and blood gases are monitored.

Induction of cardiac arrest

Mitral valve repair requires a bloodless and motionless field of vision. This is achieved by infusing a cardioplegia solution into the coronary arteries via the aortic root. A catheter is inserted through a purse-string suture on the left lateral side of the ascending aorta. The aorta is occluded using a vascular clamp placed distal to the cardioplegia cannula and proximal to the brachiocephalic artery. Cardioplegic solution is immediately infused into root of the aorta to induce cardiac
arrest (Video 1). Administration of cardioplegia solution is repeated every 20 min. Although this is the standard protocol for intracardiac procedures, it is also possible to utilize an on-beat cardiac surgery technique, which diminishes the risk of ischemia-reperfusion injury. However, this may cause blood to leak from the aorta obscuring the surgical field.

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Discontinuing CPB

The patient is re-warmed to > 36 °C prior to weaning from CPB. After the left atrium has been closed, the aortic clamp is removed. As coronary circulation restored, cardiac rhythm may return spontaneously (Video 3). Use of a defibrillator at 10–30 J may be required if ventricular fibrillation is observed. The flow rate is decreased in a stepwise fashion until CPB is terminated. Once the cannulae have been removed, it is generally necessary to administer protamine (1.0–1.5 mg of protamine per 100 units of heparin) to reverse the effects of heparin. Protamine activates the complement cascade through the classic pathway and occasionally provokes temporary severe bronchospasm, elevation of pulmonary vascular resistance, and hypotension. These reactions can cause severe hypotension and hypoventilation. These adverse reactions are reduced by slow stepwise administration of protamine (0.1–3.2 mg/kg per 5–20 min).

Mitral valve repair

Our team employs a left atriotomy approach to perform mitral valve repair. This enables visualization of ruptured mitral chordae tendineae through the opened left atrium (Video 2). Several methods of mitral repair have been reported in humans. The Carpentier technique, which uses leaflet resection and rigid or semi-rigid annuloplasty rings, has been widely used in humans. However, this technique substantially disrupts important functions of the mitral valve complex, and as a result, most centers have found it difficult to repair more than 50–60% of insufficient valves. An alternative is the technique reported by Lawrie, who used artificial chords and a flexible annuloplasty ring sutured in place with a running technique without leaflet resection. This method can be correlated with the normally functioning mitral valve in the beating heart. Resection of the mitral leaflet would be a particularly difficult procedure in small-breed dogs because of their small size. These results suggest that mitral valve repair in dogs is best achieved with artificial chordal replacement and mitral annuloplasty without mitral resection.

Mitral chordal replacement

Replacement of chordae tendineae has been established as the most effective technique in repair of mitral chordal rupture; supplanting
partial leaflet resection, chordal transfer, and chordal shortening.\textsuperscript{6,30–35} The main challenge in chordal replacement is the difficulty of adjusting artificial chordae to the appropriate length. Ideally artificial chordae length should match that of the opposing chordae to ensure proper coaptation of the opposing leaflets. Several methods, including application of a caliper, transesophageal echocardiography, and multiple knots\textsuperscript{6,30,36,37} have been reported to ensure that artificial chordae are of the optimal length. However, these techniques may be difficult to apply to the hearts of small-breed dogs. Instead, a temporary Alfieri (edge-to-edge) stitch can be used to maintain the visual field and ensure proper coaptation of the leaflets.\textsuperscript{38} After observing a tendency toward over-shortening of artificial chordae, we have successfully employed a temporary Alfieri stitch to place artificial chordae in the septal and mural mitral leaflets. Placement of artificial chordae is accomplished by passing a double-armed expanded-polytetrafluoroethylene (ePTFE) suture (CV-6) through lateral portion of the septal leaflet and then though the cranio-lateral papillary muscle. The double-armed suture is then passed back through the septal leaflet. We now prefer to use a pledget in the papillary muscle as we have observed papillary muscle rupture in one patient. We then place a second ePTFE chordae tendineae between the medial portion of the septal leaflet and the caudomedial papillary muscle (Fig. 2, Video 2). A third ePTFE suture is placed between the mid-portion of the mural mitral leaflet and the caudomedial papillary. After all the artificial chordae are placed, a temporary Alfieri stitch is placed and the artificial chordae are adjusted for length and tied.

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Mitral annuloplasty

Mitral annuloplasty plays an important role in maintaining long-term durability after mitral valve repair.\textsuperscript{39} The saddle-shaped mitral annulus is higher at the cranial and caudal segments and lower at the commissures.\textsuperscript{40–42} The mitral area is reduced from mid-diastole to late systole, such that the mitral annulus exhibits translational motion during systole.\textsuperscript{40,43} This sphincter mechanism increases the depth of leaflet coaptation during systole, and increases the annular orifice area during diastole.\textsuperscript{40–42} These physiological motions of the annulus should be maintained during mitral annuloplasty. Annular stabilization with prosthetic materials enhances durability by increasing leaflet coaptation and preventing future annular dilatation.\textsuperscript{39} Saddle-shaped annuloplasty rings provide superior uniform annular force distribution compared to flat rings, and appear to minimize out-of-plane forces that could be transmitted to leaflets and chords.\textsuperscript{44} Prosthetic rings designed for humans are not of a suitable size for small-breed dogs. Use of a mitral plication suture instead of an annuloplasty ring may preserve the natural shape and hemodynamic performance of the annulus.\textsuperscript{45,46} However this method is not as durable as ring...
annuloplasty due to detachment of the suture from the annulus.47–50 By contrast, prosthetic soft ring annuloplasty provides reproducible and long-term results in dogs. The best alternative for small dogs is a soft prosthetic ring made of ePTFE material that can be trimmed to an appropriate size at surgery. The size of the mitral annulus can be determined by a sizer that matches the mitral annulus and the root of the aorta.

We frequently observe annular dilatation at the cranial and caudal mitral commissures. This prevents us from achieving proper coaptation, thereby leading to nontrivial mitral regurgitation. This may be rectified by use of a plication stitch between the mural and septal leaflets at the commissures.51 Our preferred approach for mitral annuloplasty is placement of plication sutures with pledgets at the cranial and caudal commissures of the mitral annulus to reduce the size of both commissure regions. Then 5-0 sutures are pre-placed in the mitral annulus and passed through a strip of ePTFE material approximately 1.5 mm wide and 40–55 mm in length (Fig. 3, Video 3). The sutures are then tied to seat the annuloplasty ring. Antithrombotic therapy with dalteparin sodium should be started when the volume of drainage from the thoracic cavity is less than 3 mL/h and continued for 1 week. Administration of an anti-platelet agent is necessary for 1–3 months after surgery.

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Surgical outcomes

Mitral valve repair improves clinical signs, such as cough, dyspnea, and anorexia. Improved appetite can lead to gains in body weight and improved cardiac cachexia (Fig. 4). Auscultation should reveal significant reductions in the grade of the cardiac murmur. Chest X-rays should reveal significant decreases in vertebral heart size and tracheal elevation (Fig. 5). Echocardiography should show decreases in the left atrial and left ventricular end-diastolic diameters, with marked reductions in mitral regurgitation (Video 4). Mitral valve repair improves clinical signs and reverses cardiac remodeling. These outcomes reduce the need for cardiovascular drug therapy. Cumulatively, the improved clinical condition of surgically treated dogs indicates that mitral regurgitation can be effectively treated with mitral valve repair.

If left untreated, severe mitral regurgitation has a poor prognosis in canine patients.1 In most cases, dogs are not expected to survive for >1 year, even

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**Figure 3** Mitral annuloplasty techniques. Mattress sutures with pledgets are placed in the cranial and caudal commissure of the mitral annulus to reduce the size of both commissure regions (A). Interrupted sutures are placed in the mitral annulus and passed through strips of ePTFE material (B). Annuloplasty is completed by tying the sutures and seating the annuloplasty rings (C). Intraoperative mitral annuloplasty is shown (D).
Mitral valve repair in dogs using cardiopulmonary bypass is an effective treatment for severe mitral regurgitation in small dogs. Reestablishment of coaptation by annuloplasty and chordal replacements using ePTFE are the most appropriate repair methods for small dogs. Successful mitral repair offers the probably of decreased clinical signs, reduced need for cardiac medical therapies, and improved survival in dogs with severe mitral regurgitation.

Conflict of interest

The author has no conflicts of interest to declare.

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References


Figure 4  Dog with severe mitral regurgitation before and after mitral valve repair. Prior to surgery, the dog was thin, had a poor hair coat and abdominal distension (A). Six months after surgery, the dog had gained weight, its coat condition had improved, and the abdomen distension had resolved (B).

Figure 5  Thoracic radiographs before (A) and after (B) mitral valve repair demonstrating significant decrease in cardiac size.