Cardiac function assessed by systolic time intervals after aortocoronary saphenous vein bypass surgery¹

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Systolic time intervals were measured in 33 patients undergoing aortocoronary saphenous vein bypass, before operation and 7 days after operation. Eighteen patients had normal systolic time intervals before operation (group I), and 15 had abnormal preoperative intervals (group II). Group I patients experienced significant shortening of the left ventricular ejection time index from 404 msec to 371 msec postoperatively ($P < 0.001$), with no significant change in the pre-ejection phase index. These changes are consistent with acute left ventricular dysfunction in the early postoperative period. Group II patients had an entirely different response, with no significant change in the postoperative left ventricular ejection time index and a significant decrease in the pre-ejection phase index from 155 msec to 143 msec ($P < 0.001$). The shortening of pre-ejection phase index may have represented improved ventricular function after operation. An alternative explanation for pre-ejection phase index shortening would be the effects of adrenergic stimulation. Later observations at 1 to 2 months suggested that the group I response was transient and the group II response was sustained.

During recent years, there has been a resurgence of interest in the surgical approach to coronary artery disease. This has been brought about by the technique of aortocoronary saphenous vein bypass surgery, which has been shown to alleviate angina pectoris in a high percentage of patients (Johnson *et al.*, 1969; Mitchell *et al.*, 1970; Spencer, 1970). Though most observers agree that relief of angina is significant, there are less detailed data available on the effect of the operation on left ventricular haemodynamics. Several studies in relatively small groups of patients have shown postoperative improvements in ejection fraction (Rees *et al.*, 1971; Chatterjee *et al.*, 1971; Mailhot, Sandler, and Harrison, 1971), end-systolic volume (Rees *et al.*, 1971), and post-exercise left ventricular end-diastolic pressure (Rees *et al.*, 1971; Chatterjee *et al.*, 1971; Johnson *et al.*, 1970; Campeau *et al.*, 1971). In one study by Dorchak *et al.* (1971), no improvement in ejection fraction was noted in 17 of 18 patients with abnormal preoperative values.

Most of the aforementioned studies were performed several weeks to months after operation. The purpose of the present study was to assess the early haemodynamic effects of aortocoronary vein bypass surgery in a reasonably large group of patients. Because of its reported reliability and ease of performance, the method of externally measured systolic time intervals (Weissler, Harris, and Schoenfeld, 1968, 1969; Martin *et al.*, 1971; Spodick, Dorr, and Calabrese, 1969) was chosen as the means of comparing pre- and postoperative ventricular function.

Subjects and methods

Thirty-three patients undergoing aortocoronary vein bypass surgery were evaluated by phonocardiographic measurement of systolic time intervals as described by Weissler *et al.* (1968). An Elema Scholander 4-channel recorder was used for recording in all patients. All records were made at a paper speed of 100 mm/sec. The carotid pulse was recorded with a pressure cup via rubber tubing in series with an air-coupled transducer (Hewlett Packard Model 2 1051 D). The left ventricular ejection time was measured from the onset of the rapid carotid upstroke to the dicrotic notch. Total electromechanical systole, or the qS_2 interval, was measured from the onset of the q wave of the electrocardiogram to the onset of the first high frequency vibrations of the

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second heart sound. The pre-ejection phase was derived by subtracting the left ventricular ejection time from the qS_2 interval for each individual set of measurements. All intervals represented the average of 10 individually measured cardiac cycles.

All patients were studied one day before operation and again at one week after operation. Fifteen patients were restudied one to two months after operation. Most of the patients were studied in the fasting state in the early morning. Where this was not possible, pre- and postoperative studies were done at the same time of day for each patient in order to avoid the minor effects of diurnal variation (Weissler *et al.*, 1965). All patients were in normal sinus rhythm without AV or intraventricular conduction disturbances. Patients receiving digitalis preparations were included only if they were taking the same dose at the time of both measurements.

The 33 patients underwent vein bypass operation on cardiopulmonary bypass. Serial electrocardiograms and serum enzymes were available on all patients.

In order to correct for the effects of heart rate on systolic time intervals, the following equations, derived by Weissler *et al.* (1968), were used:

- 1) Left ventricular ejection time index (msec).
 $(LVETI) = \text{measured LVET} + 1.7 \times \text{HR (men)}$
 $\text{and} = \text{measured LVET} + 1.6 \times \text{HR (women)}.$
- 2) Pre-ejection phase index (msec).
 $(PEPI) = \text{measured PEP} + 0.4 \times \text{HR (men and women)}.$
- 3) PEP/LVET ratio was expressed as the ratio of the two directly measured intervals, uncorrected for heart rate.

Results

General

There were 33 patients studied pre- and postoperatively, consisting of 27 men and 6 women. The mean age of the group was 48 years. One death occurred in a 58-year-old woman (Case 8) who died three weeks after operation after sustaining intraoperative and postoperative myocardial infarctions. None of the patients was in obvious congestive heart failure preoperatively, though 6 were on digitalis preparations. Six patients had suspected or proven intraoperative myocardial infarctions (Table). One patient had suspected infarction on the basis of a peak postoperative serum aspartate aminotransferase greater than 100 IU/l. (with upper limit of normal 40 Sigma Frankel/l.) (Hultgren *et al.*, 1971; Greenberg *et al.*, 1970) without new q waves. Five patients had developed new q waves as well as aspartate aminotransferase values greater than 100 Sigma Frankel/l. None of the 27 patients with peak postoperative aminotransferase values below 100 Sigma Frankel/l. had new q waves in the postoperative cardiograms.

Preoperative systolic time intervals

The study population was separated into two sub-

groups, on the basis of the preoperative pre-ejection phase-left ventricular ejection time ratio (PEP/LVET). Using a cutoff ratio of 0.43, there were 18 patients below and 15 patients above this value. The 18 patients with ratios below 0.43 were considered to have essentially normal systolic time intervals and are referred to as group I patients. The 15 with ratios over 0.43 were felt to have abnormal systolic time intervals and are designated group II. The cutoff point of 0.43 was based on studies by Weissler, which indicated that a value of 0.43 would be two standard deviations above a normal population mean of 0.35 (Weissler *et al.*, 1969). The ratio has been shown to have good correlation with directly measured parameters of left ventricular function (Weissler *et al.*, 1969; Garrard, Weissler, and Dodge, 1970). The preoperative intervals differed between these two groups (Table). Group I patients had a mean left ventricular ejection time interval of 404, a pre-ejection phase index of 134, and a PEP/LVET ratio of 0.37. These values all fall within the normal range described by Weissler *et al.* (1969). Group II patients had abnormalities of all three parameters, with left ventricular ejection time index of 377, a pre-ejection phase index of 155, and a PEP/LVET ratio of 0.50.

Adequate left ventriculograms for calculation of ejection fraction were available for 7 group I and 9 group II patients. Measurements were made using the single plane, area-length method of Sandler and Dodge (1968). The mean ejection fraction for group I was 77.6 per cent (± 7.6) and for group II was 58.1 per cent (± 9.3). These values were significantly different ($P < 0.01$). In addition, 8 of the 9 group II studies showed localized abnormalities in left ventricular contraction which were not present in any of the 7 group I ventriculograms. Therefore, the two groups seemed separable on the basis of invasive studies, as well as the preoperative systolic time intervals.

Postoperative changes

The two groups were not only different in their initial values, but seemed to differ in their early systolic time interval response to operation (Table and Fig. 1-3). Group I patients showed a shortening of left ventricular ejection time index from 404 preoperatively to 371 msec postoperatively ($P < 0.001$). The group II patients sustained a statistically insignificant drop in the index from 377 to 371 msec (Fig. 1). The pre-ejection phase index in group I was unaltered, with pre- and postoperative values of 134 and 133 msec, respectively (Fig. 2). Group II patients, on the other hand, underwent a shortening of the pre-ejection phase index from

TABLE Pre- and postoperative systolic time intervals, heart rate, and serum aspartate aminotransferase (SGOT)

Case No.	Age (yr)	Sex	LVETI (msec)		PEPI (msec)		PEP/LVET		Peak SGOT	Heart rate	
			Preop.	Postop.	Preop.	Postop.	Preop.	Postop.	Postop.	Preop.	Postop.
Group I											
1	55	M	396	366	139	145	0.39	0.54	71	74	100
2	53	M	433	372	138	125	0.34	0.37	240*	45	69
3	65	F	424	373	140	146	0.32	0.45	31	56	70
4	47	M	425	381	135	125	0.35	0.41	36	63	80
5	39	F	381	368	136	151	0.39	0.52	60	56	91
6	55	M	419	374	125	151	0.32	0.51	25	62	86
7	55	M	409	373	134	136	0.38	0.45	33	70	88
8	58	F	402	341	138	140	0.38	0.50	512*	69	76
9	36	M	422	373	144	109	0.39	0.33	36	78	88
10	54	M	418	371	131	141	0.33	0.47	70	57	76
11	49	M	388	372	113	118	0.31	0.39	226*	60	72
12	49	M	396	367	128	128	0.35	0.39	34	61	65
13	42	M	366	372	124	130	0.38	0.42	70	55	86
14	47	M	401	364	147	135	0.41	0.47	52	62	88
15	42	M	394	385	139	129	0.41	0.41	152*	73	97
16	34	M	414	370	132	140	0.36	0.50	60	79	100
17	60	M	387	361	144	118	0.42	0.38	42	60	71
18	52	M	404	379	132	132	0.37	0.42	31	79	82
Mean $\pm$ (SEM)			404 (± 4)	371 (± 2) P < 0.001	134 (± 2)	133 (± 3) P = NS	0.37 (± 0.01)	0.44 (± 0.01) P < 0.001		64 (± 2)	84 (± 3) P < 0.01
Group II											
19	50	M	383	350	165	138	0.52	0.41	30	67	91
20	59	M	378	354	139	127	0.43	0.42	119†	67	68
21	48	M	388	390	155	150	0.48	0.48	27	77	92
22	48	M	384	379	145	150	0.43	0.48	59	61	76
23	50	M	374	377	157	148	0.46	0.46	38	67	69
24	49	M	380	354	160	162	0.57	0.52	44	100	79
25	45	M	390	378	145	142	0.46	0.47	44	88	90
26	58	M	389	375	160	136	0.49	0.46	70	70	91
27	52	M	384	402	159	143	0.51	0.42	62	79	79
28	26	F	381	381	147	124	0.45	0.37	64	62	95
29	44	M	359	364	158	145	0.55	0.52	50	72	98
30	52	M	360	345	138	135	0.46	0.52	190	71	91
31	50	M	372	375	174	144	0.56	0.48	29	60	85
32	45	M	397	371	155	141	0.45	0.50	NA	63	71
33	60	M	341	332	163	160	0.65	0.63	56	83	82
Mean $\pm$ (SEM)			377 (± 4)	371 (± 5) P = NS	155 (± 3)	143 (± 3) P < 0.001	0.50 (± 0.02)	0.48 (± 0.02) P = NS		74 (± 3)	83 (± 2) P < 0.05

* Peak postoperative serum aspartate aminotransferase > 100 IU/l., with electrocardiographic evidence of acute infarction.

† Peak postoperative serum aspartate aminotransferase > 100 IU/l., without electrocardiographic evidence of acute infarction. LVETI = left ventricular ejection time index; PEPI = pre-ejection phase index.

155 to 143 msec ($P < 0.001$). Thirteen of the 15 patients in group II demonstrated a shortened pre-ejection phase index postoperatively. The PEP/LVET ratio in group I rose significantly from 0.37 to 0.44 ($P < 0.001$). The group II response again differed by dropping slightly from 0.50 to 0.48 (Fig. 3). This change was not statistically significant.

Six patients were suspected of sustaining intra-operative myocardial infarction on the basis of postoperative serum aspartate aminotransferase values exceeding 100 IU/l. (Hultgren *et al.*, 1971; Greenberg *et al.*, 1970). The left ventricular ejection time

index in this group decreased from 392 to 362 postoperatively. The pre-ejection phase index went from 134 to 129, and the PEP/LVET ratio from 0.39 to 0.44. These responses are similar to that of the group I patients.

Group I patients with normal preoperative systolic time intervals showed abnormal systolic time intervals postoperatively consisting of significant shortening of the left ventricular ejection time index, a rise in the PEP/LVET ratio, and no change in the pre-ejection phase index. Group II patients had a very different response, including a shortened pre-

FIG. 1.

FIG. 1 Left ventricular ejection time index (LVETI) before and 7 days after operation.

FIG. 2.

FIG. 2 Pre-ejection phase index (PEPI) before and 7 days after operation.

FIG. 3.

FIG. 3 PEP/LVET ratio before and 7 days after operation.

ejection phase index without significant change in left ventricular ejection time index or PEP/LVET ratios.

Discussion

The 18 group I patients with normal preoperative systolic time intervals had evidence of acute left ventricular dysfunction postoperatively, as evidenced by significant shortening of the left ventricular ejection time index and increase in the PEP/LVET ratio, without change in the pre-ejection phase index. These types of changes are identical to previously reported effects of acute myocardial infarction on systolic time intervals (Toutouzas *et al.*, 1969; Heikkilä, Luomanmaki, and Pyörälä, 1971; Jain and Lindahl, 1971). They differ from intervals noted in patients with chronic heart failure, in whom a lengthened pre-ejection phase has been reported, in addition to a shortened left ventricular ejection time (Weissler *et al.*, 1968; Garrard *et al.*, 1970).

The pre-ejection phase comprises isovolumic contraction time and the electromechanical delay. The isovolumic contraction time lengthens when chronic myocardial dysfunction is present (Weissler *et al.*, 1968) and shortens under the influence of catecholamines (Harris *et al.*, 1966). Since patients with acute left ventricular dysfunction (e.g. myocardial infarction) are in a state of adrenergic stimulation (Valori, Thomas, and Shillingford, 1967), the opposing effects result in little or no net effect on the pre-ejection phase (Toutouzas *et al.*, 1969; Heikkilä *et al.*, 1971; Jain and Lindahl, 1971). The left ventricular ejection time index shortening probably reflects a drop in stroke volume (Heikkilä *et al.*, 1971).

The decrease in left ventricular ejection time index in group I patients could theoretically be due entirely to an enhanced systolic ejection rate induced by catecholamine secretion in the early postoperative period. If one assumes this and rejects the hypothesis of acute lowering of stroke volume, then one would expect that the pre-ejection phase index would be shortened rather than remain unchanged for the group. Harris and co-workers have shown that adrenaline or isoprenaline infusion results in a shortening of both the pre-ejection phase and left ventricular ejection time (Harris *et al.*, 1966). Furthermore, the pre-ejection phase shortening was relatively greater than left ventricular ejection time shortening. Thus, if one calculates the pre- and post-catecholamine infusion PEP/LVET ratios from Harris's study, there was a decrease rather than the increase noted in our group I patients postoperatively.

Another argument favouring acute myocardial dysfunction in group I is that their postoperative changes were the same as the 6 patients who had suspected or documented intraoperative myocardial infarctions.

The acute alterations in left ventricular ejection time intervals in group I were transient. Ten of these patients were available for restudy one to two months postoperatively. Fig. 4 shows that the left ventricular ejection time index in all of these patients returned to normal values of 400 msec or greater.

One would not expect the group I patients to have improved systolic time intervals postoperatively, since they already had evidence for normal left ventricular function preoperatively. We feel that the

FIG. 4 Left ventricular ejection time index (LVETI) in 10 group I patients, measured 7 days before, and 1 to 2 months after operation.

acute, transient depression of systolic time intervals observed in these patients reflects the acute deleterious effects of cardiopulmonary bypass, as well as the temporary coronary inflow occlusion required during the time necessary for anastomosing the saphenous vein to the distal coronary artery (Kirklin and Rastelli, 1967; Greenberg and Edmunds, 1961; Stoney and Roe, 1964).

Group II patients had evidence for chronic myocardial dysfunction preoperatively on the basis of abnormal systolic time intervals with a short left ven-

tricular ejection time index, long pre-ejection phase index, long and high PEP/LVET ratio (Weissler *et al.*, 1968; Garrard *et al.*, 1970). Postoperatively their changes in systolic time intervals differed from those of group I. There was no significant change in left ventricular ejection time index or PEP/LVET ratio, but there was a significant shortening of the pre-ejection phase index. There was no parameter which indicated the acute depression seen in group I patients, and indeed, the shortened pre-ejection phase index could be interpreted as showing improved left ventricular performance with a more rapid isovolumic contraction time (Weissler *et al.*, 1968, 1969). An alternative explanation would be that there was no net postoperative effect on ventricular performance, and that the shortened pre-ejection phase index reflected the effects of endogenous catecholamine stimulation (Harris *et al.*, 1966).

Although both groups of patients were exposed to the same surgical procedures, they differed in their systolic time interval response after operation. This might be interpreted as suggesting that the improved coronary blood flow achieved in group II improved myocardial function enough to offset the deleterious effects of operation, whereas the group I patients, with normal preoperative systolic time intervals, showed the deleterious effects only.

In order further to substantiate improvements in group II patients, it would have been helpful to have later measurements of systolic time intervals at a time when the acute effects of operation were no longer present. Unfortunately, only 5 of these patients were available for restudy, one to two months after operation. Of the 5 patients, 4 experienced lengthening of the left ventricular ejection time index, a shortened pre-ejection phase index,

FIG. 5 Left ventricular ejection time index, pre-ejection phase index, and PEP/LVET ratio in 5 group II patients, measured before and 1 to 2 months after operation.

and a lowered PEP/LVET ratio (Fig. 5). Though the number of observations is small, there is a suggestion of haemodynamic improvement reflected in these values. These late changes are very similar to the results of Johnson and O'Rourke who studied a group of 10 patients with abnormal preoperative systolic time intervals (Johnson and O'Rourke, 1971). These patients had improved intervals one month after operation.

In summary, these data suggest that patients with angina and abnormal systolic time intervals experience some improvement in systolic time intervals after aortocoronary saphenous vein bypass, which is detectable in the early postoperative period. This has also been suggested in several other studies performed several weeks after operation using invasive techniques (Rees *et al.*, 1971; Chatterjee *et al.*, 1971; Mailhot *et al.*, 1971; Johnson *et al.*, 1970; Campeau *et al.*, 1971).

Another aspect of the present study is that patients with normal preoperative systolic time intervals show evidence for depressed myocardial function transiently in the early postoperative period.

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