Preoperative modeling of an optimal left ventricle volume for surgical treatment of ventricular aneurysms


Abstract

Objective: We evaluated the results of surgical treatment postinfarction ventricular aneurysms, with preoperative modeling of an optimal left ventricle volume. Methods: From January 1998 to December 2000, 41 patients underwent left ventricular (LV) aneurysm repair. There were 39 men and two women, with mean age 45.6 ± 6.2 years. With echocardiography study, an optimal end-diastolic volume of LV was modeled on the basis of the proper stroke index and the contractile ejection fraction (EF). A permissible area of aneurysm resection was calculated by using a difference between the initial and the projected surface area of LV. The patch position and sizes were measured preoperatively. Ventricular reconstruction was performed by using linear plasty in eight patients, septal plasty of the Stoney et al. technique in 14 patients, and endoventriculoplasty of the Dor et al. technique in 19 patients. Results: The mean NYHA functional class decreased from 2.9 ± 0.6 to 1.6 ± 0.7 postoperatively. The improvement of LV contracting function made itself evident in a decreased end-diastolic volume from 216 ± 98 to 158 ± 35 ml, and end-systolic volume from 133 ± 85 to 80 ± 34 ml postoperatively. The mean EF increased from 38 ± 11 to 49 ± 9% after operation. We noted that preoperative contractile EF corresponded with postoperative EF (49.8 ± 11% and 49.3 ± 9%, respectively). The projected optimal end-diastolic volume of LV estimated before operation agreed with postoperative data (152 ± 33 ml and 158 ± 35 ml, respectively). The hospital mortality rate was 7.3%. Conclusions: Preoperative modeling of an optimal LV volume allows for the estimation of a permissible area of aneurysm resection, the position and sizes of the patch, as well as for the prevention of an excessive reduction of the LV cavity after aneurysm repair. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Left ventricular aneurysm; Endoventriculoplasty; Left ventricular geometry

1. Introduction

The main purpose of surgical treatment of postinfarction ventricular aneurysms is to ultimately remove the asynergia areas and to reconstruct the correct geometry of the left ventricle (LV) [1–6]. However, with an extensive damaging of LV, radical removal of the asynergy zone might lead to an inadequate reduction in the LV cavity [7–10]. The majority of surgeons determine the volume to be corrected by intuition. There are no conventional methods of estimating the area of LV aneurysm resection when performing linear plasty, as well as of positioning and sizing a patch during endoventriculoplasty [2,8,11]. The objective of our study was to estimate preoperative modeling of an optimal left ventricular volume in surgical treatment of postinfarction aneurysms.

2. Materials and methods

2.1. Clinical characteristics

From January 1998 to December 2000, 41 patients underwent LV aneurysm repair. There were 39 men and two women, with mean age 45.6 ± 6.2 (range 32–61) years. The indications for operations were angina pectoris in 11 patients (26.8%), congestive heart failure in nine patients (22%), or a combination of these symptoms in 21 patients (51.2%). The mean NYHA functional class was 2.9 ± 0.6 preoperatively.

All patients had anterior left ventricular aneurysm. In every case the aneurysm resulted from a critical lesion of the left anterior descending artery (LAD). One-vessel disease was observed in five patients (12.2%), two-vessel disease in ten patients (24.4%), and triple-vessel disease in 26 patients (63.4%).

2.2. Echocardiography

M-mode and two-dimensional echocardiography and
color Doppler examination were performed preoperatively and postoperatively in all patients. Left ventricular chamber sizes were obtained from M-mode findings at the basal level. Left ventricular volumes and ejection fraction were calculated using the model of Wyatt et al. [12]. Contractile ejection fraction (EF) was determined by the method described by Louagie et al. [13].

Depending on contractility of the nonaneurysmal portion of the LV, all aneurysms were divided into two types. Type I included the aneurysms with good contraction of the nonaneurysmal portion of LV, and contractile EF was more than 0.5. Type II included the aneurysms with poor contraction of the nonaneurysmal portion of LV and with segments of hypokinesia or akinesia, and contractile EF was less than 0.5 (Fig. 1).

We modeled an optimal end-diastolic volume of a ‘new’ LV that should be remained after aneurysm repair. In doing so, we outlined the end-diastolic volume (EDV) of the contractile portion of LV, while keeping the stroke index (SI) at a proper level equal to an average of 40 ml/m². If after modeling SI was equal to or exceed 40 ml/m², then optimal EDV of LV was assumed to be equal to EDV of the contractile portion of LV. If SI was less than 40 ml/m², EDV of the contractile portion of LV was increased.

Considering the proper SI and the contractile EF, we determined an optimal EDV of the ‘new’ LV required to maintain a normal cardiac output after aneurysm repair by using the following equation:

\[
\text{Optimal EDV LV} = \frac{SV}{EFC_{LV}} = \frac{SI \times BSA}{EFC_{LV}}
\]

where Optimal EDV LV is an optimal end-diastolic volume of LV, SV is a stroke volume (ml), SI is a stroke index (ml/m²), BSA is a body surface area (m²), EFC_{LV} is a contractile ejection fraction of LV.

In patients with good contraction of the nonaneurysmal portion of LV (type I) a mean value of the optimal EDV LV was equal to 144 ± 32 ml, while in those with poor contraction of the nonaneurysmal portion of LV (type II) it was much higher and amounted on the average to 187 ± 24 ml.

At the next stage we measured the geometrical parameters of a projected LV: LV basoapical dimension, LV surface area, sizes and position of the patch. To determine LV surface area, we encircle the border of EDV of LV on the echocardiograph screen and obtain a section of LV divided into 20 disks. The following formula is used to estimate the LV surface area:

\[
S = m^2 \pi \sum_{i=1}^{21} \frac{d_i + d_{i+1}}{2} \times \sqrt{\left(\frac{d_i + d_{i+1}}{2}\right)^2 + \left(\frac{L}{21}\right)^2}
\]

where \(d_i\) is the disk diameter, \(L\) is the basal–apical dimension of LV, \(m\) is the scale (the ratio between real dimensions and those in the photo).

A specially developed computer program allowed us to calculate the surface area of an initial LV with aneurysm and surface area of a projected LV (Fig. 2). A permissible area of aneurysm resection was calculated by using a difference between the initial and projected surface area of LV.

The position of a patch was determined by measuring the distance from the mitral ring to the outline of the projected LV along the lateral, posterior walls of LV and the interventricular septum. The patch sizes were then measured (Fig. 3).

### 2.3. Operative technique

All operations were performed with cardiopulmonary bypass and aortic cross clamping. Moderate systemic hypothermia (26–30°C) and cold antegrade cardioplegia were used. Ventricular reconstruction was performed by using linear plasty in eight patients, septal plasty of the Stoney et al. technique in 14 patients, and endoventriculoplasty of the Dor et al. technique in 19 patients.

The longitudinal incision was made over the apex and the thinnest portion of the aneurysm. Then we measured the extent of the scar area in the left ventricle and chose the optimum technique of LV plasty.

When the scar area of LV was equal to the permissible...
area of aneurysm resection estimated preoperatively, we used linear or septal plasty of LV. Simple excision and linear closure were used to repair apical aneurysms. In patients with anteroseptal aneurysm, the operation was performed by using septal plasty as described by Stoney et al. [14].

Fig. 2. Determining a surface area of the left ventricle. (a) Surface area of the initial LV with an aneurysm. (b) Surface area of the projected LV.
If the scar area of LV exceeded the permissible area of aneurysm resection, we used endoventriculoplasty in order to avoid an inadequate decrease in the LV cavity. The synthetic ‘Vascutek’ patch was tailored to suit the predetermined sizes, and then inserted in the estimated position. The aneurysmal wall was sutured over the patch by means of over-and-over suturing.

Thirty-nine patients (95%) underwent complete myocardial revascularization (Table 1). Open endarterectomy of the LAD was performed in two patients. The left internal...
thoracic artery was grafted in 26 patients (63.4%) to LAD. The mean number of bypass grafts was 2.4.

2.4. Statistical analysis

All values are expressed as mean ± standard deviation. The comparisons between preoperative and postoperative data were statistically analyzed by using paired or nonpaired Student’s test. Significance was achieved at a P-value of less than 0.05.

3. Results

All surviving patients had early postoperative study (1–3 months after operation). The mean NYHA functional class decreased from 2.9 ± 0.6 to 1.6 ± 0.7 postoperatively. The mean CCS functional class of angina pectoris decreased from 2.7 ± 0.9 to 1.5 ± 0.7 postoperatively.

The improvement of LV contracting function made itself evident in a decreased end-diastolic volume index from 127 ± 57 to 92 ± 21 ml/m² and end-systolic volume index from 78 ± 50 to 47 ± 20 ml/m² postoperatively. The mean EF increased significantly from 38 ± 11% to 49 ± 9% (P = 0.001) after operation (Table 2).

We noted that preoperative contractile EF was consistent with postoperative EF. Thus, a mean preoperative contractile EF and postoperative EF were 49.8 ± 11% and 49.3 ± 9%, respectively. This is proof that preoperative contractile EF can be considered as postoperative EF and thus used to estimate an optimal EDV of projected LV.

Control echocardiography showed that the projected EDV of LV estimated before operation agreed with postoperative data. Thus, a mean value of preoperative optimal EDV of LV, 152 ± 33 ml, corresponded to that of postoperative EDV of LV, 158 ± 35 ml.

When we performed linear or septal plasty of LV, the scar area of LV corresponded with the permissible area of aneurysm resection estimated preoperatively (43 ± 8 and 41 ± 9 cm², respectively). When we performed endoventriculoplasty, the scar area of LV exceeded the permissible area of aneurysm resection (68 ± 18 and 48 ± 16 cm², respectively) (Table 3).

The hospital mortality rate was 7.3% (3/41). Heart failure was the cause of death of 2 patient with poor contractility of the nonaneurysmal portion of LV (type II), and mean contractile EF was equal to 33 ± 1%. One patient died of stroke 6 days after operation. Thus, the low cardiac output syndrome accounted for death in 4.9%.

4. Discussion

There are a number of challenges in surgery of postinfarction LV aneurysm. One of the problems is to adequately restore the volume and geometry of LV after aneurysm repair [1,2,8,14–18].

Salati et al. reported that 8% of patients had a severe diastolic dysfunction after endoventriculoplasty [8]. The authors stated that postoperative heart failure resulted from a sudden reduction of the ventricular volume, leaving a ‘shorter’ ventricle. Thus, the line of patch implantation should be equal to the predicted apex-base length (usually 7.0–7.5 cm) and the diameter of the patch should be greater 5 cm in high-risk patients [8].

Dor et al. also mentioned the some disappointing cases with good immediate results after endoventriculoplasty followed by recurrence of cardiac insufficiency [2]. This made the authors think that too small volume can lead to

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**Table 1**

Methods of LV aneurysm repair and concomitant procedures

<table>
<thead>
<tr>
<th>Procedure</th>
<th>No. of patients</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear plasty</td>
<td>8</td>
<td>19.5</td>
</tr>
<tr>
<td>Septal plasty</td>
<td>14</td>
<td>34.2</td>
</tr>
<tr>
<td>Endoventriculoplasty</td>
<td>19</td>
<td>46.3</td>
</tr>
<tr>
<td>Thrombectomy</td>
<td>27</td>
<td>65.8</td>
</tr>
<tr>
<td>Myocardial revascularization</td>
<td>39</td>
<td>95.0</td>
</tr>
<tr>
<td>LAD graft</td>
<td>26</td>
<td>63.4</td>
</tr>
</tbody>
</table>

*a* LAD, left anterior descending coronary artery.

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**Table 2**

Preoperative and postoperative echocardiographic data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preoperative (mean ± SD)</th>
<th>Postoperative (mean ± SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDD (cm)</td>
<td>6.2 ± 0.7</td>
<td>5.8 ± 0.4</td>
<td>0.01</td>
</tr>
<tr>
<td>ESD (cm)</td>
<td>4.6 ± 0.9</td>
<td>4.2 ± 0.6</td>
<td>0.01</td>
</tr>
<tr>
<td>EDVI (ml/m²)</td>
<td>127 ± 57</td>
<td>92 ± 21</td>
<td>0.001</td>
</tr>
<tr>
<td>ESVI (ml/m²)</td>
<td>78 ± 50</td>
<td>47 ± 20</td>
<td>0.001</td>
</tr>
<tr>
<td>SI (ml/m²)</td>
<td>47 ± 13</td>
<td>45 ± 12</td>
<td>0.2</td>
</tr>
<tr>
<td>EF (%)</td>
<td>38 ± 11</td>
<td>49 ± 9</td>
<td>0.001</td>
</tr>
<tr>
<td>EFc (%)</td>
<td>50 ± 11</td>
<td>49 ± 9</td>
<td></td>
</tr>
</tbody>
</table>

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**Table 3**

Preoperative and operative parameters of LV aneurysms

<table>
<thead>
<tr>
<th>Variable</th>
<th>Linear or septal plasty</th>
<th>Endoventriculoplasty</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDV (ml)</td>
<td>192 ± 43</td>
<td>227 ± 67</td>
</tr>
<tr>
<td>EF (%)</td>
<td>46 ± 9</td>
<td>39 ± 12</td>
</tr>
<tr>
<td>EFc (%)</td>
<td>53 ± 7</td>
<td>44 ± 11</td>
</tr>
<tr>
<td>OEDV of projected LV (ml)</td>
<td>134 ± 16</td>
<td>158 ± 24</td>
</tr>
<tr>
<td>Surface area of initial LV (cm²)</td>
<td>179 ± 27</td>
<td>197 ± 32</td>
</tr>
<tr>
<td>Surface area of projected LV (cm²)</td>
<td>138 ± 14</td>
<td>149 ± 27</td>
</tr>
<tr>
<td>Permissible area of aneurysm resection (cm²)</td>
<td>41 ± 9</td>
<td>48 ± 16</td>
</tr>
<tr>
<td>Scar area of LV (cm²)</td>
<td>43 ± 8</td>
<td>68 ± 18</td>
</tr>
<tr>
<td>Area of patch (cm²)</td>
<td>–</td>
<td>21 ± 6</td>
</tr>
</tbody>
</table>

*a* EDV, end-diastolic volume; OEDV, optimal end-diastolic volume.
disturbed diastolic compliance of the new ventricle. Therefore, it was suggested that the patch size should be increased from a half to a full diameter of the internal hole of the left ventricle after endocardial resection [2]. Jatene described an opposite situation, when due to a large size of the patch there occurred marked cardiac insufficiency, which made him further decrease the LV cavity during re-operation [1].

These examples clearly demonstrate that after repairing LV aneurysm the cardiac function depends heavily on adequate reconstruction of the LV cavity. However, it is difficult to visually determine the extent of intervention in some cases [19]. Therefore, the proposed method of preoperative estimation of an optimal LV volume could help in avoiding an inadequate LV reduction after aneurysm repair. Based on preoperative evaluation of contractility of the nonaneurysmal portion, we determine an optimal EDV of LV that is needed to provide adequate hemodynamics.

For example, with a big anterior septal aneurysm of LV and good contraction of the remaining myocardium (type I), without hypo- or akinesia segments of the nonaneurysmal portion, and with contractile EF being equal to 0.5, we can estimate an optimal EDV of the ‘new’ LV. If the patient’s body surface area is 1.7 m², then

\[
\text{Optimal EDV LV} = \frac{40 \text{ ml/m}² \times 1.7 \text{ m}²}{0.5} = 136 \text{ ml}
\]

So, with such EDV and EF postoperatively, LV will provide a normal cardiac output – 40 ml/m².

Considering the opposite situation, with a diffuse LV aneurysm, hypo- and akinesia segments of the nonaneurysmal portion, with the interventricular septum extensively damaged and with contractile EF being equal to 0.35 (type II), an optimal EDV of the ‘new’ LV will be equal to

\[
\text{Optimal EDV LV} = \frac{40 \text{ ml/m}² \times 1.7 \text{ m}²}{0.35} = 194 \text{ ml}
\]

Therefore, after inadequate correction, with EDV approximated to normal values (120 ml) and postoperative EF being equal to 0.35, the stroke volume would be 42 ml only (120 ml × 0.35 = 42 ml). As is evident, in this situation it would be possible to prognosticate the low cardiac output syndrome due to an inadequate LV reduction.

In patients with global hypokinesia LV dilatation is a compensatory mechanism [18] and therefore, it is important to estimate an optimal EDV of the ‘new’ LV preoperatively. Too small an LV cavity tends to develop a low cardiac output and diastolic dysfunction, while too big an LV cavity decreases the ejection fraction and increases myocardial stress [9]. Thus, it was important to find an ideal relationship between the advantage gained from decreasing the tension of myocardium due to LV reduction and the required LV cavity in order to provide an adequate cardiac output.

In conclusion, preoperative modeling of an optimal LV volume allows one to estimate a permissible area of aneurysm resection, a position and sizes of the patch, as well as to avoid an inadequate LV reduction after aneurysm repair.

References