Failure modes of left ventricular reconstruction or the Dor procedure: a multi-institutional perspective

Jaishankar Raman a,b,*, Anand Dixit c, Gil Bolotin a, Valluvan Jeevanandam a

a Section of Cardiothoracic Surgery, Department of Surgery, University of Chicago Medical Center, MC 5040, 5841 South Maryland Avenue, Chicago, IL 60637, USA

b Department of Cardiac Surgery, Austin Hospital, University of Melbourne, Heidelberg, Vic., Australia

c Department of Cardiothoracic Surgery, Royal Hobart Hospital, University of Hobart, Hobart, Tasmania, Australia

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Abstract

Background: Complex ventricular reconstruction (CVR) is now being employed increasingly thanks to the pioneering work of Dor. However, little is known about the failure mode of CVR. We present experience from three centres with CVR and an analysis of the failure modes. Methods: Between January 1997 and February 2005, 284 patients underwent CVR in three centres in Australia and USA. All of the procedures were performed as adjuncts to coronary artery surgery and/or valvular surgery. Patients were followed-up clinically and/or echocardiographically. Failure modes were classified as fatal or non-fatal. Non-fatal failure mode (NFM) was defined as either persistent heart failure, recurrence of LV scar, need for ventricular assistance, persistent ventricular arrhythmia, or a combination. Results: Operative mortality rate (OMR) was 8% (23 deaths). This fatal failure mode was most related to urgency of surgery and cardiogenic shock in 15 patients (5.3% of OMR), stroke in 5 patients (1.8%) or postoperative bi-ventricular failure (1%). Non-fatal failure modes accounted for morbidity in 26 patients (9%). This was predominantly due to persistent septal dyskinesis in 7 patients (2.46%), persistent mitral regurgitation in 5 (1.8%), postoperative ventricular tachycardia in 4 (1.4%), sub-optimal myocardial protection in 4 (1.4%), use of a large, stiff patch in 4 (1.4%). One hundred and ninety-nine of the surviving 261 patients (76%) were in NYHA Class I. Conclusions: Complex ventricular reconstruction is a robust technique that has lasting benefit. Failure modes have been identified and could be minimized by appropriate patient and procedure selection.

Keywords: Left ventricular reconstruction; Dor procedure; Failure mode; Heart failure; Septal plication; Endo-ventricular repair

1. Introduction

Ventricular reconstruction is a technique that has evolved over the years from linear closure of large ventricular aneurysms (Likoff and Bailey) [1] to present geometric iterations. Despite the improvement in function, shape and size of the ventricles after these procedures, these operations were viewed with trepidations. We now have an era where heart failure is the most common cause for hospital admissions. The geometric left ventricular reconstructive procedures following principles set down by Dor (Dor and Sabatier) are now gaining widespread acceptance and use.

Much has been written about the techniques and the patients that benefit from this kind of surgical technique. Little is mentioned about the patients that have a poor outcome. In any kind of new procedure, case selection is important to achieve optimal results. We therefore studied the failure mode of left ventricular reconstructive procedures over an 8-year period in three major hospitals in two continents to identify risk factors in these patients.

2. Materials and methods

This is a retrospective study that looked at the adverse outcomes of left ventricular reconstructive techniques. We studied all patients that underwent geometric left ventricular reconstructive procedures between 1997 and 2005 at the University of Melbourne Hospitals, University of Hobart Hospital, and the University of Chicago Hospitals. All patients that underwent a left ventricular reconstruction (modified Dor procedure) were included. Patient data were gleaned from hospital records, outpatient records and follow-up investigations.
Patients were included regardless of the acuity and mode of presentation.

Perioperative outcomes were measured and postoperative complications tabulated. When mortality occurred, postmortem examinations were requested and the results recorded.

Complications were classified as fatal and non-fatal.

All deaths as a consequence of the surgery, however remote were recorded to derive the operative mortality.

Non-fatal complications included were as follows:

- low cardiac output
- end-organ dysfunction, such as renal failure, liver dysfunction, etc.
- ventricular arrhythmias
- neurological dysfunction including TIA, stroke, etc.
- persistent congestive heart failure
- prolonged respiratory support as a consequence of cardiac decompensation
- persistent cardiac failure
- need for prolonged ventricular assistance

Recurrence of cardiac failure and late decompensation, if any, were recorded. Where possible, patients were followed by heart failure cardiologists or a service dedicated to looking after patients with heart failure. Patients were reviewed every 6–12 months clinically where possible. Repeat echocardiography was advised to all patients. All adverse events were recorded. In the absence of contact or follow-up, attempts were made to contact referring physicians to accurately obtain quality of life information and late complications if there were any.

Between January 1997 and February 2005, 284 patients underwent left ventricular reconstruction. Table 1 outlines the preoperative status of the patients and the medications they were on at the time of surgery. Mean ejection fraction was 24.5 ± 7%. Mean NYHA functional class was 3.2. All of the procedures were performed as adjuncts to coronary artery surgery and/or valvular surgery. Table 2 specifies the different procedures that the patients underwent.

### 2.1. Evolution of surgical technique

Early in this experience, the classic Dor procedure was performed with a stiff Dacron patch and a Fontan stitch.

### Table 1

**Patient characteristics and medical therapy**

<table>
<thead>
<tr>
<th>Characteristics, medical therapy</th>
<th>Number of patients</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age</td>
<td>67 ± 8</td>
<td></td>
</tr>
<tr>
<td>Male patients</td>
<td>199</td>
<td>70.07</td>
</tr>
<tr>
<td>Female patients</td>
<td>85</td>
<td>29.92</td>
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<tr>
<td>Emergency or urgent procedures</td>
<td>65</td>
<td>22.8</td>
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<tr>
<td>Cardiogenic shock as presentation</td>
<td>46</td>
<td>16.2</td>
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<tr>
<td>ACE inhibitor used preoperatively</td>
<td>176</td>
<td>61.9</td>
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<tr>
<td>Preoperative beta blockade</td>
<td>125</td>
<td>44</td>
</tr>
<tr>
<td>NYHA Class III</td>
<td>200</td>
<td>70.4</td>
</tr>
<tr>
<td>NYHA Class IV</td>
<td>64</td>
<td>22.5</td>
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<tr>
<td>Preoperative balloon pump</td>
<td>40</td>
<td>14.1</td>
</tr>
<tr>
<td>Preoperative renal dysfunction</td>
<td>103</td>
<td>36.3</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>138</td>
<td>48.6</td>
</tr>
<tr>
<td>Perioperative milrinone use</td>
<td>250</td>
<td>88</td>
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</table>

### Table 2

**Associated cardiac procedures**

<table>
<thead>
<tr>
<th>Type of procedure</th>
<th>Number of patients</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anteroseptal GER</td>
<td>244</td>
<td>85.9</td>
</tr>
<tr>
<td>Inferior GER</td>
<td>40</td>
<td>14.1</td>
</tr>
<tr>
<td>CABG</td>
<td>260</td>
<td>91.5</td>
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<tr>
<td>MV repair</td>
<td>110</td>
<td>38.7</td>
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<tr>
<td>Perioperative IABP</td>
<td>174</td>
<td>61.3</td>
</tr>
<tr>
<td>Tricuspid valve repair</td>
<td>44</td>
<td>15.5</td>
</tr>
<tr>
<td>Aortic valve replacement</td>
<td>10</td>
<td>3.5</td>
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<tr>
<td>Septal plication</td>
<td>124</td>
<td>43.6</td>
</tr>
<tr>
<td>Cross clamp and cardioplegia</td>
<td>170</td>
<td>59.8</td>
</tr>
</tbody>
</table>

### Table 3

**Hemodynamic data**

<table>
<thead>
<tr>
<th>Hemodynamic parameter</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate</td>
<td>92 ± 12</td>
<td>99 ± 16</td>
<td>84 ± 10</td>
</tr>
<tr>
<td>Mean arterial pressure</td>
<td>75 ± 13</td>
<td>66 ± 17</td>
<td>72 ± 15</td>
</tr>
<tr>
<td>CVP</td>
<td>14 ± 9</td>
<td>18 ± 8</td>
<td>n/a</td>
</tr>
<tr>
<td>Ejection fraction (echo)</td>
<td>24.5 ± 7</td>
<td>36.6 ± 8</td>
<td>38.7 ± 7</td>
</tr>
<tr>
<td>Cardiac index</td>
<td>2.2 ± 0.7</td>
<td>2.5 ± 0.9</td>
<td>n/a</td>
</tr>
</tbody>
</table>

However, as our experience grew, we found the stiff patch limiting and that the purse-string suture at the borderzone could be tightened to varying degrees. We also found that scars varied in size and shape. Through the duration of this experience, we developed and refined our techniques. We were also able to develop a coordinated approach to scars of different configurations, shapes, and locations.

During the year 1997, all scars were reconstructed using the classic Dor procedure, which included the Fontan purse-string stitch, the stiff Dacron patch and tucking of the scarred edges over the repair with glue. Thereafter, the technique morphed into a softer patch using Goretex initially and eventually bovine pericardium. The Fontan stitch was discarded in favor of a measured patch, which usually was one-third the diameter of the border zone. The patch was implanted with radially placed sutures in two layers. Fig. 1 (panels a–c) illustrates the principles of this approach. Since scars smaller than 4 cm in diameter required a patch of less that 1.5 cm in diameter, these were technically difficult to implant. In these patients we used the McCarthy modification whereby we just used one or more purse-string sutures. Early in the experience, the patch was used exclude the septal component. However, we found that this looked ineffective on echocardiography and adopted a technique of plicating the septal component in a linear fashion. Fig. 2 (panels a and b) shows schematically the likely improvement with this strategy. Fig. 3 shows a plicated septum with a patch insertion within the borderzone.

Table 3 tries to give an idea of the hemodynamic profile of these patients. The mean arterial pressure fell in the postoperative period, presumably as a consequence of the systemic inflammatory response from CPB. Also, the improvement in cardiac index might be partly related to inotrope usage and improved function. Patients were followed up clinically and/or echocardiographically. Failure modes were classified as fatal or non-fatal. Non-fatal failure mode (NFM) was defined as either persistent heart failure, recurrence of LV scar, need for ventricular assistance, persistent ventricular arrhythmia, or a combination.
3. Results

Operative mortality rate (OMR) was defined as perioperative death or death as a complication of the surgical procedure, regardless of length of hospital stay. Operative mortality therefore not confined to the first 30 days beyond the procedure, but all mortality as a consequence of left ventricular reconstructive surgery. Operative mortality was 8% (23 deaths). This fatal failure mode was most related to urgency of surgery and cardiogenic shock in 15 patients (5.3% of OMR), stroke in 5 patients (1.8%) or postoperative biventricular failure in 3 (1%). In this category, most of the patients (n = 17) were in established cardiogenic shock with a combination of inotropes, pressors, and balloon counterpulsation. Surgery was performed as an emergency or on an urgent basis. This was often in the setting of an acute infarct complicating an already poor ventricle. Postoperative biventricular failure was seen in three patients that was prolonged and required delayed implementation of ventricular assistance, often in the setting of intractable postoperative ventricular arrhythmias.

Unexpected intraventricular clot was found in four patients despite good quality preoperative echocardiography, intraoperative transesophageal echocardiography. The nature of the clot was often friable, soft and this made them embolize relatively easily. The size of each of these clots was over 3 cm, representing a failure of trans-esophageal echo in recognizing these early soft thrombi. The embolism occurred despite minimal manipulation of the heart before ventriculotomy.

Non-fatal failure modes accounted for morbidity in 26 patients (9%). This was predominantly due to persistent septal dyskinesis in 7 patients (2.46%), persistent mitral regurgitation in 5 (2.5%), postoperative ventricular tachycardia in 4 (1.4%), sub-optimal myocardial protection in 4 (1.4%), use of a large, stiff patch in 4 (1.4%).

Persistent septal dyskinesis resulted in discoordinate ventricular contraction with only partial improvement in ventricular function. This was despite using a patch to exclude the septal component of the scar. This was also early in the experience. Complete coverage of a large area of septal dykinesis with a patch was often difficult.

Persistent mitral regurgitation was seen in five patients. All of these patients had multiple patchy scars with some remodeling of the inferobasal wall. The mechanism of MR was due to an akinetic or sluggish inferobasal ventricular wall. These patients had moderate mitral regurgitation which was left alone at the time of surgery, because of the lack of consensus on what to do about these patients.

Early in the experience, we followed the principles described by Dor. The Dacron patch was stiff and tended to almost stent open the area to be reconstructed. This invariably resulted in a sub-optimal result with residual heart failure. Over the early phase of this experience, we moved from Dacron to Goretex patches and settled down to

Fig. 1. Principles of left ventricular reconstruction. (a) Left ventricle in longitudinal section with antero-apical scar. ‘x’ marks the diameter of the border zone. (b) End-on view of the bovine pericardial patch being implanted within the borderzone with radially placed sutures. x/3 is the measurement of the patch diameter, which is roughly one-third of the diameter of the border zone which is x. (c) The reconstructed left ventricle in a longitudinal section with the endo-ventricular patch and scar remnants closed over the patch.
using Bovine Pericardial patches (Supple Perigard™, manufactured by Synovis Biomedical Inc., St Paul, MN, USA).

Postoperative ventricular tachycardia was seen in four patients. In two of these patients, it was profound and early in the postoperative period. In one of these patients, it caused profound hemodynamic compromise, requiring mechanical assistance with extra-corporeal membrane oxygenation (ECMO). The ventricular tachy-arrhythmia slowly resolved after 48 h. However, the patient had an embolic episode during his period of assistance and support was withdrawn despite a reasonable chance of cardiac recovery.

In two patients, there were late episodes of ventricular tachy-arrhythmia, both of which were at home. Both patients were successfully resuscitated, cardioverted and admitted for insertion of automatic internal cardioverter defibrillators. Since then, our policy in treating these patients has changed. Any patient with a pre-existing history of ventricular arrhythmia gets an endocardial ablation at the borderzone. If patients have any postoperative ventricular arrhythmias, they undergo an electrophysiological study. The threshold for electrophysiological intervention now is quite low.

Four patients spent a long time recovering from surgery with gradual resolution of cardiac failure. These patients had predominantly right sided cardiac failure which was presumably because of inadequate myocardial protection of the right coronary artery territory during the cross-clamp period. We have changed our techniques over the past in 100 patients to avoidance of the cross-clamp and cardioplegia. If there is a large clot and the cross clamp is required, this is done first followed by myocardial revascularization which is then performed on a beating heart.

The use of a stiff and relatively big patch (4—5 cm in diameter) accounted for significant morbidity in four patients. Two of these patients presented with localized recurrence near the edge of the patch. In one of them, this was the focus of ventricular tachycardia. In two other patients, the patch seemed to be associated with progression of mitral regurgitation from mild to moderate.

One hundred and ninety-nine of the surviving 261 patients (76%) were in NYHA Class I. Twenty patients were lost to follow-up. All patients in NYHA Class I were maintained on a combination of ACE inhibition, beta blockage, and diuretics. There were no instances of recurrent ischemia or heart failure decompensation in this group.

We were not able to construct accurate survival curves because of the missing data on patients lost to follow-up. One salutary finding with respect to follow-up was that patients seemed to do well if they made regular visits to a heart failure oriented cardiologist.

4. Discussion

Ventricular reconstruction was initially a technique used predominantly for repairing ventricular aneurysms. Linear repair of aneurysms were the accepted norm for almost three decades thereafter [2,3]. Despite the relative ease of these procedures popularized by Cooley [4], the perioperative
complications gave ventricular aneurysm repair a bad name. Jatene [5] and Dor et al. [6] independently showed the importance of a geometric approach to repairing the left ventricle, is such a way that the conical shape is recreated. The improved results with a circular repair or a geometric approach have now been well accepted for over a decade [7]. The next phase in the evolution of left ventricular reconstructive surgery was to address not just frankly aneurismal or dyskinetic anterior ventricular scars but to attempt correction in cases where there was akinesis of a large confluent anterior left ventricular scar [8]. As percutaneous treatment of acute coronary syndromes has improved all over the world, truly ventricular aneurysms have become more uncommon. There is also the appreciation based on the STICH trial that aggressive myocardial revascularization alone cannot alter the function and shape of a ventricle remodeled by infarction [9]. However, the physiological effects of geometric left ventricular reconstruction have been successfully applied to post-ischemic akinetic dilatation of the left ventricle [10].

Across the board, the operative mortality in these sick patients ranges from 7 to 12% [11—13]. Many of these publications have focused rightly on the positive outcomes of these reconstructive procedures. This is particularly important as the incidence of heart failure increases and there is greater acceptance of the role of left reconstructive procedures in the surgical armamentarium [14]. While the surgical community is embracing these new techniques with greater enthusiasm, appropriate case selection is very important.

We present our experience with left ventricular reconstruction over an 8-year period encompassing 284 patients at three institutions in two continents. We presented some of our learning experiences to help improve the surgical technique to accommodate all types of patients.

Based on our experience, we now know that left ventricular reconstruction in the presence of cardiogenic shock or as an emergent procedure carries a considerable risk of mortality. If there is end-organ failure, our strategy now is to connect the patient to some kind of mechanical ventricular assistance. We routinely advocate insertion of an intraventricular balloon pump preoperatively, if one has not been inserted already. We also have a low threshold for insertion of a ventricular assist device as the patient is being weaned off cardiopulmonary bypass.

To reduce myocardial dysfunction in these patients, we have also switched to performing most of these procedures on cardiopulmonary bypass with the heart beating. The only caveat to that is when there is evidence of ventricular clot on echocardiography. In those instances, we use the cross clamp and cardioplegic arrest early to allow reconstruction of the ventricle with safe extraction of the thrombus. Thereafter, we tend to perform the coronary artery bypass procedures with the heart beating, thereby limiting the cross-clamp period. This has also reduced the need for post-cardiectomy mechanical ventricular support for inadequate myocardial protection.

Ventricular arrhythmias can frequently be a complication and cause of poor outcome in patients undergoing left ventricular reconstruction. We have adopted various techniques to reduce the incidence of these arrhythmias post-operatively, ranging from intraoperative ablation of the endocardium, to electrophysiology studies and insertion of AICDs [15]. Extensive work has been done by Dor and colleagues [16] in this area and we follow most of his principles in dealing with ventricular arrhythmias.

The use of a stiff patch was interestingly associated with some adverse long-term outcomes, which included recurrent scar formation at the edge of the patch, and progression of mitral regurgitation. We have since completely switched to using small bovine pericardial patches to help recreate the conical shape of the ventricle. The septal component of the scar is now routinely plicated in a linear fashion using techniques promulgated by Jatene. This has allowed an even better geometric reconstruction of the ventricle.

The limitations of this multi-center experience are that even though the data was collected prospectively, the evaluation of the failure mode was in a retrospective fashion. The surgical technique evolved through the experience and has been reported as such. The follow-up was not complete. All these factors mitigated against stringent statistical analyses.

5. Conclusions

Complex ventricular reconstruction (CVR) is a technique that has lasting benefit, in a group of patients considered to be very high risk previously. Failure modes have been identified and could be minimized by appropriate patient and procedure selection.

This publication is an attempt to identify some of the common complications following left ventricular reconstruction and our measures to reduce some of these effects.

References


Appendix A. Conference discussion

**Dr D. Lindblom** (Stockholm, Sweden): We have done 140 of these operations now, and I think that when talking about the failure modes, one has to consider the ventricle that’s too small or too big postoperatively. You didn’t mention anything about that. We have seen at least five patients where I made the ventricle too small, which is a disaster for the patient. A few of these patients actually survived, and after a few years, their hearts redilated and then they became less symptomatic. Do you have any comments about the too small or too big ventricle and the outcome for these patients? And do you use any measurements to size? Dr Menicanti has proposed the balloon to size and shape the ventricle.

**Dr Bolotin**: First, I think it’s an important issue. We looked at it in our series and we didn’t find it. There was one patient that we had doubts whether the ventricle was too small, but did not find the problem in all the others. And we actually didn’t use the balloon, although I think in the future, especially when you start a program of this procedure, we should start using the balloon in the beginning. I guess that our patient selection and the scar that was probably not too big helped us to avoid getting ventricles too small.

**Dr R. Dion (Leiden, The Netherlands)**: I would like to go back to the mitral regurgitation. In our series we have seen that patients who have mild mitral regurgitation before the operation are not always improved by the reshaping of the left ventricle, and about the half of them have an increased mitral regurgitation (grade 2) after the operation and we have to go back on bypass and fix the mitral valve. Therefore we are quite aggressive with mitral annuloplasty in left ventricular reshaping and perform it whenever the preoperative length of coaptation is less than 5 mm. Did you find that in your series? I would like you to comment on that.

**Dr Bolotin**: Yes, we found the same results. I think I mentioned five patients in whom the non-fatal failure mode was mitral regurgitation, and, as you suggested, we also became more aggressive in repairing the mitral valve. If there was any doubt, we repaired it during the first operation.

**Dr Dion**: And then the septal plication: if you use the Dor method, you should exclude all the scars in the septum. You said that you wanted to improve the result by septal plication. Don’t you sometimes exclude all the septal scars?

**Dr Bolotin**: No. In some of the cases we prefer and we find the results are as good without excluding all the scars, just plication of the septum, linear plication of the septum.

**Dr Y. Yalcinbas (Istanbul, Turkey)**: Can you comment on avoiding the use of a patch, with the use of a second circular stitch and getting rid of an akinetic area without the use of a patch?

**Dr Bolotin**: Yes. As I mentioned, we used this technique as long as the scar, the border zone, was not too large. So if the area is not too large, we just use the Cooley technique, and actually get a good result without the need for a patch. However, when the scar is too big, I think you should start with reducing the size, but then add the patch as well. It depends on the size of the scar actually.

**Dr Yalcinbas**: Do you have a specific number or limit or criteria for too big?

**Dr Bolotin**: No, I cannot tell you, but generally, more than a 4 cm diameter, 4 or 5 cm diameter, you cannot do just narrowing. You should do some narrowing and a patch as well.