Postinfarction ventricular septal defect (VSD) is relatively infrequent but highly life threatening. The poor results of medical therapy make surgical intervention necessary; however, emergent surgery is associated with tissue fragility, which subsequently causes a residual shunt. Recent evolution of surgical techniques has encouraged early repair and has eliminated mortality during medical observation. This review describes recent improvements in surgical intervention for postinfarction VSDs.

History

In 1845, Latham first described postinfarction VSD, and in 1923, Brunn made the first antemortem diagnosis. Sager established the clinical criteria for diagnosis and stressed the association of VSD with coronary artery disease. In 1957, Cooley, et al. first reported the successful surgical repair of a postinfarction VSD. In the early 1960s, surgical repair of a VSD was limited in one-month postmyocardial infarction survivors since scarring of the edge of the infarcted myocardium was crucial for surgical closure. In the late 1960s, operating early and using prosthetic materials were recommended for patients with hemodynamic deterioration. In 1971, Kitamura, et al. reviewed 65 postinfarction VSD patients and showed that patients receiving surgical treatment had better survival than patients receiving nonsurgical treatment. In the past several decades, several approaches have been developed to improve treatment outcome. Such approaches are infarctectomy and closure, use of surgical glue, using an additional patch for infarct exclusion, septal exclusion, sandwich technique via right or left ventricular approach, and endovascular repair. This field still has room for cardiac surgeons to improve surgical strategy and technique.

Keywords: postinfarction ventricular defect, infarctectomy, infarct exclusion, septal exclusion, sandwich technique

Introduction

Postinfarction ventricular septal defect (VSD) is relatively infrequent but highly life threatening. The poor results of medical therapy make surgical intervention necessary; however, emergent surgery is associated with tissue fragility, which subsequently causes a residual shunt. Recent evolution of surgical techniques has encouraged early repair and has eliminated mortality during medical observation. This review describes recent improvements in surgical intervention for postinfarction VSDs.
with transmural acute myocardial infarction.\textsuperscript{29} It occurs from a few hours up to two weeks after the onset of a myocardial infarction.\textsuperscript{30,31} Cummings, et al.\textsuperscript{32} found that cardiogenic shock exists in 50\% to 60\% of patients. Sanders, et al.\textsuperscript{33} showed that 25\% patients died within 24 hours, 50\% of patients died within one week, and 90\% of patients died in three months. Since medical therapy provides poor results, patients should undergo an operation before cardiogenic shock develops and deteriorates their condition.\textsuperscript{34} Patients in cardiogenic shock should have intra-aortic balloon pumping, vasodilators, inotropic drugs, and assisted ventilation before surgery.\textsuperscript{35} There are some reports of using a left ventricular support device to reverse multi-organ failure before the operation.\textsuperscript{36}

Patients who are in a completely stable condition without hemodynamic support represent 5\% or less of postinfarction VSD cases, and can delay the operation with surgical ease and good results.\textsuperscript{16,34,37} Patients in cardiogenic shock represent a true surgical emergency that requires immediate surgery. Delaying treating patients in cardiogenic shock represents a “failed strategy”.\textsuperscript{34,38} Patients who are in an intermediate position between shock and a stable condition should be operated on promptly (usually within 12 to 24 hours), after an appropriate preoperative evaluation. Prolonged intra-aortic balloon pump support before surgery may be beneficial in select patients;\textsuperscript{35,39} however, for most patients in an acute clinical setting, recent improvements in surgical techniques\textsuperscript{17–27} has enabled rapid surgery in which the advantage of reducing the risk of hemodynamic deterioration seems to exceed disadvantage of surgical difficulty.

**Surgical Technique and Strategy**

1. Infarctectomy and closure

Daggett and associates proposed the following principles to repairing a postinfarction septal defect: (1) making an incision through the infarcted area; (2) thorough trimming of the infarcted myocardium; (3) closure of septal defect without tension, with or without using a prosthetic material; and (4) aggressively using pledgets or a Teflon felt strip to prevent the suture cutting of fragile muscle.\textsuperscript{1}

1A. Apical amputation. Apical septal rupture\textsuperscript{1,10} is an indication for resection and closure (Fig. 1A). When myocardial necrosis is located in a limited area at the apex, generous resection of the necrotic tissue still provides enough tissue at the apex to close the septal defect and both ventricles.

1B. Single patch repair. Most anterior defects require closure with a prosthetic patch to avoid tension that could disrupt the repair (Fig. 1B). After debridement of the necrotic septum and left ventricular muscle, a series of pledgeted interrupted mattress sutures are placed around the defect.\textsuperscript{1,10,21}

1C. Extended repair of the septum and free wall. When necrotic myocardial tissue extends widely to the septum and anterior or posterior free wall, prosthetic patch replacement of the free wall and septum is necessary (Fig. 1C).\textsuperscript{1,40,41} Daggett and associates reported an overall hospital mortality of 25\% in treated patients. The mortality was 34\% in patients with a posterior defect, and 15\% for patients with an anterior defect. The long-term results of operative survival have been favorable with 1-, 5-, and 10-year survival rates of 91\%, 70\%, and 37\%, respectively. The functional class of long-term survival is good: 75\% of patients were in class I and 12.5\% were class II.\textsuperscript{42}

2. Infarct exclusion

The technique of infarct exclusion (Fig. 2) by using
endocardial patch repair has been described by Komeda, et al.,13 David, et al.,14,42 and Cooley.15 This ventricular septal rupture repair technique is an application of Dor’s technique of ventricular endoaneurysmorraphy.43 This technique involves making an incision through the left ventricle, leaving the VSD and right ventricle, performing no infarctectomy, and using a bovine pericardium patch closure with stitches at the healthy myocardium apart from infarcted area. The bovine pericardial patch is sewn in an oval shape and is 1 to 2 cm larger than the infarcted area. The average patch measures 4 cm × 6 cm. It is used to exclude the infarcted muscle from the left ventricular (LV) cavity. This is done by suturing it to healthy endocardium around the infarct. David reported 6 (13.6%) operative deaths in 44 patients.14 The actuarial survival was 66% at six years. The functional class in 53% of survivors was class I; in 44% of survivors, class II; and in 3% of survivors, class III.

3. Reproducibility of infarctectomy and closure, infarct exclusion, and other techniques

Even after the introduction of the Daggett and David technique, residual shunting, uncontrolled bleeding, low cardiac output, and technical difficulty have been problematic after a postinfarction VSD repair.16 Skillington, et al.21 reported 101 patients who had an early mortality rate of 20.8% and an actuarial survival rate of 71% at five years. The most common procedure in the patients was a single patch repair (57%) that Daggett described; sandwiching of the septal defect and right ventricular (RV) free wall (20%); septal exclusion (10%); and a free wall patch (7%). In 1998, Dalrymple-Hay, et al.37 reported postinfarction ventricular septal rupture in 179 patients who underwent infarctectomy or other repair techniques; they had an operative mortality of 27% and a five-year survival of 49%. In 2000, Deja, et al.16 reported 110 patients who had undergone either the Dagget tech-

4. Application of surgical glue

Seguin, et al.44 applied fibrin sealant to repair postinfarction VSD (Fig. 3). They used fibrin sealant to reinforce the recently necrosed myocardium and to adhere the patch to septum. No deaths occurred in their three patients who underwent surgery within four days of a myocardial infarction. Musumeci, et al. and other surgeons applied gelatin-resorcin-formol (GRF) biological glue (Pharmacie Centrale, CHU, Henri Mondor, Creteil, France) as a sealant between the patch and the interventricular septum in the exclusion technique.17,19,20,22 They proposed that GRF glue reinforcement enabled the early repair of a VSD and prevented the formation of a residual shunt. GRF glue seems to have three to seven times the adhesive force of fibrin glue.45,46 GRF glue also plays a role in sealing the defect, reinforcing the necrosed myocardium, and preventing suture cut by the crosslinking of fragile tissue; by contrast, fibrin sealant does not crosslink surrounding tissue.22,23 To use GRF glue, a surgeon needs to control the ratio of adhesive (i.e., gelatin and resorcin) to hardener (i.e., formalin and glutaraldehyde).18 An inadequate ratio of adhesive and hardener results in inadequate adhesive force or results in residual aldehyde remaining in the tissue, both of which are potentially harmful.18,45,46 BioGlue (Cryolife Inc., Kennesaw, Georgia, USA) has been recently used to seal a VSD defect.22,23 Since the ratio of the adhesive and the hardener is mostly controlled by the applicator, BioGlue may solve the problem of residual aldehyde; however, the long-term result is not fully clear.

5. Modification of infarct exclusion

Many surgeons have modified the infarct exclusion technique to improve technical ease and reduce the risk of postoperative leak. Shibata, et al.,48 Tashiro, et al.,49 and Imagawa, et al.50 report dividing the exclusion patch into two patches to make a three-dimensional pouch because infarct exclusion is easier to perform than a
procedure using a single exclusion patch (Fig. 4A). After the introduction of GRF glue, additional closure of the septal defect obtained new meaning to help sealing of the glue. The second patch plays a role in preventing leaks or glue embolization. Tabuchi, et al.\(^{19}\) (Fig. 4B) reported a repair with a double patch by first using a large patch sewed to the endocardium (i.e., excluding myocardial infarction) and a second small direct patch sewed to close septal defect; GRF glue was applied to the space between first and second patches. Tanaka, et al.\(^{20}\) (Fig. 4C) also reported similar technique with a second patch excluding the ventricular septum. Sugimoto, et al.\(^{51}\) applied a three-patch technique in which two of the patches were used for the infarct exclusion and one patch was used to directly close the defect.

6. Septal exclusion

The septal exclusion technique can be a modification of the single patch repair\(^{1,11,40}\) and can be a modification of infarct exclusion\(^{13,14}\). The left ventricular closure line is subjected to LV pressure, and this technique excludes the septal infarction and leaves the free wall infarction. Skillington, et al.\(^{21}\) used bovine pericardium to cover the entire septum on the left side in 10 patients of 101 patients who had infarct-related VSDs. Ito, et al.\(^{52}\) reported using an entire septal patch (Fig. 5A), which was fixed to the posterior wall with transmural sutures that were placed in the posterior LV free wall. Hirotani, et al.\(^{53}\) reported using a similar technique in which they applied a full thickness mattress suture with plegets at the LV posterior endocardium. Yamamoto, et al.\(^{22}\) used a small patch to close septal defects, a large patch for the septal exclusion technique, and GRF glue (injected between two patches) to prevent leaks (Fig. 5B).

7. Sandwich repair, RV approach

Hill, et al.\(^{54}\) reported 19 patients with postinfarction VSDs; eight patients were treated with a technique using a LV patch and RV wall reinforcement through a LV incision. RV wall with Teflon felt and LV patch sandwiched the defect; four of the eight patients survived. Loisance, et al.\(^{55}\) reported combining a patch at the right ventricle with another patch at the LV side through a RV incision and LV incision. Usui, et al.\(^{56}\) reported the successful repair of a posterior septal rupture by using two sheets of equine pericardium to sandwich the infarcted posterior myocardial wall, including the septal defect, and ventriculotomy through a LV incision.

In 1957, Cooley\(^6\) performed the first successful repair of a postinfarction VSD through a RV approach. Dobell\(^7\) applied a LV side patch from a RV approach through the defect; Dobell’s technique was similar to the present sandwiching technique.\(^{23-26}\) After the introduction of the Dagget and David technique, the RV approach was not widely used because of the concern of RV failure with a RV incision. The trabeculae in the right ventricle hinders a surgeon’s view, and funnel-shaped myocardial necrosis has a small ostium at the RV side, causing the surgeon to underestimate the defect size.
Isoda, et al.\textsuperscript{23,24} reported applying the sandwich technique via a RV incision to repair a postinfarction VSD by using epicardial echo clearing location and the shape of the defect and trabecula formation (Fig. 6A). Generous resection of the necrosed myocardium at the defect is necessary to introduce the LV patch through the defect, and it results in obtaining appropriate viable myocardial tissue at the suturing edge.\textsuperscript{23,24} The right ventricular approach has a lower risk of bleeding. GRF glue to seal and reinforce the edge reduces the risk of leaks. Sutures pinching the ventricular septum enable the surgeon to maintain the sewing line away from the myocardial infarction, whereas a single patch suture puts a tearing force at the fragile edge of the defect. Caimmi\textsuperscript{26} reported applying a similar technique through a LV incision, and showed that the sandwich technique also can be approached via a LV incision (Fig. 6B). Isoda, et al.\textsuperscript{32} reported using the sandwich technique via a right ventricular approach in seven patients; there were no leaks (other than trivial leaks) and no deaths after 30 days. The author found that five of the seven patients survived for more than one year after the surgery, and the actuarial survival rate was 71\% at 10 years in the same group. Asai\textsuperscript{27} reported applying the sandwich technique by using Bio-glue in 12 patients; an extended sandwich patch controlled apical necrosis of the septum (Fig. 6C). The superiority of surgical results of the sandwich technique in comparison to other techniques has not yet been demonstrated; the technical ease of this technique has nevertheless become accepted recently.

8. Less invasive approaches

Since Lock, et al.\textsuperscript{57} introduced interventional postin-
has been addressed in regard to cardiopulmonary bypass and heart arrest. In select patients, on-pump beating heart repair and off-pump repair of postinfarction VSD has been reported. The location of the defect seems to be a crucial point for the indication for surgery, and cautious summing of experience is expected.

**Overview**

Thoroughly trimming the infarcted myocardium (described by Daggett) and excluding infarcted myocardium from viable myocardium (as simplified by David) have been technically modified because of the recent evolution of longer arrest time limits with better myocardial protection, chemical sealants, chemical modification of the twilight necrotic myocardium, and intraoperative echo guide for better surgical results. Although the technical strategy varies, a basic principle that appears to remain unchanged is that surgeons should put a firm stitch at the healthier myocardial tissue with enough bite after adequate debridement. This field still has room for cardiac surgeons to improve surgical strategy and technique.

**Disclosure Statement**

The authors have no conflict of interest to declare.

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