Evaluation by exercise testing and atrial pacing of results of aorto-coronary bypass surgery

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The results are reported of investigation and surgery in 109 patients with angina pectoris who have undergone aorto-coronary bypass surgery. There were 7 hospital and no late deaths. Of 50 patients followed for more than 6 months, 36 became symptom free and a further 12 improved. This clinical improvement was accompanied by significant increase in exercise performance which was related to the preoperative state of the left ventricle. Thirty-three patients were catheterized postoperatively and in this group also clinical improvement correlated well with the results of exercise and pacing tests. Of 52 grafts, 43 (83%) were patent and there was a close association between evidence of revascularization and clinical result.

Aorto-coronary bypass surgery is now widely used in the treatment of patients with coronary artery disease. Previous operations have been abandoned largely because of the lack of objective evidence of both symptomatic improvement and revascularization. In the assessment of this operation we have therefore used exercise ergometry and cardiac pacing to provide a more objective assessment of the value of this procedure.

Patients and methods

Patients presenting with angina pectoris from November 1970 to June 1973 were considered for surgery and admitted to hospital for evaluation. Digoxin and beta-adrenergic blocking agents were stopped 48 hours before admission. Angina was graded from 1 to 4 using the same criteria as the New York Heart Association grading for dyspnoea. Routine chest radiographs and electrocardiograms were obtained, and fasting serum cholesterol was estimated. The patients performed a standardized exercise test in the upright position on a bicycle ergometer with recording of a bipolar chest lead. The exercise started at 150 kpm/min and increased by increments of 150 kpm/min every 2 minutes until the

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development of angina, 2 mm ST segment depression on the electrocardiogram, dyspnoea, or fatigue.

Left and right heart cardiac catheterization was performed from the right arm after premedication with 20 to 25 mg of intramuscular diazepam. The resting left ventricular end-diastolic pressure was recorded, and the heart was then paced usually from the right atrium (or right ventricle if block developed) until the patient developed angina or a rate of 180 b.p.m. was reached. Left ventriculography was performed in the right anterior oblique projection and followed by selective coronary angiography in multiple projections, preferably using the Sones technique. A caesium iodide image intensifier was used and 35 mm cine film was exposed at 36 frames per second.

The angiographic severity of coronary artery disease was represented by a numerical score. Each major vessel was scored on a scale of 0 to 4; 0 was normal, 4 total occlusion, and 1 to 3 stenoses of increasing severity. A similar system was applied to the left ventriculogram. Grade 0 was normal and 1 to 4 increasing extent of dyskinesia.

Surgery

Operation was usually performed within one month of investigation. After removal of a length of saphenous vein, the coronary anastomoses were performed under normothermic cardiopulmonary bypass with intermittent aortic cross clamping. In some of the later patients endarterectomy was done before graft insertion, and in some direct internal mammary artery anastomosis was used.

Postoperative follow-up

The patients were seen at 3-monthly intervals for the first year and then at 6-monthly intervals. Exercise tests were performed at each visit. A small group of patients had a postoperative catheterization similar to the pre-operative study, but including graft angiography.

Clinical data

The clinical data are shown in Table 1. There were 109 patients, 95 men and 14 women, with ages ranging from 30 to 65, with an average of 50 years. Seventy patients had severe angina (grades 3 and

TABLE 1 *Clinical details*

Case No.	Age (yr)	Sex	Angina		Previous myo-cardial infarct	Electro-cardiogram	Chest radiograph	Cholesterol (mg/100 ml)	Nitro-glycerin	Beta adrenergic blocking agents	
			Grade	Duration (mth)							Dose/day (mg)
1	53	M	4	96	+	Abnormal	Normal	540	+	Propranolol	160
2	58	F	3	84	—	Abnormal	Normal	300	+	Propranolol	120
3	57	M	4	24	—	Abnormal	Normal	260	+	Propranolol	160
4	48	M	3	24	—	Normal	Normal	290	+	Practolol	400
5	50	M	3	48	—	Abnormal	Normal	340	—	Propranolol	140
6	57	M	3	60	—	Abnormal	Normal	240	+	Propranolol	140
7	65	M	3	19	—	Abnormal	Normal	230	+	Propranolol	160
8	30	F	2	228	—	Abnormal	Normal	234	+	Practolol	400
9	58	M	3	36	+	Abnormal	Normal	303	—	Practolol	300
10	58	F	3	12	—	Normal	Normal	188	+	Propranolol	160
11	56	F	3	36	—	Normal	Normal	268	+	Oxprenolol	160
12	56	M	2	168	+	Abnormal	Normal	250	+	Propranolol	320
13	62	M	3	24	—	Abnormal	Enlarged heart	395	+	Practolol	800
14	62	M	4	120	—	Abnormal	Normal	215	+	Propranolol	120
15	46	M	2	18	—	Abnormal	Normal	247	+	Propranolol	160
16	36	M	3	14	—	Abnormal	Normal	236	+	Practolol	600
17	53	F	3	24	—	Abnormal	Normal	360	+	Propranolol	240
18	55	M	3	48	+	Abnormal	Enlarged heart	294	+	Propranolol	160
19	57	M	3	144	+	Abnormal	Enlarged heart and pulm. venous congestion	302	+	Practolol	800
20	61	M	2	9	+	Abnormal	Normal	202	+	Practolol	800
21	55	M	2	6	+	Abnormal	Enlarged heart	272	+	Practolol	400
22	47	F	3	12	—	Normal	Normal	256	+	Propranolol	320
23	51	M	3	36	—	Abnormal	Normal	282	+	Propranolol	160
24	42	M	3	32	+	Abnormal	Normal	274	—	Practolol	300
25	40	M	3	60	+	Abnormal	Enlarged heart	*	+	None	—
26	50	F	3	10	—	Abnormal	Normal	200	+	Propranolol	240
27	44	M	3	7	+	Abnormal	Normal	*	+	Practolol	800
28	55	M	4	144	—	Abnormal	Normal	370	+	Practolol	600
29	47	F	3	9	—	Abnormal	Normal	226	+	Propranolol	60
30	35	M	2	14	—	Abnormal	Normal	242	+	Practolol	600
31	39	M	4	6	—	Normal	Normal	236	+	Practolol	600
32	30	M	3	5	—	Abnormal	Normal	376	+	Practolol	800
33	55	M	3	36	—	Abnormal	Normal	312	+	Propranolol	120
34	49	M	3	6	—	Abnormal	Normal	280	+	Propranolol	120
35	43	M	2	6	—	Normal	Normal	*	+	Practolol	300
36	54	M	3	84	—	Abnormal	Enlarged heart	308	+	Practolol	400
37	50	M	2	60	—	Abnormal	Normal	*	+	Propranolol	480
38	58	M	2	72	—	Abnormal	Enlarged heart	256	+	Propranolol	240
39	62	M	2	3	—	Abnormal	Normal	200	+	Practolol	300
40	49	M	2	72	—	Abnormal	Normal	256	+	Propranolol	320
41	60	M	3	2	+	Abnormal	Normal	250	+	Propranolol	480
42	51	M	2	24	—	Abnormal	Normal	260	+	Practolol	400
43	51	M	2	6	+	Abnormal	Enlarged heart	310	+	None	—
44	52	M	4	1	+	Abnormal	Normal	250	+	Propranolol	120
45	56	F	4	12	+	Abnormal	Normal	330	+	Propranolol	360
46	50	M	3	72	—	Abnormal	Normal	336	+	Propranolol	240
47	46	M	3	42	—	Normal	Normal	200	+	Propranolol	640
48	44	M	1	12	—	Abnormal	Normal	*	+	Propranolol	160
49	42	M	2	48	—	Normal	Normal	362	+	Propranolol	120

* Some cholesterol not measured

TABLE I (Cont'd)

Case No.	Age (yr)	Sex	Angina		Previous myocardial infarct	Electrocardiogram	Chest radiograph	Cholesterol (mg/100 ml)	Nitro-glycerin	Beta adrenergic blocking agents	
			Grade	Duration (mth)							Dose/day (mg)
50	50	M	3	12	+	Abnormal	Normal	198	+	Practolol	900
51	57	M	3	15	—	Abnormal	Normal	*	+	Propranolol	240
52	52	M	2	20	+	Abnormal	Enlarged heart	282	+	Practolol	200
53	50	M	2	8	—	Abnormal	Normal	252	+	Propranolol	120
54	37	F	3	7	+	Abnormal	Normal	*	+	Propranolol	240
55	42	M	3	10	—	Abnormal	Normal	*	+	Propranolol	240
56	44	M	3	24	+	Abnormal	Enlarged heart	*	+	Oxprenolol	120
57	48	M	2	12	—	Normal	Normal	286	+	Practolol	300
58	47	M	2	4	—	Abnormal	Normal	266	+	Propranolol	120
59	50	M	2	72	—	Normal	Normal	260	+	Propranolol	120
60	40	M	1	12	—	Normal	Normal	*	+	Propranolol	120
61	52	M	4	12	—	Abnormal	Normal	164	+	Oxprenolol	120
62	42	M	2	8	+	Abnormal	Enlarged heart	232	+		
63	49	M	3	13	—	Abnormal	Normal	276	+	Propranolol	240
64	56	M	3	12	—	Normal	Enlarged heart	306	+		
65	45	M	3	48	—	Abnormal	Normal	260	+	Practolol	200
66	40	M	2	200	—	Normal	Normal	206	+	Propranolol	160
67	53	M	3	84	—	Abnormal	Normal	280	+	Propranolol	320
68	54	M	3	36	—	Normal	Normal	*	+	Practolol	600
69	51	M	2	6	—	Normal	Normal	*	+	Practolol	400
70	60	F	4	8	+	Abnormal	Normal	340	+	Propranolol	240
71	56	M	2	3	—	Normal	Normal	*	+		
72	43	M	3	8	—	Normal	Normal	230	+	Propranolol	120
73	61	M	4	72	—	Abnormal	Normal	272	+		
74	43	M	3	4	+	Abnormal	Normal	252	—	Propranolol	120
75	49	F	3	12	—	Normal	Normal	*	+	Propranolol	240
76	48	M	2	18	—	Normal	Normal	164	+		
77	39	M	4	0.2	—	Abnormal	Normal		—		
78	31	M	4	0.5	—	Abnormal	Normal		+		
79	38	M	1	24	—	Normal	Normal		+	Practolol	300
80	58	M	4	48	+	Abnormal	Pulm. venous congestion		+	Oxprenolol	1000
81	47	M	3	36	—	Normal	Normal		—		
82	64	M	3	60	+	Abnormal	Normal		+	Propranolol	240
83	51	F	2	6	—	Abnormal	Normal		—	Propranolol	60
84	42	M	4	1	—	Abnormal	Enlarged heart		+	Propranolol	120
85	38	M	3	36	+	Abnormal	Normal	310	+	Oxprenolol	160
86	55	M	4	120	—	Abnormal	Normal	258	+	Practolol	600
87	62	M	3	7	—	Abnormal	Normal	246	+	Propranolol	240
88	46	M	3	108	—	Normal	Normal		+	Practolol	800
89	52	M	3	24	—	Normal	Normal	390	+	Propranolol	80
90	42	M	2	30	+	Abnormal	Enlarged heart	256	—	Propranolol	240
91	43	M	2	4	+	Abnormal	Enlarged heart		+	Practolol	300
92	34	M	2	30	—	Normal	Normal	206	+		
93	45	M	3	36	+	Abnormal	Normal	204	+	Practolol	200
94	49	M	3	60	+	Abnormal	Normal		+	Propranolol	240
95	48	F	4	24	—	Normal	Normal		+	Propranolol	720
96	51	M	4	3	—	Abnormal	Normal	188	+		
97	55	M	3	48	+	Abnormal	Normal		+	Oxprenolol	120
98	56	M	2	6	—	Abnormal	Normal	270	+	Propranolol	240
99	46	M	2	3	+	Abnormal	Normal		+	Practolol	600
100	51	M	3	4	—	Abnormal	Normal	189	+	Practolol	300
101	43	M	2	2	—	Abnormal	Normal	248	—	Propranolol	120
102	59	M	2	2	+	Abnormal	Normal	168	+		
103	55	M	3	1	—	Abnormal	Normal	234	—	Practolol	300
104	56	M	2	6	—	Normal	Normal	345	+	Propranolol	120
105	42	M	2	9	—	Abnormal	Normal		+	Propranolol	120
106	49	M	2	60	+	Abnormal	Normal		+	Propranolol	120
107	51	M	4	4	—	Abnormal	Normal		+	Propranolol	120
108	51	M	3	96	+	Abnormal	Normal	270	+		
109	41	M	4	0.5	—	Normal	Normal		—		

4). The average grade for the whole series was 2.8. The duration of angina varied from 1 week to 19 years and averaged 35 months. Eighty-two (76%) of the patients had an abnormal resting electrocardiogram and there was evidence of previous infarction in 33 (30%). In 16 patients (15%) the chest radiograph showed either cardiomegaly or pulmonary venous congestion. The average fasting serum cholesterol ranged from 164 to 540 with an average of 264 mg/100 ml.

Ninety-eight (90%) patients had been treated with sublingual nitroglycerin, and 94 (86%) with beta-adrenergic blocking agents. These drugs were propranolol (56 patients, average dose 206 mg per day), practolol (32 patients, average dose 487 mg per day), and oxprenolol (6 patients, average dose 280 mg per day).

Table 2 gives the individual results of the pre-operative exercise and pacing tests and angiographic assessment.

Exercise test

Twenty-two patients did not have an exercise test, 9 because they had angina at rest and 13 for other reasons. The maximum work load varied from 150 to 900, with an average of 488 kpm/min. In 66 the limiting factor was angina or ST depression.

Pacing test

The resting left ventricular end-diastolic pressure (LVEDP) ranged from 5 to 46 with a mean of 15 mmHg. Seven patients were not paced because of angina at rest at the time of investigation, and in 9 the tests were technically unsatisfactory. Eighty-eight (95%) of the remaining 93 patients developed

angina on pacing, 2 had dyspnoea, and 3 reached the maximum rate of 180 b.p.m. without symptoms.

Angiography

The individual coronary scores are shown in Table 2. Thirty-nine (36%) patients had major lesions (score 3 or 4) of a single vessel, 40 (37%) of two, and 30 (27%) of three vessels. Eight (7%) patients had a major lesion of the left main coronary artery. The left ventriculogram was normal in 60 (55%) patients, the remainder having varying extent of dyskinesia.

Surgery

The individual vessels bypassed and the type of graft are indicated in Table 2. Forty-seven patients had a single graft, 45 two grafts, 16 three grafts, and 1 four grafts. A prior endarterectomy was done on 7 vessels, and the left internal mammary artery was used 17 times. The details of graft distribution and preoperative flow measurements are shown in Table 3. Flows ranged from 5 to 240 ml/min, with an average of 73 ml/min.

Seven patients died in hospital (Table 2): 3 from pulmonary embolism, 2 from respiratory complications, 1 from primary ventricular fibrillation, and 1 from haemorrhage. Of the 3 patients who died of pulmonary embolism, 2 had poor left ventricular function (Cases 28 and 45), and 1 of these died on the operating table (Case 28); the other 2 occurred late in patients who had been slow to mobilize. All occurred before routine postoperative anticoagulation was used. A third patient with poor left ventricular function (Case 73) died of sudden ventricular fibrillation. Four of the deaths occurred

TABLE 2 Results of investigation

Case No.	Maximum exercise load (kpm/min)	End point	Left ventricular end-diastolic pressure (mmHg)	Maximum pacing rate	End point	Coronary arteries: grading of disease			Left ventricular dyskinesia
						Left anterior descending	Left circumflex	Right	
1	450	Dyspnoea	28	110	Angina	4*	2	4	2
2			8	140	Angina	3	4*	1	0
3	Angina at rest		46	120	Angina	L 4*	4*	3	2
4	450	Angina	10	140	Angina	3*	3*	4	0
5	150	Angina	12	120	Angina	2	3*	4*	0
6	600	Angina	16	130	Dyspnoea	1	3*	4	0
7	450	Dyspnoea	5	130	Angina	2*	4*	0	0
8	450	Angina	10	170	Angina	2*	3*	2*	0
9			14	140	Angina	2*	3*	1	0
10	300	Dyspnoea	9	140	Angina	3*	0	0	0
11			7	110	Angina	3*	0	0	0
12	600	Angina	22	150	Angina	3	3*	4*	0

†, hospital death; L, left main stem stenosis ≥ 75 per cent; D, diagonal branch left anterior descending grafted; *, vessel bypassed with saphenous vein; ‡, vessel bypassed with left internal mammary artery; E, endarterectomy; †, LV surgery.

TABLE 2 (Cont'd)

Case No.	Maximum exercise load (kpm/min)	End point	Left ventricular end-diastolic pressure (mmHg)	Maximum pacing rate	End point	Coronary arteries: grading of disease			Left ventricular dyskinesia
						Left anterior descending	Left circumflex	Right	
†13	600	ST de-pression ≥ 2 mm	22	110	Angina	3*	3	3*	1
14	Angina at rest		8	Angina at rest		2	2	4*	1
15	600	ST de-pression ≥ 2 mm	18	130	Angina	3*	0	3	0
16	450	Angina	10	130	Angina	3*	2	4	0
17	450	ST de-pression ≥ 2 mm	7	140	Angina	1	1	4*	1
18	150	Angina	30	120	Angina	2	2	3*	2
19	450	ST de-pression ≥ 2 mm	17	160	Angina	3*	3*	4*	3
20	300	Angina	25	140	Angina	3*	1	0	0
21	600	Angina	20	140	Angina	4	3*	4*	3
22	750	Angina	20	150	Angina	3	1	4*	0
23	300	Angina	8	170	Angina	3*	2	1	0
24	150	Angina	15	150	Angina	4*	1	2	1
25			5			4*	0	0	1
26	300	Angina	15	120	Angina	0	3*	0	0
27	450	Angina	8	140	Angina	2	3*	1	2
†28	Angina at rest		17	Angina at rest		3*	3	4*	3
29	Angina at rest		7	Angina at rest		0	3*	1	
30	450	ST de-pression ≥ 2 mm	10	160	Angina	3*	0	1	0
31	Angina at rest		16	Angina at rest		4*	2	1	0
32	450	Angina, ST de-pression ≥ 2 mm	17	150	Angina	4*	3	3	1
33	300	Angina	12	140	Angina	L 4*	4	2*	1
34	300	Angina	11	170	Angina	3	0	4*	1
35	300	Dyspnoea	14	130	Angina	3*	1	4*	2
36	450	Angina	15	150	Angina	3*	4	4*	4
37			33			3*	1	0	0
†38	450	Angina	19	120	Angina	2*	0	3*	0
39			8	140	Angina	3*	3*	0	0
40			12			3*	3	4*	2
41	450	Angina, ST de-pression ≥ 2 mm	9	150	Angina	3*	1	3*	1
†42	450	Dyspnoea	12	170	Angina	3*	3*	1	0
43			15	120	Angina	3*	4	3	3
44	450	Fatigue	8	160	Angina	4*	2	3*	3
†45			15	140	Angina	3	1	3*	3
46	450	ST de-pression ≥ 2 mm	7	120	Angina	3*	1	3	0
47	300	Dyspnoea	9			D* 2	2*	3	0
48	750	ST de-pression ≥ 2 mm	13			3*	0	2	0

TABLE 2 (Cont'd)

Case No.	Maximum exercise load (kpm/min)	End point	Left ventricular end-diastolic pressure (mmHg)	Maximum pacing rate	End point	Coronary arteries: grading of disease			Left ventricular dyskinesia
						Left anterior descending	Left circumflex	Right	
49	600	Angina	5	150	Angina	4*	4*	2	0
50	300	Angina	10	170	Angina	3*	0	1	0
51	450	Angina	18	110	Angina	3*	4	3*	2
52	750	Dyspnoea	14	150	Angina	D* 4*	0	4*	0
53	750	Angina, ST depression > 2 mm	16	150	Angina	4*	2	2	0
54	300	Dyspnoea	10	150	Angina	4*	3	2	1
55	600	ST depression > 2 mm	10	130	Angina	D§ 2	3*	0	0
56	300	ST depression > 2 mm	6	160	Angina	4*	2	2	2
57	600	Angina	7	110	Angina	L 3*	3*	3	2
58	450	Angina	7	180	Angina	D§ 3*	2*	0	0
59	450	Fatigue	15	110	Angina	1	3	3*	0
60	900	Fatigue	13	140	Angina	4*	3*	3*	1
61	Angina at rest		10	130	Angina	L 3*	0	3*	2
62	600	Angina	23	140	Angina	4	2*	3	3‡
63	450	Angina, ST depression > 2 mm	14	Angina at rest		4*	3*	4*	0
64	450	Angina, ST depression > 2 mm	15	180	Angina	4*	4*	3*	1
65	600	Angina, ST depression > 2 mm	15	160	Dyspnoea	4*	3*	3	1
66	600	Angina	12	150	Angina	D* 3	3*	4	1
67	300	Angina	15	100	Angina	3§	3	4*	2
68	600	Dyspnoea	17	140	Angina	3§	2	0	0
69	450	Angina, ST depression > 2 mm	15	170	Angina	4	0	3*	0
70	450	Dyspnoea	13	130	Angina	4*	0	0	0
71	450	Angina	12	110	Angina	3§	0	0	0
72	600	Dyspnoea	16	170	Angina	D* 3*	0	0	0
†73	450	Angina	15	Angina at rest		D* 2*	3	3*	2
74	450	Angina, ST depression > 2 mm	10	130	Angina	4*	0	2	1
75	300	Angina	18	140	Angina	0	0	3*	0
76	750	ST depression > 2 mm	11	180	Angina	3*	2	2	0
77	Angina at rest		11	Angina at rest		D* 3*	3*	3*	0
78	Angina at rest		13	180		D* 3*	0	2	0

TABLE 2 (Cont'd)

Case No.	Maximum exercise load (kpm/min)	End point	Left ventricular en-diastolic pressure (mmHg)	Maximum pacing rate	End point	Coronary arteries: grading of disease			Left ventricular dyskinesia
						Left anterior descending	Left circumflex	Right	
79	900	Fatigue	10	150	Angina	3*	4*	2	0
80	900	Fatigue	10	150	Angina	3	2*	4*	4
81	450	Angina, ST depression > 2 mm	20	100	Angina	2*	3*	3	0
82	600	Angina	12			4*	3*	3	2
83	450	Angina	15			L 4*	3*	3*	0
84	450	Dyspnoea	15	150	Angina	E§ 4	3	3	3
85	750	Fatigue	19	130	Angina	4*	3	0	0
86	Angina at rest		17	180	Angina	4*	3*	4*	3
87	300	Angina, ST depression > 2 mm	40	110	Angina	3*	3	1	0
88	300	Angina, ST depression > 2 mm	12	150	Angina	3§	3*	4*	0
89	300	Angina	10			2§	0	3*	0
90	450	Angina		160	Angina	4	1	3*	2†
91	750	Angina	30	130	Angina	3*	3§	4*	2
92	900	Fatigue	15	150	Angina	D§ 4E*	3E*	3	0
93	750	Dyspnoea	10	130	Angina	3*	0	1	0
94	600	Angina	13	150	Angina	L 3§	3	1	0
95	300	Angina	17	120	Angina	3*	3*E	3	1
96	300	Angina, ST depression > 2 mm	15	180	Angina	4*	1	3*	0
97	450	Angina, ST depression > 2 mm	20	120	Angina	3§	3*	4E*	1
98	300	Angina	13	180		3*	0	0	0
99	450	Angina, ST depression > 2 mm	12	160	Angina	4§	0	4*	0
100			15	180		4*	0	3*	1
101	300	Angina, ST depression > 2 mm	20	160	Angina	2	3§	4*E	0
102			23	120	Angina	4*	2	4	2
103			20			3§	3*	1	0
104	600	Angina, ST depression > 2 mm	9	180	Angina	D* L 4	3*	2	0
105	900	ST depression > 2 mm	19	140	Angina	3*	4*	1	1
106	450	Angina	10	170	Angina	L 4*	0	3*	1
107			20	110	Angina	4*	0	0	0
108	600	Dyspnoea	25	140	Angina	4E§	3	4*	2
†109	600	Angina	17	150	Angina	3§	3*	3*	0

TABLE 3 Graft distribution and flow

Site of anastomosis	Graft used	No. of patients	Flow (ml/min)		
			Average	Range	No. of patients
Left anterior descending	Vein	72	78	5-240	52
	Artery	13	63	20-140	7
Diagonal	Vein	9	46	17-80	8
	Artery	2	50		1
Circumflex	Vein	44	72	10-160	21
	Artery	2			
Right coronary artery	Vein	47	77	7-150	27
Totals		189	73	5-240	116

in patients with grade 0 or 1 preoperative left ventricular angiograms, Cases 13 and 38 of respiratory complications, Case 42 from pulmonary embolism, and Case 109 from haemorrhage. Of the 102 survivors, 7 developed fresh Q waves on the postoperative electrocardiogram.

Postoperative follow-up

There have been no deaths in the 102 patients who left hospital and have been followed for up to 34 months. Five patients have had a documented myocardial infarction, one of whom (Case 31) had a further bypass operation. Postoperative T wave inversion has persisted in a further 23 patients.

The exercise performance frequently improved considerably between the first and second postoperative visits and this was attributed to recovery

from the residual effects of major surgery. The follow-up data of the 50 patients who have been followed for more than 6 months (average 13.9 months) are therefore presented. Thirty-six (72%) of them have had no further angina; this has improved by at least one clinical grade in a further 12 (24%) patients and 2 (4%) patients are unchanged. The average grade of angina has fallen from 2.8 to 0.5. Fig. 1 shows the results of the preoperative and the latest postoperative exercise test in the 37 patients in whom data are available. Twenty-one patients with a normal preoperative ventriculogram increased their performance from an average of 471 kpm/min to 664 kpm/min ($P < 0.001$). The 16 patients with abnormal ventriculograms started out at a significantly ($P < 0.05$) lower average level, 319 kpm/min, but improved their exercise performance by a similar amount to an average of 478 kpm/min ($P < 0.01$).

Postoperative reinvestigations

Table 4 compares the results of the pre- and postoperative studies in the 33 patients who were reinvestigated, at an average of 8 months after operation. The group includes 12 patients who either had angina or who had an attack of chest pain at rest without having evidence of infarction, and one who had an infarct (Case 31) and later had a second operation to bypass a new lesion in the circumflex artery and gave their informed consent to reinvestigation. The remaining 20 were free of angina. Fig. 2 compares the pre- and postoperative distribution of the clinical grading and the results of exercise and pacing tests. Of the 7 patients whose clinical angina persisted after operation, 4 had an occluded graft. The exercise performance increased from an average of 394 kpm/min to an average of 587 kpm/min ($P < 0.01$); 28 of the 31 patients were limited by angina or ST depression before opera-

FIG. 1 The results of pre- and postoperative exercise tests.

TABLE 4 Comparison of pre- and postoperative investigation

Case No.	Angina grade		Maximum exercise load and end point		Maximum pacing rate and end point		Left ventricular end-diastolic pressure		Left ventricular dyskinesia score		Total coronary score		Graft patency
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
1	4	3	450, dys-pnoea	300, angina	110, angina	160A	28	17	2		10	9	●
2	3	0			140, angina	180	8	15	0	0	8		○
4	3	0	450, angina	750, ST depression > 2 mm	140, angina	170	8	10	0	0	10		○
5	3	0	150, angina	600, fatigue	120, angina	180	12	16	0	0	9	8	○
12	2	0	600, angina	300, angina	150, angina	180	22	33	0		10	8	○
14	4	3	Angina at rest	300, angina	Angina at rest		8	7	1	0	8	8	●
15	2	0	600, angina	600, fatigue	130, angina	180	18	5	0	0	6	5	○
16	3	0	450, angina	600, fatigue	130, angina	180	13	15	0	0	10	11	●
17	3	0	450, ST depression > 2 mm	450, fatigue	140, angina	180	7	7	1		6	5	○
18	3	2	150, angina	600, fatigue	120, angina	170	30	25	2		7	8	○
19	3	0	450, ST depression > 2 mm	750, fatigue	160, angina	180	17	12	3		10		○
20	2	0	300, angina	450, dys-pnoea	140, angina	180	25	13	0	0	4	4	○
21	2	0	600, angina	600, dys-pnoea	140, angina	160, angina	20	28	3	4	11	11	●
22	3	0	750, angina	600, fatigue	150, angina		20	7	0	0	8	6	○
23	3	0	300, angina	750, fatigue	170, angina	180	8	11	0	0	6	6	○
24	3	3	150, angina	300, angina	150, angina	140, angina	15	11	1	1	7	7	○
25	3	0		750, fatigue			5	14	1	0	4	7	○
29	3	0	Angina at rest	600, dys-pnoea	Angina at rest	150, angina	7	12			4	6	○
30	2	0	450, ST depression > 2 mm	1050, fatigue	160, angina	180	10	12	0	0	4	7	○
31	4	2	Angina at rest	600, dys-pnoea	Angina at rest	160, angina	16	22	0	2	7	10	○
32	3	1	450, ST depression > 2 mm	750, angina	150, angina	160, angina	17	15	1	1	10	11	○

TABLE 4 (Cont'd)

Case No.	Angina grade		Maximum exercise load and end point		Maximum pacing rate and end point		Left ventricular end-diastolic pressure		Left ventricular dyskinesia score		Total coronary score		Graft patency
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
33	3	0	300, angina	750, fatigue	140, angina	170, angina	12	15	1	1	10	10	○
34	3	0	300, angina	600, ST depression ≥ 2 mm	170, angina	180	11	12	1	1	8	10	○
36	3	0	450, angina	300, dyspnoea	150, angina		7	10	4	4	11	9	○
41	3	3	450, angina	450, angina	150, angina	120, angina	9	11	1	4	7	11	○
49	2	0	600, angina	900, fatigue	150, angina	180	5	9	0	0	8	9	○
52	2	0	750, dyspnoea	450, dyspnoea	150, angina		14	10	0	1	8	11	○
53	2	0	750, ST depression	900, fatigue	150, angina	180	16	12	0	0	8	8	○
59	2	0	450, fatigue	450, angina	110, angina		15	12	0	0	7		○
62	2	0	600, angina	450, dyspnoea	140, angina	180	23	30	3	4	9	10	●
77	4	0	Angina at rest	750, ST depression ≥ 2 mm	Angina at rest	160, angina	11	12	1	1	9	10	○ ●
78	4	0	Angina at rest	750, dyspnoea	180, angina	170, angina	13	14	0	0	5	5	○
84	4	0	Angina at rest	450, dyspnoea	130, angina		9		3		9	8	○

○, patent graft; ●, occluded graft; other abbreviations as in Table 2.

tion and 9 after. The average maximum pacing rate increased from 134 to 163 b.p.m. ($P < 0.001$). Angina was induced in all 32 patients before operation and in only 10 after.

Average left ventricular end-diastolic pressure was 13.9 before and 14.2 after surgery. This difference is not significant. The average left ventricular dyskinesia score is unchanged at 0.9 and total coronary score did not change significantly (8.1 to 8.2). Because the follow-up time in this subgroup is short, little information is available on the progression of lesions in the native circulation. It was noted, however, that approximately 25 per cent of the grafted vessels had become occluded proximal to the anastomosis.

Of the 52 grafts, 43 (83%) were patent at the time of reinvestigation; 24 (72%) of 33 patients had all grafts patent, 6 (18%) had 1 patent and 1 occluded graft, and 3 (9%) did not have a patent graft.

Discussion

The patients reported here represent approximately 40 per cent of all patients investigated for ischaemic heart disease during the period mentioned. The main indication for operation was the severity of angina and the way in which it limited any given patient's life. They in effect selected themselves in the majority by complaining of unacceptable symptoms in spite of treatment with nitroglycerin and beta-adrenergic blocking agents.

FIG. 2 The comparison of pre- and postoperative clinical grades and stress tests. RP = Angina at rest; ST ↓ = ST segment depression of ≥ 2 mm.

Patients with severe left ventricular dysfunction were excluded, though the left ventriculogram was abnormal in 45 per cent. A few patients with severe diffuse coronary artery disease were also excluded at the beginning of the series but later bypass grafting with prior endarterectomy was used in some. The vein graft distribution and flows are similar to those previously reported (Johnson *et al.*, 1970; Grondin *et al.*, 1972; Danielson, Gau, and Davis, 1973). The operative mortality was 6.4 per cent which compared favourably with other series (Reul *et al.*, 1972; Ross *et al.*, 1972; Grondin *et al.*, 1972; Manley and Johnson, 1972; Hammond and Poirier, 1973; Danielson *et al.*, 1973), though 4 of the 7 deaths were in patients who had near normal left ventricular function preoperatively, and were caused by possibly avoidable complications, 3 deaths were caused by pulmonary embolism which did not occur after routine anticoagulation was used. Figures as low as 3 per cent have been achieved in the largest reported group (Favaloro, 1972; Sheldon *et al.*, 1972). These figures have to be compared with the expected mortality without operation. The yearly figure in patients with angina pectoris is now recognized to be in the region of 3 to 4 per cent (Zukel *et al.*, 1969; Kannel and Feinleib, 1972). This

applies to a heterogeneous group of patients with all grades of disease. Recent publications have shown that the natural history is determined by the severity of the lesions. Patients with normal vessels have a lower mortality rate than the general population (Brushke, Proudfit, and Sones, 1973a) and survival decreases with increasing severity of disease (Freisinger, Page, and Ross, 1970; Brushke, Proudfit, and Sones, 1973b). The overall one year mortality for patients with coronary artery lesions of at least 50 per cent was greater than 10 per cent in a group with a distribution of disease very similar to ours (Brushke *et al.*, 1973b). In our patients, using 75 per cent stenosis as the criterion for inclusion the operative mortality is lower than the one-year figure as reported for each of the 2 and 3 vessel disease groups. There have been no late deaths. Our patients also include 8 patients with major stenosis of the left main coronary artery (Table 2), all of whom survived, though this lesion is recognized to have a very high untreated mortality (Cohen *et al.*, 1972; Brushke *et al.*, 1973b). We did not define a subgroup with unstable angina, but there were 19 patients with recurrent pain at rest (grade 4; Table 1) of whom 4 died. The operative mortality in the 90 remaining patients with stable

angina of effort was 3.3 per cent. The overall figure did not therefore exceed that expected from available data on natural history.

Intraoperative studies have shown that occlusion of a newly anastomosed bypass graft adversely affects left ventricular function as judged by derivatives of left ventricular pressure (Bolooki *et al.*, 1971). Early postoperative studies have shown varying effects on overall ventricular function (Marlon *et al.*, 1971; Mailhot, Sandler, and Harrison, 1971; Rees *et al.*, 1971; Chatterjee *et al.*, 1973) though contraction of hypokinetic areas has been shown to improve (Rees *et al.*, 1971; Chatterjee *et al.*, 1973). We saw no overall change in pre- and postoperative angiograms.

Of the 50 patients followed for more than 6 months, 36 are free of angina without drug therapy and a further 12 have improved. This excellent clinical result is similar to that obtained by others (Reul *et al.*, 1972; Adam *et al.*, 1972; Ross *et al.*, 1972; Manley and Johnson, 1972; Friedberg, 1972). It has been suggested that the relief of pain may be due to perioperative myocardial infarction (Friedberg, 1972). Incidence of new Q waves of up to 20 per cent has been reported (Ross *et al.*, 1972). Our figure was 7 per cent of the survivors. A vectorcardiographic study (Friedberg *et al.*, 1973) has suggested that the true incidence of new infarction is lower than that indicated by the scalar electrocardiogram.

In common with other comparable series our patients showed a significant improvement in exercise performance (Amsterdam *et al.*, 1970; Manley *et al.*, 1970; Lapin *et al.*, 1973). The patients with abnormal preoperative left ventriculograms had lower exercise capability both before and after operation but showed similar improvement to those with normal left ventriculograms.

The patients who were reinvestigated also showed a significant clinical improvement and increase in exercise capability. The pacing stress test (Sowton *et al.*, 1967), which provides a more objective assessment, confirmed these findings in both ours and Manley's patients (Manley *et al.*, 1970). Of the 12 patients who were restudied because of chest pain, 7 had an occluded graft and all the patients who had no patent graft had postoperative angina. No patient was relieved of symptoms without a patent graft. Eighty-three per cent (43 of 52) of grafts were patent, a figure similar to that of other reported series (Sheldon *et al.*, 1972; Flemma *et al.*, 1972; Walker *et al.*, 1972; Bourassa *et al.*, 1972; Danielson *et al.*, 1973). Approximately 25 per cent of grafted vessels became occluded proximally as has been previously observed (Malinow *et al.*, 1973).

Conclusions

These initial results have shown that aorto-coronary bypass grafting is a relatively safe operation in our hands, with an operative mortality not exceeding the expected yearly mortality for an untreated group of patients. Both subjective and objective assessment have demonstrated considerable symptomatic improvement which is related to graft patency. We have been encouraged by these results to consider surgery earlier in the course of the disease in patients who are less limited by angina as we feel that it offers greater likelihood of complete relief of symptoms than medical treatment.

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