Thorax (1974), **29**, 359.

Assessment of left ventricular function following coronary bypass surgery: a non-invasive study

T. HARDARSON, G. M. ZIADY and H. N. KHATTRI

Department of Medicine (Clinical Cardiology), Hammersmith Hospital, Royal Postgraduate Medical School, Ducane Road, London W12

Hardarson, T., Ziady, G. M., and Khattri, H. N. (1974). *Thorax*, **29**, 359–365. **Assessment of left ventricular function following coronary bypass surgery: a non-invasive study.** In a series of 15 patients with ischaemic heart disease, systolic time intervals (STI) were measured before, and at one week, three months, and six months following coronary vein-graft surgery. Preoperatively, the left ventricular ejection time (LVET) was abnormally short in seven patients, while the pre-ejection period was abnormally long in seven patients, suggesting impaired left ventricular function. At one week after surgery LVET and total electromechanical systole (QA2) were significantly abbreviated. This may be explained by the transient fall in cardiac output or postoperative neurohumoral changes. For the group as a whole, no significant changes were found at three or six months, suggesting that cardiac function was generally preserved rather than improved. However, in individual patients changes in STI correlated with the clinical and angiographic estimate of success of the operative treatment.

While the relief of angina is achieved in the majority of patients with ischaemic heart disease who are subjected to myocardial revascularization procedures (Mitchel *et al.*, 1970; Spencer, Green, Tice, and Glassman, 1971; Morris *et al.*, 1972) the effects on cardiac function are less certain.

The work of Weissler, Harris, and Schoenfeld (1968, 1969) suggests that systolic time intervals (STI) are a relevant and informative measure of left ventricular (LV) function. Being non-invasive and easily derived, these methods open the possibility of serial measurements over extended periods of time in a large number of patients. This further avoids the risk associated with repeated cardiac catheterizations and angiography.

We have followed a series of 15 patients over

TABLE I

CLINICAL AND ANGIOGRAPHIC FEATURES OF 15 PATIENTS WITH ISCHAEMIC HEART DISEASE

Patient	Age	Sex	Angina Pectoris[1]			Previous Myocardial Infarction (yr)	BP[2] (mmHg)
			Years	Exercise (0–3)	Rest (0–3)		
V.C.	50	F	6	2	0	6	165/85
M.J.	39	M	7	2	1	4	170/90
T.W.	37	M	3	3	1	3	140/100
W.D.	37	M	1	3	2	1	170/80
B.P.	31	M	4	3	3	3	130/90
G.S.	37	M	6	3	2	—	130/80
L.B.	47	M	2	1	0	2	160/90
F.B.	53	M	1	2	0	—	150/90
G.J.	54	M	3	3	2	1	120/80
K.C.	40	M	3	3	1	—	130/70
J.E.	52	M	6	3	2	—	120/70
R.C.	36	M	5	3	2	—	140/90
B.D.	55	F	1	3	2	—	160/90
T.M.	42	M	1	2	0	1	130/80
D.A.	42	M	2	3	1	3	140/85

[1]Angina pectoris was graded 0–3 according to severity: 0, no angina; 1, angina on severe exercise; 2, angina on mild exercise; 3, angina sometimes at rest. Rest angina graded according to frequency of attacks.
[2]BP arterial blood pressure

Thorax: first published as 10.1136/thx.29.3.359 on 1 May 1974. Downloaded from http://thorax.bmj.com/ on April 10, 2024 by guest. Protected by copyright.

TABLE II

TYPE OF OPERATION, RESULTS, AND FOLLOW-UP

Patient	Type of Graft			Result	Follow-up (mth)	Repeat Coronary Arteriography and Months post-op.	LVEDP (mmHg)	LV Angio.	Coronary Arteriography			
	LAD	RC	LC						LAD	RC	LC	Collat'ls
V.C.	X			Good	13	—	20	—[1]	N[2]	Marked narrowing	Occluded	—
M.J.		X		Good	11	Graft patent 7	5	Marked LV thickening	Mild narrowing	Subtotal obstruction	Mild narrowing	L – R
T.W.	X			Good	10	Graft thrombosed ½	14	LV aneurysm	Complete obstruction	N	N	R – L
W.D.	X	X		Good	9	—	22	Mild mitral reflux	Moderate narrowing	Marked obstruction	N	—
B.P.	X			Good for 3 months then developed angina	16	Graft patent but increased stenosis 5	7	—	Total obstruction	Near total obstruction	Near total occlusion	L – R
G.S.	X	X		No improvement	16	Both grafts thrombosed 3	13	LV aneurysm	Marked narrowing	Complete occlusion	Near total occlusion	L – R
L.B.	X			Good	15	—	14	—	Diffuse Narrowing	Total occlusion	Diffuse narrowing	L – R
F.B.	X			Good	15	—	—	—	Total occlusion	Total occlusion	N	L – R
G.J.	X			Good	10	—	—	—	Near total occlusion	Mild narrowing	N	—
K.C.	X			Good	9	—	16	—	Marked narrowing	Slight narrowing	Near total occlusion	R – L
J.E.		X		Good	9	Graft patent 3	15	—	Diffuse narrowing	Moderate obstruction	Mild narrowing	—
R.C.	X			Only slight improvement	8	Graft patent 6	16	—	Moderate narrowing	Complete occlusion	N	L – R
B.D.		X		Clear improvement but still in pain	8	—	3	—	Minor narrowing	Complete obstruction	N	L – R
T.M.	X	X		—	8	Both grafts thrombosed ½	18	—	Diffuse narrowing	Complete occlusion	N	L – R
D.A.		X		Good	11	Graft patent 7	18	LV aneurysm	Mild narrowing	Severe obstruction	Severe obstruction	—

Result of operation was judged in terms of amelioration of angina pectoris.
LVEDP=LV end-diastolic pressure; LAD=left anterior descending; RC=right coronary artery; LC=left circumflex.
[1]Many patients showed minor segmental variations in LV contraction.
[2]N=normal vessel.

Thorax: first published as 10.1136/thx.29.3.359 on 1 May 1974. Downloaded from http://thorax.bmj.com/ on April 10, 2024 by guest. Protected by copyright.

a minimum period of six months following coronary vein-graft surgery. The results of STI measurements preoperatively and at one week, three months, and six months postoperatively are presented.

PATIENTS AND METHODS

The clinical details of 15 patients selected for this study are presented in Table I. Their ages ranged from 31 to 54 and all, except two, were men. All except one had severe angina pectoris on exercise and most had had angina at rest. Nine patients had suffered myocardial infarction previously and three had evidence of an LV aneurysm on angiography. None was markedly hypertensive. Table II shows the type of operation performed, the symptomatic results, and duration of follow-up. Only one patient (G.S.) had electrocardiographic evidence of a myocardial infarct after surgery, while one (F.B.) had an infarct during coronary arteriography before the operation. The results, as regards the alleviation of angina pectoris, were mostly good. In eight patients the grafts were examined two weeks to seven months postoperatively and these were found to be patent in five patients.

The STI were recorded using a 6-channel machine (Cambridge Scientific Instruments type 72112) (Figure). The same sensitivity settings were used throughout. A phonocardiogram was recorded at the second and fourth intercostal spaces along the left sternal border with low frequency filtration (250—1000 Hz). A bipolar ECG lead showing clearly the onset of ventricular depolarization was selected. The carotid displacement curve was recorded simultaneously, using a hand-held polyethylene funnel connected to a piezo-electric transducer with a pulse amplifier (time constant more than 1·6 sec).

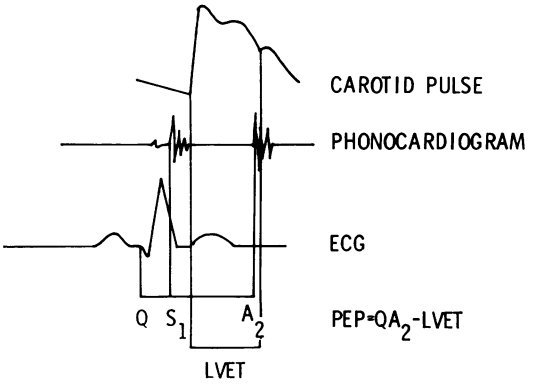

FIGURE. *The recording and measurement of systolic time intervals. The tracings represent, from top to bottom, the carotid displacement curve, a phonocardiogram, and an ECG lead. The intervals were measured to the nearest 5 msec and the means of at least five consecutive cardiac cycles were estimated. The paper speed was 200 mm/sec.*

Two time intervals were measured: (1) the left ventricular ejection time (LVET) measured from the beginning of the steep rise of the carotid pulse to the dicrotic notch; (2) the electromechanical systole (QA2) measured from the beginning of the Q-wave of the ECG to the first high-frequency component of the second heart sound.

The pre-ejection period (PEP) was calculated by subtracting the LVET from the QA2. The intervals were then corrected for heart rate, using the indices of Weissler *et al.* (1969), and the subsequent discussion refers to these corrected values. None of the patients had bundle-branch block and all were in sinus rhythm.

The STI were recorded in a supine position in a postabsorptive state. The first recordings were performed two to three days before the operation and subsequently at one week, three months, and six months postoperatively. Eleven patients had been taking β-adrenergic blocking agents before surgery and four continued this medication after the operation. In every instance, however, the drug was withdrawn at least 36 hours before the non-invasive study. No patient was taking digitalis. No significant difference was noted in the arterial blood pressure pre and postoperatively.

For comparison with the patient's STI the normal values for this laboratory are listed in Table III.

TABLE III
NORMAL VALUES FOR STI

QA2	526±6 msec (1 SD)
LVET	410±14 msec
PEP	117±11 msec

RESULTS

The results of the STI measurements are presented in Table IV. Comparison with the normal shows that seven patients had LVET below one standard deviation of the normal mean and seven patients had PEP above one standard deviation of the normal mean. No clear relationship was found, however, between the coronary artery involvement and the STI abnormalities. On the other hand, the three patients who had a left ventricular aneurysm all had short LVET. The only striking postoperative changes in STI in the group as a whole were found at one week after surgery when LVET and QA2 were significantly shortened. A consequent increase in PEP/LVET was found, although PEP was unaltered. No significant change in STI was found at three or six months for the group as a whole.

Thorax: first published as 10.1136/thx.29.3.359 on 1 May 1974. Downloaded from http://thorax.bmj.com/ on April 10, 2024 by guest. Protected by copyright.

TABLE IV

STI IN 15 PATIENTS BEFORE AND AFTER MYOCARDIAL REVASCULARIZATION

Patient	Control Values				1 Week				3 Months				6 Months			
	LVET	PEP	PEP/LVET	QA2	LVET	PEP	PEP/LVET	QA2	LVET	PEP	PEP/LEVT	QA2	LVET	PEP	PEP/LVET	QA2
V.C.	430	138	0·341	568	369	95	0·263	465	411	129	0·337	540	416	136	0·350	552
M.J.	376	159	0·524	535	363	154	0·547	517	389	137	0·405	533	394	128	0·389	531
T.W.	378	123	0·370	502	355	137	0·488	492	395	124	0·362	518	399	121	0·329	526
W.D.	399	142	0·432	542	369	118	0·397	488	373	151	0·488	530	378	148	0·453	526
B.P.	382	127	0·355	507	379	123	0·397	502	399	137	0·405	536	387	136	0·426	532
G.S.	393	138	0·403	532	389	139	0·453	528	396	126	0·360	522	402	134	0·380	536
L.B.	415	94	0·225	509	353	139	0·550	493	425	124	0·311	549	391	136	0·388	527
F.B.	392	121	0·334	513	353	160	0·642	513	378	133	0·406	511	361	160	0·540	522
G.J.	411	136	0·381	547	381	94	0·311	485	397	116	0·333	513	405	122	0·323	533
K.C.	411	114	0·323	525	362	125	0·408	487	418	140	0·391	558	407	133	0·274	549
J.E.	413	128	0·328	542	380	129	0·389	516	422	118	0·295	546	430	110	0·262	545
R.C.	412	129	0·345	541	398	133	0·380	532	397	134	0·398	532	402	138	0·386	547
B.D.	381	156	0·502	538	390	153	0·462	543	396	148	0·425	544	397	151	0·436	549
T.M.	391	116	0·329	507	344	139	0·495	533	363	146	0·511	518	371	139	0·474	519
D.A.	396	101	0·379	526	394	132	0·378	528	402	112	0·305	523	410	116	0·306	534
Mean	399	128	0·371	529	372	131	0·437	508	397	132	0·382	531	399	134	0·381	535
SD	16	18	0·074	19	17	19	0·097	23	17	12	0·063	14	18	13	0·077	11
SEM	4	5	0·019	5	4	5	0·025	6	4	3	0·016	4	5	3	0·020	3
P					< 0·0005	ns	< 0·05	< 0·025	ns	ns	ns	ns	ns	ns	ns	ns

All values in milliseconds.

Thorax: first published as 10.1136/thx.29.3.359 on 1 May 1974. Downloaded from http://thorax.bmj.com/ on April 10, 2024 by guest. Protected by copyright.

DISCUSSION

Several reports have appeared in recent years on the pre and postoperative haemodynamics of the left ventricle. Hamilton, Stewart, Gould, and Kennedy (1972) found in a series of 11 patients that the LV end-diastolic pressure, end-diastolic volume, stroke volume, and ejection fraction did not change significantly following bypass surgery and concluded that ventricular performance was preserved rather than improved. In a study utilizing submaximal exercise testing, Manley, Johnson, Flemma, and Lepley (1972), however, found a significant improvement in LV performance in a group of patients with good LV contraction preoperatively. Less striking improvement was found in the presence of moderate to severe impairment of LV contraction, although angina pectoris was usually relieved. Johnson, Flemma, Manley, and Lepley (1970) noted also a fall in the filling pressure of the LV after surgery and an increase in cardiac output on supine leg exercise. Amsterdam *et al.* (1970) found that the maximum product of heart rate and systolic arterial pressure was increased after surgery and suggested that myocardial oxygen delivery was improved. Rees *et al.* (1971) reported an increase in LV ejection fraction and velocity of circumferential fibre shortening in eight patients, while in six patients LV function deteriorated, usually due to graft occlusion. Bolooki, Rubinson, Michie, and Jude (1971) examined the effects on LV contractility (Vmax) of two minutes' occlusion of a newly inserted venous graft. In patients who had good LV function Vmax decreased on clamping the graft, while no such effect was noted in patients with poor LV function. Myocardial revascularization procedures have also shown little or no beneficial effect on the LV filling pressures in surviving patients who were in cardiac failure at the time of the operation (Kong, Behar, Peter, and Morris, 1971; Mundth *et al.*, 1971; Spencer *et al.*, 1971). A number of patients, furthermore, sustain myocardial infarction at the time of surgery, although the haemodynamic import of these lesions is still uncertain (Morris *et al.*, 1972).

In general, a short LVET can be regarded to reflect a low cardiac output (Weissler, Peeler, and Roehill, 1961), while a long PEP is an indirect reflection of a slow rate of rise of LV pressure (Talley, Meyer, and McNay, 1971). The ratio PEP/LVET has been suggested as a useful general measure of LV performance (Weissler *et al.*, 1969).

In the present study, all the significant findings for the group as a whole were observed one week postoperatively. Several alternative explanations could account for these changes:

1. a fall in cardiac output;
2. postoperative neurohumoral effects, including increased catecholamine secretion;
3. a temporary deterioration of myocardial function.

A fall in cardiac output could account for the shortening of LVET and, secondarily, QA2. This has been observed in patients undergoing haemodialysis (Prakash and Wegner, 1972). An increased rate of ejection due to excessive catecholamine secretion could also be responsible for the shortening of these intervals as reported following myocardial infarction (Toutouzas, Gupta, Samson, and Shillingford, 1969; Lewis, Boudoulas, Forester, and Weissler, 1972). This seems unlikely, however, in view of the constancy of PEP. Similarly, a fall in the rate of rise of LV pressure would be expected to produce a prolongation of PEP.

Therefore, although other factors cannot be ruled out, the short LVET and QA2 at one week seem to be most easily explained by a fall in output. This may be due, at least partly, to dehydration or other peripheral factors.

Improvement in STI was defined as a shortening of PEP or prolongation of LVET by at least 10 msec to within 1·5 SD of the normal mean, and deterioration in STI was conversely defined as an opposite change of at least 10 msec, resulting in values outside this range.

Using these criteria, the long-term results indicate an improvement of STI in four patients (M.J., T.W., B.D., and G.J.). In all of them angina was improved. Two were investigated postoperatively. In patient M.J. the graft was found to be patent seven months postoperatively. In patient T.W., the graft was occluded only a fortnight after surgery. However, plication of an LV aneurysm, which was done in conjunction with the bypass operation, may account for the STI improvement. Three patients showed worse STI results after surgery (F.B., B.P., and T.M.). In patient T.M. both grafts were found to be occluded two weeks postoperatively. Patient F.B. was the only subject to suffer myocardial infarction during coronary arteriography which was done after the control STI measurements. In patient B.P. the graft was patent at five months, but the arteriosclerotic lesions were found to have progressed. In only one further patient (G.S.) was a graft occulusion found three months after sur-

Thorax: first published as 10.1136/thx.29.3.359 on 1 May 1974. Downloaded from http://thorax.bmj.com/ on April 10, 2024 by guest. Protected by copyright.

gery. He had experienced no amelioration of angina pectoris and the STI were unaltered.

Johnson, O'Rourke, Karliner, and Burian (1972) reported STI changes following myocardial revascularization in a series of 11 patients. They found that LVET was significantly increased after surgery, while PEP was abbreviated. These workers did not find a transient deterioration in the STI values at one week. It is conceivable that postoperative treatment may have been different from the present series in some important aspect, but this cannot be decided from the published data. In three of their patients, a deterioration from initially improved PEP and PEP/LVET values was found corresponding to a recurrence of symptoms.

The results of Johnson *et al.* (1972) semed to indicate an improvement in LV function following myocardial revascularization procedures. This was not borne out in the present study, and LV function may therefore have been preserved rather than improved in this series of patients. However, individual changes in STI corresponded with clinical and angiographic assessment of sucess or failure of the operation. The indications and outcome of saphenous vein bypass grafting of the coronary arteries are still widely debated. Further studies of myocardial integrity following such interventions are therefore necessary. As a supplement to clinical evaluation and invasive measurements, STI offer an attractive physiological method, whose chief advantages are easy repeatability and absence of procedural hazards.

The authors wish to thank Professor J. F. Goodwin for valuable advice.

This work was supported by the British Heart Foundation.

REFERENCES

Amsterdam, E. A., Iben, A., Hurley, E. J., Mansour, E., Hughes, J. L., Salel, A. F., Zelis, R., and Mason, D. T. (1970). Saphenous vein bypass graft for refractory angina pectoris: Physiological evidence for enhanced blood flow to the ischemic myocardium (abstract). *American Journal of Cardiology*, **26,** 623.

Bolooki, H., Rubinson, R. M., Michie, D. D., and Jude, J. R. (1971). Assessment of myocardial contractility after coronary bypass grafts. *Journal of Thoracic and Cardiovascular Surgery*, **62,** 543.

Hamilton, G. W., Stewart, D. K., Gould, K. L., and Kennedy, J. W. (1972). Left ventricular function following successful aortocoronary vein bypass (abstract). *American Journal of Cardiology*, **29,** 268.

Johnson, A. D., O'Rourke, R. A., Karliner, J. S., and Burian, C. (1972). Effect of myocardial revascularization on systolic time intervals in patients with left ventricular dysfunction. *Circulation*, **45,** Suppl. I, p. 91.

Johnson, W. D., Flemma, R. J., Manley, J. C., and Lepley, D. (1970). The physiological parameters of ventricular function as affected by direct coronary surgery. *Journal of Thoracic and Cardiovascular Surgery*, **60,** 483.

Kong, Y., Behar, V. S., Peter, R. H., and Morris, J. J. (1971). Aortocoronary bypass graft: Preoperative assessment and early follow-up. *Clinical Research*, **19,** 323.

Lewis, R. P., Boudoulas, H., Forester, W. F., and Weissler, A. M. (1972). Shortening of electromechanical systole as a manifestation of excessive adrenergic stimulation in acute myocardial infarction. *Circulation*, **46,** 856.

Manley, J. C., Johnson, W. D., Flemma, R. J., and Lepley, D. (1972). Objective evaluation of the effects of direct myocardial revascularization on ventricular performance utilizing submaximal ergometer exercise testing (abstract). *American Journal of Cardiology*, **29,** 277.

Mitchel, B. F., Adam, M., Lambert, C. J., Sungu, U., and Shiekh, S. (1970). Ascending aorta-to-coronary artery saphenous vein bypass grafts. *Journal of Thoracic and Cardiovascular Surgery*, **60,** 457.

Morris, G. C., Reul, G. J., Howell, J. F., Crawford, E. S., Chapman, D. W., Beazley, H. L., Winters, W. L., Peterson, P. K., and Lewis, J. M. (1972). Follow-up results of distal coronary artery bypass for ischemic heart disease. *American Journal of Cardiology*, **29,** 180.

Mundth, E. D., Harthorne, J. W., Buckley, M. J., Dinsmore, R., and Austen, W. G. (1971). Direct coronary arterial revascularization: Treatment of cardiac failure associated with coronary artery disease. *Archives of Surgery*, **103,** 529.

Prakash, R. and Wegner, S. (1972). Indirect assessment of left ventricular function following hemodialysis in patients with chronic renal disease. *American Journal of the Medical Sciences*, **264,** 127.

Rees, G., Bristow, J. D., Kremkau, E. L., Green, G. S., Herr, R. H., and Starr, A. (1971). Influence of aortocoronary bypass surgery on left ventricular performance. *New England Journal of Medicine*, **284,** 1116.

Spencer, F. C., Green, G. E., Tice, D. A., and Glassman, E. (1971). Bypass grafting for occlusive disease of the coronary arteries: Report of experience with 195 patients. *Annals of Surgery*, **173,** 1029.

Talley, R. C., Meyer, J. F., and McNay, J. L. (1971). Evaluation of the pre-ejection period as an estimate of myocardial contractility in dogs. *American Journal of Cardiology*, **27,** 384.

Toutouzas, P., Gupta, D., Samson, R., and Shillingford, J. (1969). Q-second sound interval in acute myocardial infarction. *British Heart Journal*, **31,** 462.

Thorax: first published as 10.1136/thx.29.3.359 on 1 May 1974. Downloaded from http://thorax.bmj.com/ on April 10, 2024 by guest. Protected by copyright.

Weissler, A. M., Harris, W. S., and Schoenfeld, C. D. (1968). Systolic time intervals in heart failure in man. *Circulation*, **37**, 149.

——, ——, and —— (1969). Bedside technics for the evaluation of ventricular function in man. *American Journal of Cardiology*, **23**, 577.

——, Peeler, R. G., and Roehill, W. H. (1961). Relationships between left ventricular ejection time, stroke volume, and heart rate in normal individuals and patients with cardiovascular disease. *American Heart Journal*, **62**, 367.

Requests for reprints to: Dr. T. Hardarson, The Department of Medicine (Clinical Cardiology), Hammersmith Hospital, Royal Postgraduate Medical School, Ducane Road, London W12.

Thorax: first published as 10.1136/thx.29.3.359 on 1 May 1974. Downloaded from http://thorax.bmj.com/ on April 10, 2024 by guest. Protected by copyright.