SERIAL ASSESSMENT OF LEFT VENTRICULAR FUNCTION FOLLOWING CORONARY BYPASS SURGERY BY RADIONUCLIDE ANGIOCARDIOGRAPHY

Michio Kawasuji, M.D., Shigeharu Sawa, M.D., Naoki Sakakibara, M.D., Takashi Iwa, M.D., Junichi Taki, M.D. and Hisashi Bunko, M.D.

The serial change in left ventricular function was investigated by radionuclide angiocardiography in 25 patients undergoing coronary artery bypass grafting (CABG). Multiple gated equilibrium blood pool imaging was performed at rest before, and at 1, 2 and 4 weeks after the operation and also during exercise on a supine bicycle ergometer before and 4 weeks after surgery. Global ejection fraction at rest was unchanged after CABG while peak ejection rate increased significantly at 1 and 2 weeks (p < 0.01 and p < 0.05 respectively) after the operation. Peak filling rate at rest was generally unchanged after surgery but peak filling rate during the first third of diastole at rest decreased significantly at 1 and 2 weeks (p < 0.01 and p < 0.05). After CABG, the increases in ejection fraction and peak ejection rate with exercise were significantly greater than those values measured before surgery. The increases, due to exercise, in peak filling rate and peak filling rate during the first third of diastole were unchanged after the operation. Radionuclide angiocardiography affords a safe, noninvasive, and highly reproducible procedure for serially assessing ventricular function in patients undergoing CABG. Our study revealed early diastolic dysfunction within 2 weeks of surgery and that CABG abolished abnormalities in left ventricular function induced by exercise.

SERIAL assessment of left ventricular function following coronary artery bypass grafting (CABG) surgery provides information valuable for recognizing processes of recovery from the effects of surgery, recognizing effectiveness or ineffectiveness of revascularization and optimizing individual postoperative physical training. Ventricular function following CABG could depend on the time at which assessment is made, preoperative ventricular function, the efficiency of myocardial revascularization, and myocardial injury caused by surgery. Although there have been some reports on serial changes in left ventricular function after CABG1-3 none have described serial changes during the 4 weeks following surgery. Furthermore, most previous works reported changes only in systolic ventricular function4-6,10-12 and few data are available concerning the changes in left ventricular diastolic function following CABG7,8 Radionuclide angiocardiography is a safe, noninvasive and easily reproducible procedure which measures left ventricular function and the data resulting from it have been demonstrated to be accurate by comparisons with other hemodynamic measurements.

Key words:
Ventricular function
Coronary bypass surgery
Radionuclide angiocardiography

(Received April 14, 1988; accepted June 15, 1988)
Department of Surgery (I) and *Department of Nuclear Medicine, Kanazawa University School of Medicine, Kanazawa, Japan
Mailing address: Michio Kawasuji, M.D., Department of Surgery (I), Kanazawa University School of Medicine, 13-1, Takara-cho, Kanazawa 920, Japan

Japanese Circulation Journal Vol. 52, October 1988 1149
Fig. 1. Schematic presentation of left ventricular (LV) volume curve and the first derivative (dV/dt) of the LV volume curve. PER; peak ejection rate, 1/3FR; peak filling rate of the first third of diastole, PFR; peak filling rate.

The purpose of this study was to investigate, by means of radionuclide angiography, the changes in left ventricular systolic and diastolic function before and 1, 2, and 4 weeks after CABG.

PATIENTS AND METHODS

This study was conducted on 25 patients who underwent elective CABG between September 1985 and June 1986. The patients ranged in age from 48 to 68 years, with a mean age of 57 ± 6 years. Coronary arteries with 75% or greater reduction of luminal diameter were considered to be significantly obstructed. Four of the patients had single-vessel coronary disease, 9 had double-vessel coronary disease, 9 had triple-vessel coronary disease and 3 had disease of the left main coronary artery. Thirteen patients had a history of remote myocardial infarction documented by electrocardiographic and/or cardiac enzymatic changes. Nine patients had unstable angina. CABG was carried out with myocardial preservation accomplished by the administration of a cold crystalloid K+ cardioplegic solution and topical cooling with saline slush. The surgical procedure involved single coronary bypass grafting in 4 patients, double coronary bypass grafting in 13 patients and triple coronary bypass grafting in 7 patients. An internal mammary artery was used as a graft to the left anterior descending coronary artery in 6 patients. Segments of the great saphenous vein were used as grafts to other coronary arteries. Ninety-two per cent of all grafts were patent at postoperative coronary angiography or digital subtraction angiography. Fifteen of the patients underwent anatomically complete myocardial revascularization. Aortic cross-clamp durations ranged from 20 to 85 min, with a mean duration of 50 ± 15 min. Cardiopulmonary bypass times ranged from 67 to 184 min, with a mean time of 117 ± 30 min.

Left ventricular function was evaluated by the radionuclide angiographic method before and 1, 2 and 4 weeks after surgery. Multiple gated equilibrium blood pool imaging was performed after the equilibration of 20–25 mCi 99m-Tc-labeled autologous red blood cells in the intravascular spaces. The patients were examined in 30–40° left anterior oblique projection and 10° caudal angulation, using an Anger type gamma camera (Technicare Σ 410S) equipped with a dedicated computer (Technicare VIP 460). Twenty-six frames per cycle from a total of 600 cardiac cycles, gated for the ECG, were collected and analyzed for each examination. Frame mode acquisition was performed with patients resting in the supine position before and 1, 2 and 4 weeks after the operation and also during exercise on a supine bicycle ergometer before and 4 weeks after surgery. From the left ventricular volume curve, the end-diastolic volume, the end-systolic volume and the stroke volume were determined. This method, as used in our laboratory, compares favorably with contrast ventriculography (R = 0.899)\(^8\). The global ejection fraction was calculated as end-diastolic counts minus end-systolic counts divided by background corrected end-diastolic counts. Regional ejection fraction was determined in 3 anatomically distinct segments of the left ventricle, namely the anteroseptal, apical, and inferolateral portions. Peak ejection rate, peak filling rate, and peak filling rate during the first third of diastole were calculated from the first derivative curve of the left ventricular volume curve (Fig. 1).

All patients underwent serum enzymatic evaluations of lactic dehydrogenase, glutamic oxaloacetic transaminase, total creatine kinase, and CK-MB isoenzyme during the immediate postoperative period. Electrocardiograms were also determined. Cumulative data were expressed as mean ± standard deviation of the mean with

*Japanese Circulation Journal Vol. 52, October 1988*
TABLE I DATA OF PREOPERATIVE AND POSTOPERATIVE RESTING SERIAL LEFT VENTRICULAR FUNCTION (mean ± S.D.)

<table>
<thead>
<tr>
<th></th>
<th>Before operation</th>
<th>After operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td><strong>Heart rate</strong> (beats/min)</td>
<td>72 ± 15</td>
<td>91 ± 12†</td>
</tr>
<tr>
<td><strong>End-diastolic volume</strong> (ml)</td>
<td>152 ± 44</td>
<td>102 ± 31†</td>
</tr>
<tr>
<td><strong>End-systolic volume</strong> (ml)</td>
<td>67 ± 31</td>
<td>51 ± 29</td>
</tr>
<tr>
<td><strong>Stroke volume</strong> (ml)</td>
<td>85 ± 21</td>
<td>51 ± 11†</td>
</tr>
<tr>
<td><strong>Ejection fraction (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>57 ± 11</td>
<td>53 ± 13</td>
</tr>
<tr>
<td>Antero-septal</td>
<td>36 ± 12</td>
<td>28 ± 11</td>
</tr>
<tr>
<td>Apical</td>
<td>77 ± 16</td>
<td>75 ± 19</td>
</tr>
<tr>
<td>Infero-lateral</td>
<td>62 ± 13</td>
<td>63 ± 16</td>
</tr>
<tr>
<td><strong>Peak ejection rate</strong> (sec⁻¹)</td>
<td>2.93 ± 0.75</td>
<td>3.70 ± 1.10†</td>
</tr>
<tr>
<td><strong>Peak filling rate</strong> (sec⁻¹)</td>
<td>2.30 ± 0.81</td>
<td>2.59 ± 1.00</td>
</tr>
<tr>
<td>1/3 filling rate (sec⁻¹)</td>
<td>1.79 ± 0.72</td>
<td>0.81 ± 0.57†</td>
</tr>
</tbody>
</table>

* = p < 0.05 and † = p < 0.01 compared with the value before operation.

statistical comparisons being made by Student's t-test to detect significant (p < 0.05) differences between the measured variables.

RESULTS

Resting left ventricular function

Table I shows the summarized data of left ventricular function at rest for all the patients. The mean end-diastolic volume was 152 ± 44 ml before surgery and decreased significantly 1 and 2 weeks after the operation (p < 0.01) while the mean end-systolic volume was 67 ± 31 ml before and showed no significant change after surgery. A significant decrease from 85 ± 21 ml was seen in the mean stroke volume at 1, 2 and 4 week following (p < 0.01).

Before CABG, the mean global ejection fraction was 57 ± 11% (normal, 58 to 68%); antero-septal ejection fraction was 36 ± 12% (normal, 32 to 48%), apical ejection fraction was 77 ± 16% (normal, 85 to 95%), infero-lateral ejection fraction was 62 ± 13% (normal, 57 to 75%). Surgery resulted in no significant change in the mean global ejection fraction. However, the antero-septal ejection fraction decreased significantly at 2 and 4 weeks (p < 0.01).

The mean peak ejection rate before the operation was 2.93 ± 0.75 sec⁻¹ (normal, 3.40 to 3.50 sec⁻¹). After CABG, this increased significantly at 1 week (p < 0.01) and at 2 weeks (p < 0.05), and then decreased to the preoperative mean value at 4 weeks. The mean peak filling rate was initially 2.30 ± 0.81 sec⁻¹ (normal, 2.18 to 3.30 sec⁻¹) and showed no significant change after the operation. On the other hand, the mean peak filling rate during the first third of diastole which was 1.79 ± 0.72 sec⁻¹ (normal, 1.52 to 2.56 sec⁻¹) before surgery decreased significantly at 1 week (p < 0.01) and at 2 weeks (p < 0.05), and then returned to the preoperative value at 4 weeks afterwards.

Figure 2 shows the changes in resting left ventricular function before and 4 weeks after the operation. The mean ejection fraction declined from 57 ± 11% to 53 ± 8% and the mean peak ejection rate fell from 2.93 ± 0.75 sec⁻¹ to 2.88 ± 0.55 sec⁻¹ while the mean peak filling rate increased from 2.30 ± 0.81 to 2.45 ± 0.64 sec⁻¹. The mean peak filling rate during the first third of diastole was 1.79 ± 0.72 sec⁻¹ before and 1.79 ± 0.63 sec⁻¹ 4 weeks after surgery. There
were no significant changes in ejection fraction, peak ejection rate, peak filling rate and peak filling rate of the first third of diastole before and 4 weeks after the operation.

Left ventricular function during exercise

Figure 3 shows the changes in exercise response before and 4 weeks after surgery. The mean ejection fraction decreased by 6.5 ± 6.9% with exercise before and increased by 4.1 ± 6.4% with exercise after the operation (p < 0.01). Similarly, the mean peak ejection rate decreased by 0.07 ± 0.40 sec⁻¹ with exercise before, but increased by 1.02 ± 0.76 sec⁻¹ with exercise after (p < 0.01). All 17 patients showed an increase in peak ejection rate during exercise after surgery had been performed. The mean peak filling rate increased by 1.02 ± 0.69 sec⁻¹ with exercise before CABG and also increased by 1.63 ± 0.99 sec⁻¹ with exercise afterwards, with this change in exercise response being statistically insignificant. An exercise-induced increase in the mean value of peak filling rate during the first third of diastole was seen both before (0.44 ± 0.70 sec⁻¹) and after (0.53 ± 0.68 sec⁻¹) the operation. This change in exercise response was not statistically significant. One patient (C.K.) showed a significant fall in ejection fraction during postoperative exercise as well as during preoperative exercise. This patient showed a deterioration in peak filling rate during the first third of diastole during postoperative exercise as compared with the measured preoperative exercise response.

Assessment of perioperative myocardial damage

The peak MB-CK after surgery ranged from 9 to 107 IU/l, with a mean value of 31 ± 27 IU/l.
A postoperative electrocardiogram showed the development of a new and persistent Q wave in 1 patient whose peak MB-CK value was 70 IU/l. This patient showed no significant decrease in ejection fraction postoperatively. After the operation, the conditions of all patients were satisfactory.

DISCUSSION

This study using radionuclide ventriculography, which permits serial reproducible non-invasive measurement of left ventricular function, documents important changes in left ventricular performance over 4 week period following CABG. Ventricular function after CABG could depend upon the preoperative ventricular function, operative procedure used and perioperative myocardial damage incurred, and also upon the time at which assessment is made. In previous reports, resting left ventricular ejection fraction was unchanged at 2 days, 10 1 to 2 weeks, 7, 11 6 weeks 6 and 3 to 4 months, 2, 4 or was improved at 1 and 2 weeks, 3, 12 after CABG. The results of our study showed no significant change in resting global ejection fraction during the 4 weeks following CABG, whereas peak ejection rate was seen to increase significantly at 1 and 2 weeks. This increase in peak ejection rate is considered to be due to an increase in adrenergic tone after surgery. In sequential studies of myocardial wall motion using radiopaque markers, Mintz et al 1 found increased circumferential shortening rate 1 week after surgery. Boudlas et al 9 reported that variations in adrenergic tone might influence ventricular function for at least 2 weeks after surgery.

Left ventricular function should be evaluated

Japanese Circulation Journal Vol. 52, October 1988
in terms of diastolic as well as systolic function. In this study, left ventricular diastolic function was evaluated from the peak filling rate and the peak filling rate during the first third of diastole. The former demonstrates ventricular function during the rapid ventricular filling phase and the latter demonstrates ventricular function during the isovolumic diastolic phase. Astorri et al\textsuperscript{7} reported a significant increase both in peak filling rate and peak ejection rate at 1 week after CABG. In our study, peak filling rate showed improvement at 1 week after surgery, but this was not statistically significant. Peak filling rate during the first third of diastole, however, fell significantly in the 2 weeks following the operation. Myocardial relaxation during early diastole is an active, energy-dependent process and is a sensitive indicator of abnormality in left ventricular function\textsuperscript{13} Thus, the early diastolic dysfunction noted in the left ventricle is supposedly due to intraoperative myocardial damage. Accordingly, rehabilitation of patients should be carefully performed within 2 weeks of surgery. Early diastolic dysfunction showed spontaneous improvement within 4 weeks of the operation, this result being consistent with a benign clinical course.

Assessment of ventricular response to exercise is a useful and sensitive method for evaluating myocardial ischemia. A fall in ejection fraction during exercise indicates abnormal ventricular response to exercise\textsuperscript{5–6,13} This was seen in our preoperative study where 16 out of 20 patients showed a fall in exercise ejection fraction. A fall or poor increase in peak ejection rate also revealed abnormal response to exercise in our preoperative study. The improvement in ejection fraction and peak ejection rate with postoperative exercise indicates that CABG successfully corrects the ischemic response\textsuperscript{5–6} In our postoperative study, all patients showed improvement of the exercise response in terms of ejection fraction and/or peak ejection rate. Four weeks after surgery was chosen as the time interval for exercise evaluation, because the effects of surgery on resting systolic and diastolic left ventricular function seem to largely wear off by this time.

Postoperative administration of propranolol or digitalis may have played an important role in modifying ventricular function though Taylor et al\textsuperscript{6} noted that treatment with \(\beta\) blocker had no significant effect on this. In our study, no patient received digitalis and 3 patients initially receiving propranolol continued to use this medication postoperatively. During postoperative exercise, 2 of these 3 patients showed a fall in ejection fraction and a poor increase in peak ejection rate and peak filling rate. These 2 patients revealed no signs of perioperative myocardial infarction but did show evidence of incomplete revascularization.

**LITERATURE**

1. MINITZ LJ, INGELS NB, DAUGHTERS GT, STINSON EB, ALDERMAN EL: Sequential studies of left ventricular function and wall motion after coronary bypass surgery. *Am J Cardiol* 45: 210, 1980

*Japanese Circulation Journal* Vol. 52, October 1988
