“Sandwich Technique” via a Right Ventricular Incision for Ultra-acute Repair of Post-infarction Ventricular Septal Defects: A Study of Location of Major Residual Leak

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Objective: Although untreated post-infarction ventricular septal defect (VSD) in acute phase has a high mortality rate, surgeons are reluctant to perform emergent surgery due to fragility of the infarcted myocardium. We have reported the “sandwich technique” via a right ventricular (RV) incision, to treat a post-infarction VSD even in the ultra-acute phase. This technique involves the placement of patches on both sides of the septum, pinching the VSD sealed with surgical adhesive between the two patches; the surgical adhesive fixes and strengthens the fragile infarcted tissue. One-year mortality was found to be related to a major residual leak. In this study, we attempted to determine the location of the leak after the repair using the sandwich technique via an RV incision to treat post-infarction VSD. **Materials and Methods:** We evaluated 27 consecutive patients with post-infarction VSD who underwent repair using the “sandwich technique” via an RV incision in our series. The location of the major leak was divided into eight segments around the VSD. **Results:** The mean duration from onset to operation was 2.0 days, with 78% of patients being operated in two days and 96% patients operated in one week. The 30-day mortality rate was 4%, and 1-year mortality rate was 30%. The segments were divided into four areas: apical area (6/13, 46%), free wall side area (3/13, 23%), cranial area (3/13, 23%), and septal area (1/13, 8%). **Conclusion:** The location of the leak seemed to be related to the ischemic myocardial damage depending on the absence of collateral circulation. Surgical strategy should be established to prevent and repair residual leak.

KEY WORDS: myocardial infarction, residual leak, right ventricle, ventricular septal defect

I. Introduction

Post-infarction ventricular septal defect (VSD) is a life-threatening complication of transmural acute myocardial infarction (AMI), with a poor survival rate despite medical therapy^{1,2)}. Untreated patients had a 24% mortality rate in a day and 80% within the first month^{3,4)}. Although surgical repair seems to provide better result than medical therapy, surgical results in 2014 in Ja-

pan showed 28.6% 30-day mortality rate and 33.5% in-hospital mortality rate^{5,6)}. The Society of Thoracic Surgeons database showed operative mortality rate of 54.1% when repair was attempted within 7 days after AMI⁷⁾. Although untreated post-infarction VSD in the ultra-acute phase has an extremely high mortality rate, surgeons are reluctant to perform emergent surgery due to fragility of the infarcted myocardium. Problems with the previous surgical techniques include residual leak, uncontrolled bleeding, and technical difficulty^{2,8–10)}. To resolve these problems, we have developed a sandwich technique via a right ventricular (RV) approach^{11–13)}. This technique involves the placement of patches on both the left and right sides of the septum, pinching the VSD sealed with surgical adhesive between the two patches via an RV approach (Fig. 1a). Since patients with post-infarction VSD tend to fall in severe lung edema or cardiac tamponade quickly and the condition sometimes become irreversible, necessitating postoperative cardiopulmonary support, we used our technique in the ultra-acute phase, with the

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Fig. 1

a: Schematic drawings of the original sandwich technique (11, 13). This technique involves the placement of patches on both the left and right sides of the septum, pinching the VSD sealed with surgical adhesive between the two patches via a right ventricle (RV) approach.

b: Schematic drawing of the left (LV) and right (RV) ventricular patches with originally planned size (14). Twenty millimeters of the margin to the edge of the patch from the trimmed VSD sizes was utilized for both surgical bite and additional outer space to disperse pressure to a wider area, resulting in a patch size 40 mm larger than the trimmed VSD size.

surgical adhesive providing fixation and reinforcement to the damaged myocardium and the two large patches that pinch the VSDs providing less suture tension so as to not tear the myocardium. Emergent surgery at the mean of 2.1 days after the onset of VSDs provided 100% 30-day survival and 71% 1-year survival in 25 consecutive patients, with postoperative major leak occurring in 12% of patients¹³. Previously, we found that a smaller patch tended to cause major postoperative leak¹⁴. The patch with the size 30 mm larger than the trimmed VSD size resulted in low incidence of leak than that 30 mm smaller. Since assumption of the cases made us feel that the fragility of the edge of the post-infarction VSD seemed non-uniform but there was an extremely fragile edge of the post-infarction VSD, we attempted to determine the location of the major leak after the repair with sandwich technique via an RV approach to treat post-infarction VSD to establish a better strategy for surgical repair.

II. Materials and methods

Between June 2001 and May 2016, 27 surgical cases of post-infarction VSD were treated with the sandwich technique via an RV approach, as a surgical treatment in all patients, at Yokohama City University Medical Center (20 cases), National Defense Medical College (5 cases), and Fujisawa City Hospital (2 cases) by three surgeons. Approval for the use of these data was obtained from the institutional review board of Yokohama City University Medical Center. Data are expressed as mean $\pm$ standard deviation. The follow-up rate for 1-year post-procedure was 100%. Major residual leak was defined as follows: 1. significant leak recognized during surgery that necessitated a second pump

run; 2. significant leak recognized postoperatively that necessitated reoperation; and 3. significant leak recognized by postoperative echocardiography with $Q_p/Q_s > 1.5$.

The surgical technique has been reported elsewhere^{13, 14} and is described briefly here. Under cardiopulmonary bypass, epicardial direct echocardiography enabled the surgeon to visualize the lesion, make an appropriate incision (3–7 cm in length) in the RV, and perform a trabecular resection. Through the RV incision, the necrotic myocardium around the VSD was trimmed to obtain a sufficiently firm tissue edge, first for stitching and second for the introduction of the patch into the left ventricle (LV). The original plan for the surgical bite was to be 1.0 cm from the edge of the trimmed defect. With the addition of an outer margin extending 1.0 cm from the stitch, the length and width of the patches should be 4.0 cm larger than those of the trimmed defect (Fig. 1b). In practice, the size of the patch was not always as originally planned, since the size was determined by each surgeon. The patches were a combination of Dacron®, Teflon®, or expanded polytetrafluoroethylene felt patch (Bard Peripheral Vascular, Inc., Tempe, AZ, USA) and a bovine or equine pericardial patch (Edwards Life Science Corp., Tokyo, Japan) or autologous pericardium for the surface in contact with blood. The felt and pericardial patches were attached using fibrin glue or gelatin-resorcinol-formaldehyde (GRF) glue (Japan BXI Co. Ltd., Tokyo, Japan). Gore-Tex® patches (W.L. Gore & Associates, Inc., Newark, DE, USA), 0.6 mm in thickness, were used in two cases where no pericardial patch was available. Eight or ten 4-0 or 3-0 polypropylene mattress sutures with an SH or MH needle (Ethicon, Inc., Somerville, NJ, USA), with or without felt

Fig. 2

a: Schematic drawing of the segments of the VSD edge around the VSD patch.

b: Incidents of perioperative major leak were counted at each segment around the VSD patches.

c: The same data were plotted into the schema around the VSD patch. Closed dot expresses major leak at the segments.

d: Incidents of perioperative major leak were counted at each area around the VSD patches.

pledgets, were first applied to the LV-side patch and then to the edge of the defect. After the LV-side patch was introduced into the ventricle, the sutures were lifted to make the LV-side patch fit the ventricular septum, so as to prevent the GRF glue (Japan BXI Co., Tokyo, Japan) or BioGlue (CryoLife Inc, Kennesaw, GA, USA) leaking into the LV. GRF glue or BioGlue was used to close the VSD in all cases except one and applied to the defect, edge, and needle hole. To prevent the presence of residual aldehyde, the ratio of adhesive to activator in the GRF glue was strictly controlled at 10:1¹⁵⁾. Two patches pinched the ventricular septum. The RV was closed with a running 4-0 polypropylene suture with or without felt reinforcement. When there was widespread necrosis at the edge of the free wall side of the septal defect without strength to endure suturing, we inserted the LV-side suture first through the LV free wall, on the near or far side of the left anterior descending or posterior descending artery^{16,17)}. We collected data of major leak location during surgery, postop-

erative echocardiography, and during reoperation for leak closure. The location was divided into eight segments around the post-infarction VSD (Fig. 2a), and two segments formed one area, where the areas were divided into cranial, free wall, apical, and septal. Several incidents of major leak were counted independently. For example, major leak after the first aortic cross-clamp and another major leak after correction of the leak at the second aortic cross-clamp were treated as two incidents.

III. Results

Preoperative data are shown in Table 1. The mean duration of onset to operation was 2.0 days. Ultra-acute repair in 2 days was performed in 78% of patients, and early repair within 7 days after the onset of VSDs was performed in 96% of patients. Operative and postoperative data are shown in Table 2. Extended sandwich repair¹⁶⁾ was performed in 4 cases. One patients had complete atrioventricular block, which lead to low cardiac output

Table 1 Preoperative data (n = 27)

Variable	Values
Age	74.3 years (51–86)
Sex	female, 17; male, 10
Infarcted site	anterior, 21; posterior, 6
Time from onset to operation	2.0 days (0–17)
Ultra-acute repair (<2 days)	21 (78%)
Early repair (<7 days)	26 (96%)
Papillary muscle rupture	1 (4%)
Preoperative IABP	23 (96%)
Preoperative PCPS	1 (4%)
Qp/Qs	3.83 (n=21)

IABP: intra-aortic balloon pump, PCPS: percutaneous cardiopulmonary support, Qp/Qs: pulmonary-to-systemic blood flow ratio.

syndrome, and died on postoperative day (POD) 13. Six other patients died within 1 year, and the causes of deaths were mediastinitis in two patients, pneumonia in one patient, arrhythmia in one patient, heart failure in one patient, and tracheostomy bleeding in one patient.

Major leak was found during surgery and postoperatively in four cases of anterior-type post-infarction VSD. According to the schematic drawing (Fig. 2a), the location of the leak was plotted. The leak located across two segments was counted at both segments. A total of seven major leaks were detected, and 13 segments were counted and plotted (Fig. 2b, c). The segments were divided into four areas: apical area (6/13, 46%), free wall side area (3/13, 23%), cranial area (3/13, 23%), and septal side area (1/13, 8%) (Fig. 2d).

1. Presentation of cases with major leak

Each case of perioperative major leak is presented. Patch size, use of surgical glue, and procedure to close the leak are described. Size discrepancy between the patch and trimmed VSD size < 30 mm is defined as small patch¹⁴⁾.

Case 1: The procedure was performed without surgical glue. The patch was small. Postoperative echocardiography revealed major leak at the caudal free wall side to anterior apical portion (Fig. 3a). Redo surgery was performed on POD 12. Additional sandwich patches were applied at the leak without surgical glue (Fig. 3b). Postoperative echocardiography revealed minor leak at the apical portion. The patient died due to mediastinitis on POD 40.

Case 2: A small patch was used. After aortic unclamping, major leak appeared at the free wall side by transesophageal echo (Fig. 4a). The heart was stopped, and the free wall and patch were plicated using Teflon strip at the free wall (Fig. 4b). After surgery, another major leak was observed at the contralateral

Table 2 Operative and postoperative data (n = 27)

Variable	Values
Concomitant procedures	
CABG	5 (19%)
MVR	1 (4%)
Second pump run	3 (13%), (major leak closure 2, MVR 1)
Postoperative PCPS	6 (25%) (all weaned, 0–21 days)
Postoperative IABP	23 (96%) (0–24 days)
Postoperative intubation time	13.3 days (1–93)
Postoperative ICU stay	15.1 days (1–35)
Bleeding	4 (15%)
Major residual leak	4 (15%) (postoperative, 3, intraoperative, 1)
Reoperation for major residual leak	2 (7%)
Thromboembolic event	4 (15%)
Cerebral infarction	1 (4%)
RV thrombus without PE	1 (4%)
LV thrombus	2 (8%)

CABG: coronary artery bypass graft, MVR: mitral valve replacement, PCPS: percutaneous cardiopulmonary support, IABP: intra-aortic balloon pump, ICU: intensive care unit, RV: right ventricle, LV: left ventricle, PE: pulmonary embolism.

side of plication at the apical portion (Fig. 4c). Apical leak was plicated on POD 8, and there was no residual leak (Fig. 4d). The patient died due to mediastinitis on POD 93.

Case 3: The patch was small. After surgery, major leak was observed in the cranial location (Fig. 5a). Closure of the leak was abandoned due to aspiration pneumonia. The patient died due to heart failure on POD 159.

Case 4: A small patch was used. After aortic unclamping, major leak was observed at the apical location by transesophageal echocardiography (Fig. 5b). On the 2nd cardiac arrest, apical leak was plicated, resulting in major leak at the cranial location at the counter side of the plication after aortic unclamping (Fig. 5c). On the 3rd cardiac arrest, major leak at the cranial location was closed using a new sandwich patches (Fig. 5d). The patient had a long-term survival.

IV. Discussion

Post-infarction VSD is a life-threatening complication of transmural AMI, with a poor survival rate despite medical therapy^{1,2)}. Guidelines for ST-elevation AMI by the Japan Circulation Society in 2013 recommended surgical repair as Class I, and the sandwich technique via the RV is referred as one surgical technique¹¹⁾ besides infarct excision technique and infarct exclusion

Fig. 3

Case 1: The sandwich technique was performed without surgical glue and with small patch resulting in major leak at the free wall side to the apical portion (a). Additional sandwich patches without surgical glue (b) resulted in minor leak at the apical portion.

Fig. 4

Case 2: A small patch was used. After aortic unclamping, major leak was observed at the free wall side (a), and free wall and patch were plicated using the Teflon strip (b). After surgery, major leak was observed at the apical portion, which was on the contralateral side of plication (c). Apical leak was plicated on postoperative day 8.

Fig. 5

Case 3: Small patch was used. After surgery, major leak was observed in the cranial location. Closure of the leak was abandoned due to aspiration pneumonia (a). Case 4: A small patch was used. After aortic unclamping, major leak was observed at the apical location (b), and on the 2nd cardiac arrest, apical leak was plicated, resulting in a major leak in the cranial location (c) at the counter side of the plication. On the 3rd cardiac arrest, major leak at the cranial location was closed using a new sandwich patch (d).

technique^{2, 9, 18)}. Although the Society of Thoracic Surgeons database showed operative mortality rate of 54.1% when repair was attempted within 7 days after AMI⁷⁾, ultra-acute repair using the sandwich technique via the RV incision resulted in a 4% 30-day mortality rate in this series. The midterm result of the sandwich technique via the RV was acceptable¹³⁾, being competent with the result of the infarct exclusion technique by Dr. David¹⁹⁾, where other studies using infarct exclusion technique or infarct excision technique were not successful in reproducing the result of Dr. David^{8, 20, 21)} (Fig. 6).

1. Major leak and patch size

We tried to determine the factor to change the 1-year survival¹⁴⁾, and major leak was the only factor¹⁴⁾. To reduce major leak, we studied the surgical parameters and found that a small patch causes major leak¹⁴⁾. The original design of the patches was a size 40 mm larger than the trimmed VSD size, to disperse tension of the suture to a wider area of fragile VSD edge (Fig. 1b)¹⁴⁾. The patch was a composite one in which the blood contact surface was the bovine pericardium and septal sur-

face was Dacron, Teflon, and ePTFE attached together by GRF glue or fibrin glue. We observed a major leak when the size discrepancy of the patch and trimmed VSD was < 30 mm¹⁴⁾; it was confirmed by mathematical analysis that a smaller size tended to cause the leak by Ito et al.²²⁾.

2. Location of leak

In this study, the number of major leaks is quite limited, and statistical significance is not evaluated. However, comparing the incidence of major leak at the septal side and apical location, it is likely that the difference seems to exist (Figs. 2b, c, d). Since all major leaks occurred in anterior-type VSD in our series, anterior type is used as an explanation example as follows: At the septal side, the myocardium apart from the edge should be perfused by posterior descending artery. The cranial edge of the VSD was also perfused by the conus branch and proximal septal branches if it is patent. The problem may exist in the distal portion of the VSD where the proximal coronary artery had been occluded and when there was slight collateral from posterior descending artery. Ischemic damage of the free wall side edge and

Fig. 6
Midterm survival data from our study (13) and other studies (19–22) are shown.

apical edge proposes surgical risk of dehiscence in which the myocardium causes major leak. When GRF glue was available, the high performance of the glue to reinforce damaged myocardium frequently enabled the performance of the original sandwich technique in most cases. The currently available BioGlue does not allow reinforcement of severe damage, preventing occurrence of major leak. In this situation, we need to shift from the original sandwich¹¹⁾ to extended sandwich technique in certain cases of severely damaged myocardial edge at the free wall side or apex (Fig. 7a)¹⁶⁾. If the LV free wall is widely damaged and ruptured, sandwich repair, infarct exclusion, or septal exclusion via LV incision might be the suitable technique (Fig. 7b).

3. Original or extended sandwich

Surgical glue and/or glutaraldehyde fixation can be used to reinforce the damaged myocardium, which can be tolerated with suture placement^{23, 24)}. If the fragile ischemic edge of the trimmed VSD seems tolerable for the suture, the original type of sandwich procedure via the RV is available (Figs. 1a and 7a). If the edge seems to be fragile to put suture on the free wall side or apical edge, we should use better free wall to anchor the LV-side patch (Fig. 7a)^{14, 16)}. Care should be taken to prevent laceration of the LV free wall because it can lead to severe ischemic damage. Since the extended sandwich technique uses larger LV patch than the original sandwich technique, we reported^{11, 13)} that the balance of the suture location at the LV free wall and LV-side patch should be carefully confirmed; otherwise, the suture tends to tear the LV free wall. Parallel running of the lifting suture should be confirmed when the patch is introduced into the LV and tied. If the surgeon noted imbalance of suture, correction

should be performed. Moreover, if the myocardium of the LV free wall seems fragile or ischemic, surgical glue or glutaraldehyde scrub^{24, 25)} should be applied to the myocardium around the suture.

4. Surgical glue and glutaraldehyde

Application of surgical glue seems to play a role to not only close the small gap between the patch and myocardium but also reinforce the damaged myocardium, preventing suture cut. We only have one case in which the repair was performed without surgical glue, resulting in major residual leak and death. We started our technique using GRF glue, which had better performance than the currently available BioGlue, since the elastic final form of the GRF glue adapts to motion of the heart and there was little possibility to make a crack in the hardened adhesive. We hope that the new surgical glue developed using a combination of gelatin and glutaraldehyde or combination of gelatin and ferric chloride using coordination bond, will be applied in the future. Currently, BioGlue seems to be the sole surgical glue to have cross-linking ability. Recently, we have been using 0.6% glutaraldehyde to fix, reinforce, and disinfect the tissue in the treatment of active endocarditis, where the solution is also available to reinforce damaged myocardium^{24, 25)}. Ethical committee of Fujisawa City Hospital approved use of glutaraldehyde to reinforce myocardium damaged by severe ischemia.

5. Surgical correction of major leak

Since major leak is a serious factor relating to 1-year mortality¹⁴⁾, it should be adequately treated. Application of a new sandwich to the leak is one of the recommended procedures (Figs. 3b and 5d). Although we attempted plication of the leak

Fig. 7

a: Schematic drawing of the extended sandwich technique is shown (16, 17).

b: Considerable strategy of surgical repair for post-infarction VSD is proposed. If the case is a healthy LV free wall or high location of VSD, the original sandwich technique via an RV approach (11) is simple and easy. If LV free wall is damaged, the extended sandwich technique via an RV approach may be suitable (14, 16). If the apex and LV free wall is severely damaged and mostly ruptured, the exclusion or sandwich technique via an LV approach might be the choice (5, 9, 26).

c: Schematic drawing of off-pump closure of the leak after extended sandwich technique is shown.

several times, plication results in production of new contralateral side leak in the acute phase (Figs. 4c and 5c). Since plication was only successful more than 1 week after major leak occurrence (Fig. 4d), the fragile tissue of VSD edge does not tolerate traction by the suture of the plication at least for 1 week. We recently closed a major leak at the free wall side of the patch using plication under off-pump fashion 1 month after the first sandwich technique via an RV approach (Fig. 7c). Since the free wall side and apex are the frequent locations of major leak, and the leak tends to be located just between the free wall and patch, off-pump closure might be available if the patient is not in a good condition.

6. Technique choice

There are several techniques to treat post-infarction VSD¹⁰⁾. Since the incidence of post-infarction VSD is low, and each surgeon might be able to experience one or two cases in a year except in large-volume hospitals. It is difficult for the surgeon to have much experience in each technique. We presented the advantage and disadvantage of each technique (Fig. 7b). If the case

is post-infarction VSD with healthy free wall and free wall side VSD edge, the original sandwich technique via an RV approach^{11, 14)} is simple and easy to perform. If the location is high, the original sandwich technique is also suitable. If the free wall is severely damaged and free wall side edge is bad, the extended sandwich technique via an RV approach will be suitable^{14, 16)}. If it is in the apical location and the free wall is severely damaged and mostly ruptured, exclusion or sandwich technique via an LV approach might be the choice (Fig. 7b)^{5, 9, 26)}.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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