Physical training after heart valve replacement

J P NEWELL, C T KAPPAGODA, J B STOKER, P B DEVERALL,
D A WATSON, R J LINDEN

From the Department of Cardiovascular Studies, University of Leeds, and Killingbeck Hospital

SUMMARY A controlled trial was undertaken to examine the efficacy of physical training in patients recovering from the replacement of a single heart valve.

Patients were allocated to a test or control group two weeks after operation. Each patient performed a submaximal exercise test at entry, and 12 and 24 weeks after this test. The Canadian Air Force exercise programme was undertaken by the test group, while the control group continued normal activities for the 24 weeks between the first and last exercise group.

A regression line of submaximal heart rate on oxygen consumption was calculated from the data of each exercise test in each patient. Alterations in this line were used as an "index" of changes in "cardiorespiratory fitness".

The individual results showed a consistent improvement in "cardiorespiratory fitness" over the first 12 weeks in both groups. Only patients in the test group continued to improve between 12 and 24 weeks. Thus the exercise programme modified the recovery of "cardiorespiratory fitness" after operation.

Results in patients who developed clinical complications, and were excluded from the trial, predicted a deteriorating clinical condition.

This finding suggested that sequential exercise tests are of value after cardiac surgery.

In recent years considerable interest has been shown in the physical rehabilitation of patients suffering from ischaemic heart disease and rehabilitation programmes for these patients are an integral feature of the health service of many countries. In contrast, physical training in patients with other forms of cardiac disease, particularly those undergoing surgery for valvular diseases of the heart, has received little attention.[1] A programme of physical training for these patients could be justified readily, however, from the known effects of training and bed-rest on cardiorespiratory fitness.

Patients commonly present for valve surgery after years of partial, or even complete, impairment of physical activity. Cardiorespiratory fitness will be further impaired by surgical trauma and postoperative bed-rest.[2] [3] Therefore, patients recovering from, albeit successful, cardiac surgery are not in an optimum state of cardiorespiratory fitness,[4] especially after mitral valve replacements and in patients in whom a valve lesion is caused by rheumatic heart disease known to impair cardiac performance.[5] [6] Such a proposition is supported by the observation that haemodynamic improvement (as

defined by catheter studies made at rest) is not reflected in comparable "functional" improvement.[7] [8]

The present study was undertaken to establish the efficacy of physical training in patients recovering from the replacement of a single heart valve. A suitable training programme, and an exercise test which provides a valid index of cardiorespiratory fitness have been examined and the results reported previously.[9]

Subjects and method

(1) SELECTION OF 24 PATIENTS FOR STUDY
Only patients who had undergone a single heart valve replacement (aortic or mitral) were considered for entry to the trial. Two weeks after operation these patients were assessed by a cardiologist (JBS) who, with supportive evidence from certain laboratory investigations (for example blood urea, haemoglobin, $FEV_1\%$) adjudged them to be a "satisfactory operative result". Clinical criteria adopted in reaching this decision were the absence of: (a) angina pectoris, (b) significant murmurs, (c) clinical signs of heart failure, (d) anaemia, (e)

significant pulmonary and renal disease, and (f) significant joint disease or other disabilities preventing an exercise test.

Patients who had been admitted in atrial fibrillation which was controlled with digoxin after operation were considered for entry to the trial. Patients maintained on antiarrhythmic agents after operation were excluded. Only patients who gave their formal consent to undergo a sequence of postoperative exercise tests on a bicycle ergometer were accepted for the study. The procedure for this investigation was approved by the hospital ethical committee.

At entry to the trial, the patients were allocated to a trial group or to a control group solely according to convenience of travel as determined by domicile; all patients lived and worked within the West Yorkshire industrial conurbation.

(2) PROCEDURE FOR TRIAL

Exercise tests were performed on all patients between two and three weeks after operation, and then 12 and 24 weeks after this first test, when the clinical progress of each patient was also reviewed. After their first exercise test patients in the test group undertook the training programme for 24 weeks.

(3) EXERCISE TEST

In each test, an attempt was made to obtain a relation between the heart rate and the oxygen consumption for a series of submaximal work loads.

(a) *Procedure*

All patients were tested at least two hours after their most recent meal. After sitting or lying quietly for 15 to 20 minutes they mounted an electrically braked bicycle ergometer (Elema Schonander, Type 380) and the procedure was explained to them. Saddle height was set at maximum comfortable leg extension and remained unchanged for each patient on subsequent retesting. After the attachment of electrocardiograph electrodes patients remained seated on the bicycle ergometer for five to 10 minutes in order to obtain a steady "initial heart rate". Any electrocardiographic abnormalities present at rest were recorded.

Usually six submaximal work loads were presented to each patient. These were arranged in three pairs in a discontinuous but increasing series as illustrated in Fig. 1. Each work load was pedalled for a nominal five to six minutes at 60 rpm until the criteria for a steady state, as defined below, was achieved. The heart rate and the oxygen consumption were then measured. Rest periods between loads were not fixed but prolonged until the recovery heart rate was within five to 10 per cent of the initial heart rate.
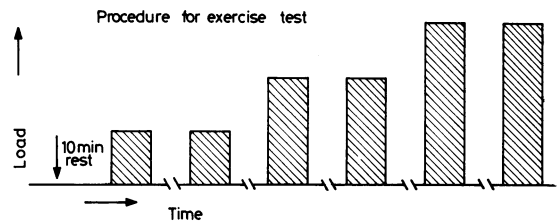

Fig. 1 *Exercise test procedure. Relative changes in work load are represented on the vertical axis. These changes are related to time on the horizontal axis. Subjects mounted the bicycle ergometer at time indicated by the arrow.*

Work loads were selected to obtain an increase in the exercise heart rate of 50 to 70 beats/min over the complete test, to permit adequate definition of the heart rate/oxygen consumption (HR/$\dot{V}o_2$) relation without departure from linearity. Thus the work loads used differed between patients but were usually 200, 300, and 400 kpm/min (32·8, 49·2, 65·6 W) for women, and 200, 400 and 600 kpm/min (32·8, 65·6, 98·4 W) for men. In some patients, an increase in exercise heart rate of 30 to 40 beats/min was accepted as the first postoperative test and an initial work load of 100 kpm/min (16·4 W) selected.

Laboratory ventilation was assisted by wall mounted fans and all patients exercised in an ambient temperature of 19 to 22°C, humidity 45 to 60 per cent. Oxygen consumption was measured continuously during exercise by an open circuit "flow through" technique which has been described previously.[10] This technique is free from systematic error and its random error (that is 95% tolerance limits) is 4 per cent. This apparatus provided a direct digital display of oxygen consumption in cm³/min. The output was also amplified (EMMA system, SE Laboratories, Feltham, Middlesex) and recorded on an ultraviolet recorder (Model 2100, SE Laboratories).

This method was particularly suitable for measuring "steady state" values of submaximal oxygen consumption since the approach and attainment of a steady state of oxygen consumption was readily assessed as a plateau in the tracing on the ultraviolet recorder. All values of oxygen consumption were expressed at 20°C and 760 mmHg (101·1 kPa).

The electrocardiogram was recorded alongside the tracing of the oxygen consumption. The heart rate was determined by counting cardiac cycles over at least one minute during the "steady state" of oxygen consumption. An additional output from the electrocardiographic amplifier was used to drive a cardiotachometer (Type 4913, SE Laboratories) to provide a continuous display of the heart rate.

Criteria for the achievement of a "steady state" were therefore: (i) a sustained "plateau" of oxygen consumption for at least one minute ($<5.0\%$ variation); and (ii) a sustained and concurrent steady heart rate ($<2.0\%$ variation).

(b) Patient monitoring and safety

All exercise tests were carried out by two medically qualified staff. The electrocardiogram of each patient was continually displayed on a memory oscilloscope (Model 434–1 SE Laboratories) permitting the retention of any electrocardiographic abnormalities during exercise. Full resuscitation facilities were available including a wall mounted DC defibrillator (Model 282, Cardiac Recorders Ltd). Exercise tests were terminated at the onset of any of the following symptoms and signs: dyspnoea, pain, arrhythmia, and conduction disturbance.

(4) TRAINING PROGRAMME

All patients in the test group followed the Royal Canadian Air Force exercise programme, 5BX for men and XBX for women,[9] [11] which has been re-commended for sedentary normal subjects. This programme was considered particularly suitable since it is well defined in terms of its frequency, duration, and age related rate of progression. As it required only 11 to 12 minutes of daily exercise we expected good patient adherence. This time was split in approximately equal proportions between muscle strengthening exercises (callisthenics) and a stationary run. The frequency of each exercise is increased with progression of training to keep within the set time. The efficacy of this training programme in improving the cardiorespiratory fitness of normal subjects has been established previously.[9] In addition, the short duration of the exercise sequences causes minimal interference with normal activities and since no special equipment is required it can be undertaken at home.

(5) TRAINING SCHEDULE FOR TEST GROUP

(a) First three weeks

Patients attended the physiotherapy department on five days a week and training was supervised by a qualified physiotherapist. This ensured that each patient was fully conversant with the timing and duration of the exercise sequences. Medical staff recorded the electrocardiogram before and after exercise and the heart rate over the first 20 seconds of recovery.

(b) Three to 13 weeks

Patients attended the physiotherapy department for supervised training twice a week. On the remaining five days training was continued unsupervised at home.

(c) Thirteen to 24 weeks

Patients trained daily at home but also attended the physiotherapy department at least once every two weeks. Several patients elected voluntarily to attend for supervised training twice weekly.

Results

The investigation was conducted on a total of 24 patients, 12 in the control group, and 12 in the test group. Their relevant anthropometric and clinical details are given in Table 1a and b. The 12 control subjects had a mean age of 39·7 years (SEM ±5·6) and a mean body weight of 66·3 kg (SEM ±3·5). Eight of the control subjects had aortic valve disease and four had mitral valve disease. The causes of valve lesion were rheumatic in six patients, congenital in four patients, and calcific aortic disease in the remaining two patients. The 12 subjects in the test group had a mean age of 39·7 years (SEM ±3·9) and a mean body weight of 63·2 kg (SEM ±1·9). Seven of the test subjects had aortic valve disease and five mitral valve disease. The causes of valve lesion were rheumatic in nine patients, congenital in two patients, and infective endocarditis in the remaining patient. Three patients in each group (cases 9, 11, and 12 in Table 1a, and cases 19, 23, and 24 in Table 1b) were taking digoxin but the doses remained constant during the trial.

RELATION BETWEEN SUBMAXIMAL HEART RATE AND OXYGEN CONSUMPTION

The data from each exercise test in each patient were analysed to provide a regression line relating submaximal heart rate to submaximal oxygen consumption. Three regression lines were therefore obtained in each patient, corresponding to each postoperative exercise test. In the first postoperative test, however, six patients (cases 4 and 10 of the control group, and cases 19, 20, 21, and 24 of the test group) did not complete six submaximal work loads because of complaints of dizziness, dyspnoea, or pains in the legs. In case 21 of the test group there were insufficient data to establish a regression line. In the remaining five patients regression analysis was based on fewer points. For similar reasons the 12-week test was terminated prematurely in case 19 of the test group and the 24-week test in case 10 of the control group.

A statistical analysis of 65 regression lines based on six measured points disclosed correlation coefficients of between 0·95 and 0·99 ($p < 0.005$ or

Table 1 *Details of patients*

Case no.	Sex	Age (y)	Wt (kg)	Valve lesion	Aetiology	ECG	Postop 0	Drug 3/12	Therapy 6/12
(a) *Control group*									
1	M	15	49·7	AS[1]	N	SR	—	—	—
2	M	49	58·1	AS[1]	R	SR	F20	—	—
3	M	15	51·2	AS[1]	N	SR	—	—	—
4	M	62	65·0	AS[1]	N	SR	—	—	—
5	M	58	70·0	AS[1]	N	SR	—	—	—
6	M	40	72·0	AS[2]	N	SR	F20	—	—
7	M	34	86·5	AR[1]	R	SR	—	—	—
8	M	58	60·0	AR[2]	N	SR	F20	F20	—
9	F	24	73·0	MS[3]	R	AF	DO25	DO25	DO25
10	F	60	53·0	MS[1]	R	SR	F40	—	—
11	M	40	81·3	MR[1]	R	AF	F40 DO5	DO5	DO5
12	M	37	76·0	MR[1]	R	SR	F40 DO25	F40 DO25	F40 DO25
Mean		39·7	66·3						
SEM		±5·6	±3·5						
(b) *Test group*									
13	M	62	59·0	AS[1]	N	SR	F40	—	—
14	M	18	64·5	AS[1]	N	SR	—	—	—
15	M	34	69·0	AR[1]	R	SR	F20	—	—
16	M	36	79·0	AR[2]	R	SR	F40	—	—
17	M	29	65·0	AR[2]	N	SR	F20	—	—
18	F	38	62·0	AR[4]	R	SR	—	—	—
19	M	58	65·0	AR[1]	R	AF	F40 DO5	DO5	DO5
20	F	44	52·0	MS[1]	R	SR	—	—	—
21	F	42	64·0	MS[1]	R	SR	—	—	—
22	M	35	62·0	MS[1]	R	SR	F40	—	—
23	F	55	59·2	MS[1]	R	AF	F40 DO5	F40 DO5	F40 DO5
24	F	25	58·0	MR[1]	R	SR	F40 DO25	F20 DO25	F20 DO25
Mean		39·7	63·2						
SEM		±3·9	±1·9						

SR, sinus rhythm; AS, aortic stenosis; MS, mitral stenosis; [1], Björk-Shiley prothesis; [2], Lillehei-Kester prothesis; [3] homograft; [4] heterograft; AF, atrial fibrillation; AR, aortic regurgitation; MR, mitral regurgitation; F, frusemide; D, digoxin (daily oral Rx in mg); R, rheumatic activity; N, nonrheumatic activity.

$p < 0.001$) on 61 occasions. A reduced correlation was obtained on four occasions at the first postoperative test, ranging from 0·85 to 0·93 ($p < 0.05$ or $p < 0.01$). The seven analyses based on four or five measured points (see above) showed correlation coefficients of 0·97 or 0·99 ($p < 0.005$ or $p < 0.001$). Therefore all the tests performed, except the first in case 9 of the test group, provided a significant positive relation between submaximal heart rate and oxygen consumption.

Three patients in the test group developed postoperative complications necessitating clinical intervention; cases 13 and 14 presented evidence of subacute bacterial endocarditis and case 19 cardiac failure. In addition, one patient (case 23) discontinued the training programme after 12 weeks. The results obtained in these four patients will be considered individually in a separate section of the Results (see later).

CHANGES IN CARDIORESPIRATORY FITNESS AFTER OPERATION

(a) *Individual data*

In individual subjects an increase in "cardiorespiratory fitness" is indicated by a movement of the submaximal $HR/\dot{V}_{O_2}$ relation to the right while a loss of fitness is indicated by a reversal of this movement.[9]

Original data from one patient in each group are shown in Fig. 2. The two patients are well matched in terms of age, height, and weight (see Table 1a and b). Both patients had undergone a valve replacement for aortic regurgitation with a clinically satisfactory result and recovery. In both subjects the 12-week test is associated with a movement to the right of the $HR/\dot{V}_{O_2}$ relation from that obtained three weeks after operation. The patient in the test group showed a further movement to the right at the 24-week test while the control patient showed a
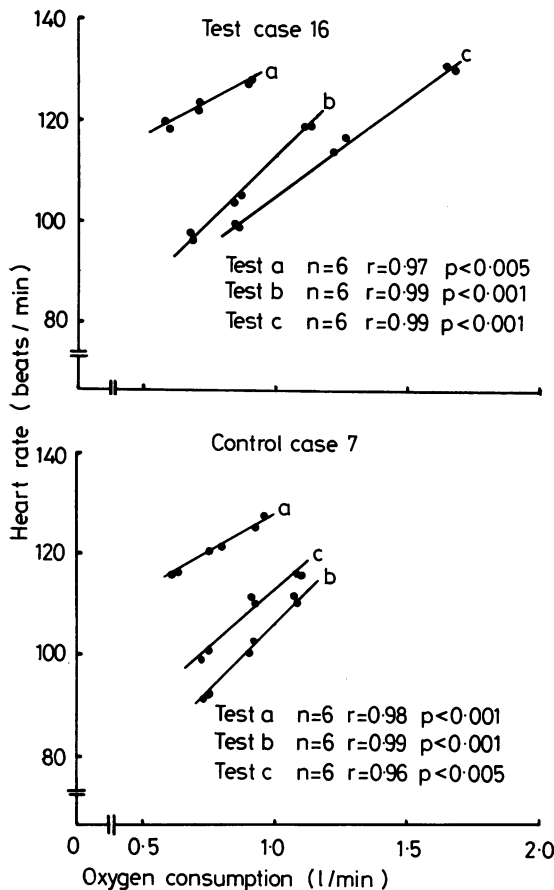
Fig. 2 *Results from test case 16, and control case 7: for each patient submaximal heart rate (beats/min) is plotted on the ordinate against submaximal oxygen consumption (l/min) on the abscissa. Measured data from exercise tests a, b, and c in each patient with the corresponding regression lines are shown. The related correlation coefficients with associated levels of significance are tabulated.*

movement to the left. This finding suggested that the training programme altered the position of the $HR/\dot{V}_{O_2}$ relation obtained at the 24-week test.

Composite plots from the remaining seven patients in the test group and the 11 patients in the control group are presented in Fig 3 and 4. In both groups the 12-week test is associated with a consistent movement of the $HR/\dot{V}_{O_2}$ relation to the right of the immediate postoperative position. In the test group, the 24-week test is associated with a further movement to the right of the $HR/\dot{V}_{O_2}$ relation from the 12-week position. In contrast, the patients in the control group show less consistent

movements between the $HR/\dot{V}_{O_2}$ relations obtained at 12 and 24 weeks.

In order to establish the statistical significance of the movements of these lines, the technique described by Snedecor and Cochran was adopted.[9] [12] This method compared first the slopes of the two regression lines, and second, the adjusted means to show whether the two groups of data fitted a single regression line or separate ones; that is whether the "movement" of the regression lines to the left or right was significant.

This test was used to compare the results of the 12-week and 24-week tests in each patient (Table 2). For this comparison the test group now consisted of four patients with mitral valve replacement and four patients with aortic valve replacement. The control group consisted of eight patients with aortic valve replacement and four patients with mitral valve replacement. The movement to the right of the $HR/\dot{V}_{O_2}$ relation between 12- and 24-week tests noted in each patient in the test group (Fig. 2 to 4) was confirmed as a significant difference ($p < 0.05$). There were also significant but less consistent alterations in slope. In the control group significant alterations in slope and movements of the regression lines were also found but inspection of Fig. 2 and 3 indicates that these differences were random rather than systematic. These differences within the control group may relate to the type of valve replacement, lesion, and aetiology. In contrast, there

Table 2 *Comparison of submaximal heart rate/oxygen consumption regression lines obtained at 12 weeks and 24 weeks*

| Case No.	Control group		Case No.	Test group	
1	Slope	NS	13	*Slope	NS
	Elevation	< 0.05		*Elevation	< 0.01
2	Slope	< 0.01	14	*Slope	NS
	Elevation	NS		*Elevation	< 0.01
3	Slope	< 0.05	15	Slope	NS
	Elevation	NS		Elevation	< 0.01
4	Slope	NS	16	Slope	< 0.01
	Elevation	< 0.05		Elevation	< 0.01
5	Slope	NS	17	Slope	NS
	Elevation	< 0.01		Elevation	< 0.01
6	Slope	NS	18	Slope	NS
	Elevation	NS		Elevation	< 0.05
7	Slope	NS	19	*Slope	NS
	Elevation	< 0.01		*Elevation	< 0.01
8	Slope	NS	20	Slope	NS
	Elevation	< 0.01		Elevation	< 0.01
9	Slope	NS	21	Slope	NS
	Elevation	< 0.01		Elevation	< 0.01
10	Slope	NS	22	Slope	< 0.01
	Elevation	< 0.01		Elevation	< 0.01
11	Slope	< 0.05	23	*Slope	NS
	Elevation	NS		*Elevation	< 0.05
12	Slope	NS	24	Slope	NS
	Elevation	< 0.01		Elevation	< 0.01

*Excluded from group comparison.
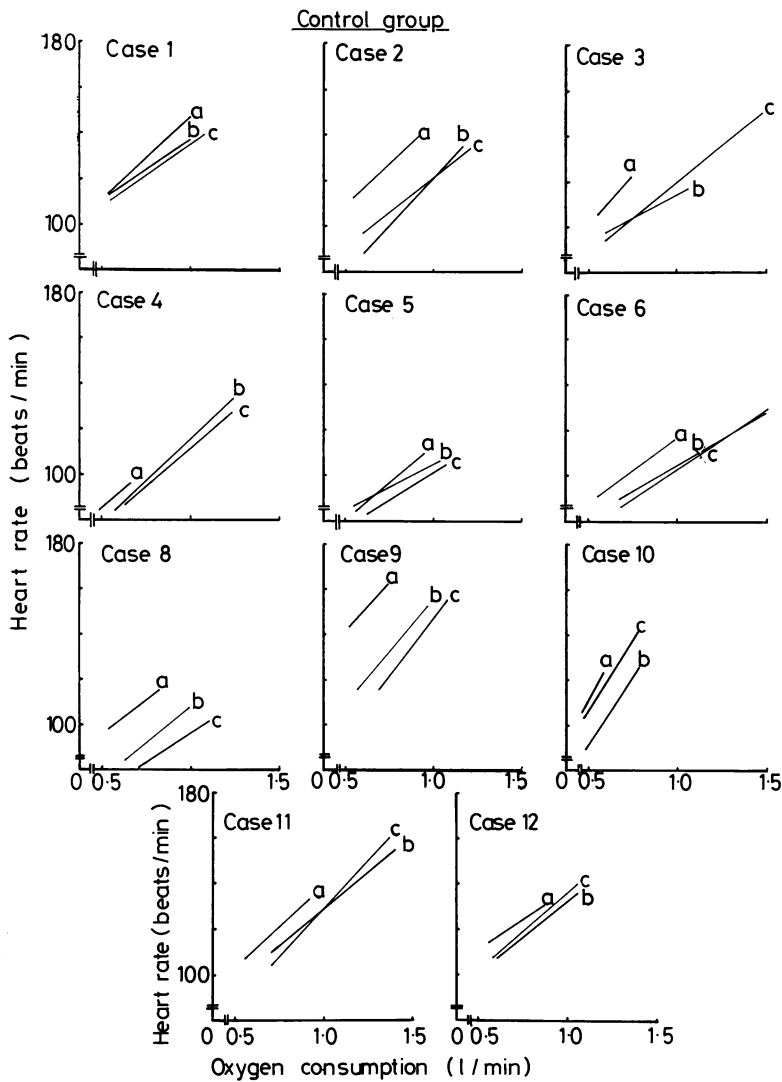
Fig. 3 *Results from 11 patients in the control group : submaximal heart rate (beats/min) is plotted on the ordinate against submaximal oxygen consumption (litre/min) on the abscissa for each patient. Regression lines calculated from the results of exercise tests a, b, and c are shown.*

was a consistent and significant movement of these regression lines to the right in the test group despite individual differences in these variables. It was therefore of interest to compare the progress of patients with rheumatic and non-rheumatic valve lesions within the control group. There were six patients with rheumatic heart disease and six patients with non-rheumatic heart disease and the exercise test appeared capable of discriminating the progress of these two subgroups. The HR/V̇o₂ regression line showed a significant movement to the right between the 12- and 24-week tests in only one of six patients with rheumatic heart disease. In contrast this movement was observed in four of

the six patients in the control group who did not have rheumatic heart disease.

It was concluded that the 5BX/XBX training programme was associated with a consistent improvement in "cardiorespiratory fitness". This was defined in individual patients of the test group by a significant movement to the right of the HR/V̇o₂ regression line, between the 12- and 24-week tests. This result is similar to that demonstrated in normal subjects.[9]

(b) *Group analysis of data*

To examine *group* differences in the alteration of cardiorespiratory fitness after operation it was

Fig. 4 *Results from seven patients in the test group: submaximal heart rate (beats/min) is plotted on the ordinate against submaximal oxygen consumption (l/min) on the abscissa for each patient. Regression lines calculated from the results of exercise tests a, b, and c are shown.*
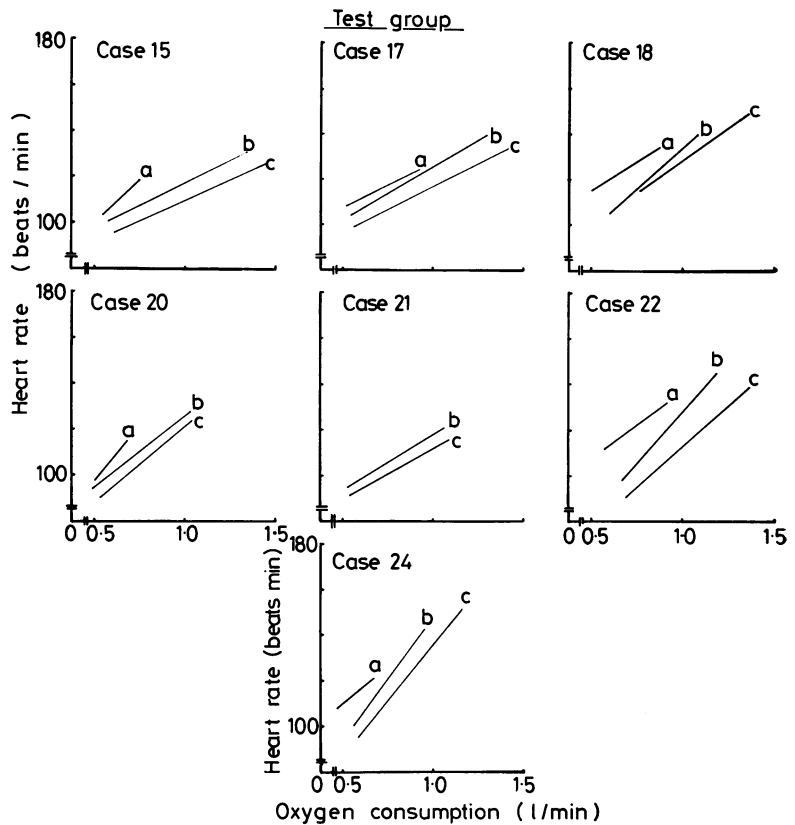
necessary to compare the complete data for each group. Three $HR/\dot{V}_{O_2}$ regression lines were calculated from the pooled data for each of these tests in each group. The pooled $HR/\dot{V}_{O_2}$ relation from the first postoperative test was not statistically significant in either group, a finding which reflected the narrow range of heart rates obtained in these tests. This proposition is supported by the observation that the $HR/\dot{V}_{O_2}$ relation in *individual* patients was significant. The pooled $HR/\dot{V}_{O_2}$ relation from the second and third postoperative tests are illustrated in Fig. 5. The pooled data from the 12-week test yielded a significant $HR/\dot{V}_{O_2}$ relation in both groups. The positions of the regression lines did not differ significantly from each other ($p > 0.05$). The pooled data from the 24-week test also yielded a significant $HR/\dot{V}_{O_2}$ relation in both groups. The regression line obtained in the control group, however, did not show a significant movement to the right from the 12-week position, whereas the line obtained in the test group did ($p < 0.05$). It was concluded that the 5BX/XBX training programme had modified the postoperative recovery of cardiorespiratory fitness in patients of the test group.

No attempt was made to determine the effort tolerance of patients. All patients, however, showed an improved subjective tolerance of the higher work loads, imposed at the 12-week test. At 24 weeks further subjective improvement was more evident in the test group. This is reflected in the consistently higher loads and thus higher levels of steady state oxygen consumption achieved (cf Fig. 3 and 4).

(c) *Results of patients excluded from trial*
Four patients were excluded, three on clinical evidence, and one who failed to continue. Individual data from these four patients, together with the fitted $HR/\dot{V}_{O_2}$ regression lines are presented in Fig. 6. The results from the statistical comparison of these regression lines at 12 and 24 weeks are summarised in Table 2.

Results of sequential postoperative exercise tests in these patients will be related to their individual clinical history during the same period.
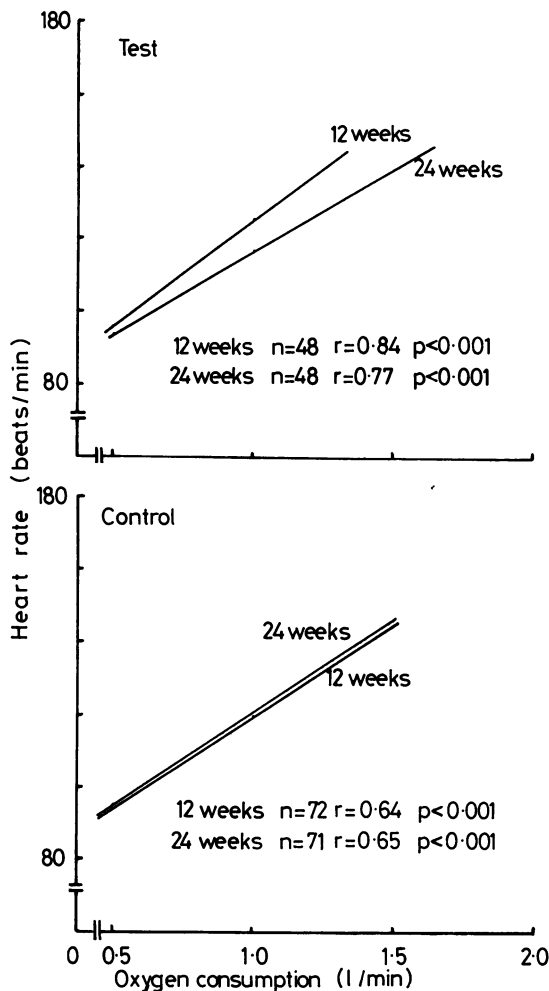
CASE 13
This 62-year-old man entered the test group after

Fig. 5 *Group results for test and control patients :*
submaximal heart rate (beats/min) is plotted on the
ordinate against submaximal oxygen consumption
(l/min) on the abscissa for each group. Regression lines
calculated from the pooled results of the exercise tests
performed 12 and 24 weeks after operation (tests b, c)
are shown for each group. The related correlation
coefficients with associated levels of significance are
tabulated.

correction of isolated aortic stenosis by aortic valve replacement. This patient made steady progress through the exercise programme over the first nine weeks. Progress then slowed, and finally halted, and was associated with a complaint of lack of energy. In the twelfth week the patient complained of tiredness and night sweats. Exercise test data at 12 weeks (line b) yielded a regression line differing little in position from that obtained immediately after

operation (line a). This finding contrasts with other results in both test and control groups (Fig. 3 and 4). Treatment was instituted for subacute bacterial endocarditis. Though this patient did not start training, the regression line obtained at 24 weeks (line c) again shows a "movement" to the right; commensurate with the results of other patients in the control group.

CASE 14
Preoperatively this 18-year-old man was asymptomatic. He entered the test group after aortic valve replacement to correct residual congenital aortic stenosis (a valvotomy had been performed when this patient was 5 years old). During the first 12 weeks he made rapid progress through the exercise programme. The regression line from the 12 week test (line b) showed pronounced movement to the right from the postoperative position (line a). Progress with training, however, then slowed. At the twenty-first postoperative week the patient complained of a persistent "flu like" illness and felt too tired to continue the exercise programme. The test at 24 weeks resulted in a regression line (line c), displaced to the left of that at 12 weeks (line b), despite some training during this period. Subacute bacterial endocarditis was later diagnosed and treated. An additional exercise test performed at 30 weeks resulted in a regression line (line d) showing a movement to the right from the 24-week position.

CASE 19
This 58-year-old man entered the trial after correction of aortic regurgitation by aortic valve replacement. After 10 weeks of training he was unable to complete the exercise sequences within the required time and exercise was associated with worsening dyspnoea and a pronounced tachycardia. He complained of feeling "worse off" than before the operation. Clinical examination confirmed a diagnosis of progressive cardiac failure. The exercise test performed at 12 weeks resulted in a regression line (line b) lying to the left of the immediate postoperative line (line a). After treatment, and on long-term diuretic therapy, this patient undertook a further exercise test at 24 weeks. This test resulted in a regression line with a position well to the right of the previous two tests.

CASE 23
This 55-year-old woman underwent mitral valve replacement for the correction of mitral stenosis. Domestic circumstances prevented her from continuing the exercise programme after 12 weeks. The test at 12 weeks resulted in a regression line (line b) lying to the right of the position after
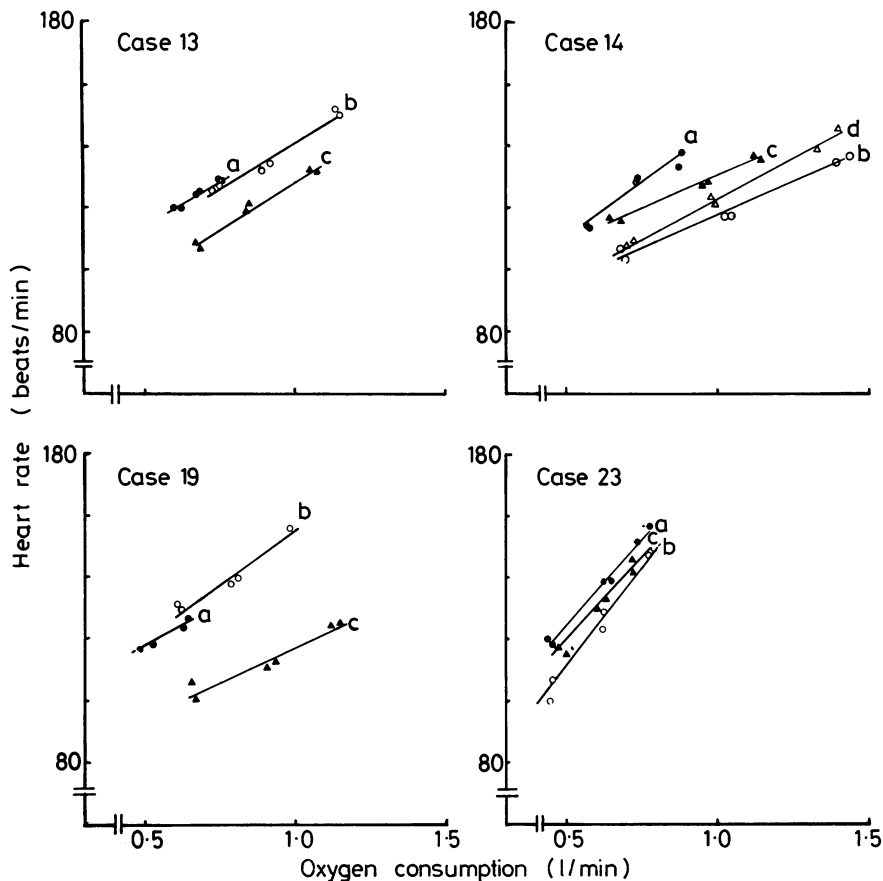
Fig. 6 *Results from patients excluded from the test group: submaximal heart rate (beats/min) is plotted on the ordinate against submaximal oxygen consumption (l/min) on the abscissa for each patient. Measured data from exercise tests a, b, and c (also d in case 14—see text) with the corresponding regression lines are shown.*

operation. However, the line from the exercise test at 24 weeks (line c), after discontinuing training, was to the left of the 12 week position, a finding previously noted in patients of the control group (Fig. 3).

Cases 13, 14, and 19 were unable to maintain steady progress through the training programme. This undoubtedly drew attention to a deteriorating clinical condition which was confirmed on formal exercise testing. Interpretation of these results necessitated additional clinical information but their development appeared to predate the appearance of unequivocal clinical signs.

Discussion

This study attempted to provide objective evidence of a change in cardiorespiratory fitness

when patients recovering from surgery for valvular heart disease undertook a programme of physical training. Only a small number of patients was studied, due mainly to strict criteria governing entry to the trial. For logistic reasons conventional randomisation between test and control groups was not possible. An allocation solely based on domicile, however, did not result in any other relevant differences in the composition of the two groups.

For this study a valid index of cardiorespiratory fitness and an acceptable training programme were required. In addition, sequential exercise tests provided an early indication of postoperative complications in three patients. The application of exercise tests in the routine follow-up of postoperative cardiac patients will therefore be examined.

VALID INDEX OF CARDIORESPIRATORY FITNESS

An index was required to show an "improvement" or deterioration in the cardiorespiratory fitness of individual patients. Validation therefore demanded the demonstration of systemic alterations in this index, with interventions designed to alter cardiorespiratory fitness (for example periods of training or detraining). This index will not provide an absolute measure of fitness but will follow *changes* in individual patients provided its reproducibility is acceptable. Maximal oxygen consumption ($\dot{V}_{O_2}$ max) is conceptually attractive to fulfil this role, since alterations in this value with training and detraining have been repeatedly shown in normal individuals, at least on the basis of a change in *group* mean values. Several points, however, must be considered before measurement of $\dot{V}_{O_2}$ max is made in a clinical population. This measurement must be divorced from any subjective considerations. The objective criteria used to define a measurement "endpoint" demand a lengthy and exhausting procedure.[13] Furthermore, the reproducibility of this measurement within a normal sedentary population is ill defined.[9] As a result, it was considered unrealistic and potentially hazardous to ask cardiac patients to adhere to a test procedure developed in well trained and motivated subjects. Adopting a "symptom limited" measurement of $\dot{V}_{O_2}$ max[14 15] was inappropriate because these methods introduce a subjective endpoint whose reproducibility cannot be adequately examined.

An index based on submaximal exercise data was therefore necessary. Since the submaximal HR/$\dot{V}_{O_2}$ relation is constructed from relatively simple measurements and its linearity permits the application of conventional statistical techniques, it has formed the basis of several such indices. Both the slope of this relation and heart rates interpolated at a fixed submaximal oxygen consumption have been incorporated into separate indices of cardiorespira-fitness.[16 17] Neither index, however, had been validated in the terms required by this study. Furthermore, neither is a complete description of a relation which may alter in both slope and elevation.[16] An earlier investigation[9] showed this relation to be a valid index of cardiorespiratory fitness provided account was taken of the complete data relating to individual regression lines. The results of a single exercise test were also found to form an adequate baseline from which to follow alterations in cardiorespiratory fitness.

This index was therefore selected to follow sequential alterations from a postoperative baseline. This baseline reflected the combined effects of preoperative limitation of activity, surgical inter-vention, and postoperative immobilisation. It was not possible to state that individual patients showed an equal deterioration of cardiorespiratory fitness at this time; only that *changes* within a given patient would be detected. In addition, it was not possible to predict the nature of the mechanism responsible for these changes. It is of interest, however, that most of the patients with rheumatic heart disease and with mitral valve replacement in the control group failed to show a detectable improvement using this index. In contrast, most of the remaining patients with non-rheumatic heart disease continued to improve in the postoperative period. That recovery in the rheumatic heart is less satisfactory than that in the non-rheumatic heart has been documented in previous investigations using catheter studies and changes in cardiac output relative to oxygen consumption at rest and exercise[5 6]

ACCEPTABLE TRAINING PROGRAMME

A training programme for cardiac patients should allow individual prescription, be gently graded, safe, and cause minimal interference with normal daily routine. The 5BX/XBX exercise programme satisfied these criteria in normal subjects[9] and in patients with angina pectoris.[18] No complications attributable to training arose in the eight patients who undertook the complete training procedure. Several patients approached closely to the age related "goal level" of this programme but none actually achieved it. This may reflect an initial low level of fitness or an inability to attain targets predicted from normal individuals. The post-exercise heart rate after a training session (recorded over the first 20 s after exercise) was between 130 and 160 beats/min. Individual recovery heart rates first became higher and then consistent as training progressed. This finding illustrates the carefully graded nature of the exercise sequences.

Twelve weeks after the first postoperative exercise test the HR/$\dot{V}_{O_2}$ relation moved to the right in the control group, indicating an improvement in "cardiorespiratory fitness". This trend, however, was not maintained over the next 12 weeks, especially in patients with rheumatic heart disease involving the mitral valves. In contrast, patients in the test group, in the majority of whom the cause of either the aortic or mitral valve lesions was rheumatic heart disease, showed an additional improvement in cardiorespiratory fitness over the same period. This finding is consistent with the hypothesis that the 5BX/XBX programme improved the cardiorespiratory fitness of patients in the test group and this occurred against a background of "spontaneous" improvement in both groups over the first 12 weeks. Most patients with

rheumatic heart disease and with mitral valve replacement who did not participate in the training programme failed to maintain this improvement.

Therefore, successful insertion of a prosthetic valve did not result in sustained improvement in cardiorespiratory fitness 12 weeks after surgery but this was endowed by a suitable physical training programme. The improvement in the test group was reflected in a reported increase in normal daily activity compared with control patients. It is not known, however, whether this improvement will be maintained when regular physical training is withdrawn 24 weeks after operation.

SEQUENTIAL POSTOPERATIVE EXERCISE TESTS
A progressive limitation of exercise tolerance is a common presenting symptom of adult valvular heart disease. Functional disability is commonly graded in these terms, to lend a degree of "objectivity" to the assessment of individual patients (for example the widely used New York Heart Association classification).[19] Assessment by means of a formal exercise test is therefore a logical development,[20][21] particularly as discrepancies have been shown between the subjective account of symptoms and the results of exercise tests.[22] This approach has not been generally adopted, however, except as an adjunct to catheter studies. Similarly, pre- and postoperative exercise tests, to adjudge the efficacy of surgical intervention, have not been developed, though several recommendations have been made to this effect.[22][23]

The results of the present study emphasise the individual pattern of recovery observed after cardiac surgery. The timing of a sequence of postoperative exercise tests would therefore require careful consideration. A major reason patients gave for consenting to enter this trial was that an exercise test would help them find out "what I can do". This suggested that sequential postoperative exercise tests might play a useful role in the follow-up and counselling of these patients. The results in patients who developed postoperative complications supported this approach, though they were essentially anecdotal observations. A formal trial of exercise tests used in this manner, however, would indicate their value.

References

1 Working Party on Cardiac Rehabilitation. *J R Coll Physicians Lond* 1975; 9: 281–346.

2 Bassey EJ, Bennett T, Birmingham AT, Fentem PH, Fitton D, Goldsmith R. Effects of surgical operation and bed rest on cardiovascular responses to exercise in hospital patients. *Cardiovasc Res* 1973; 7: 588–92.

3 Carswell S. Changes in aerobic power in patients undergoing elective surgery. *J Physiol (Lond)* 1975; 251: 42–3P.

4 Andersen A, Hillestad L, Rasmusson K, Myhre E. The cardiac response to exercise in aortic valvular disease before and after ball valve replacement. *Acta Med Scand* 1971; 190: 251–5.

5 Bristow JD, Kremkau EL. Haemodynamic changes after valve replacement with Starr-Edwards prostheses. *Am J Cardiol* 1975; 35: 716–24.

6 Hildner FJ, Javier RP, Cohen LS, et al. Myocardial dysfunction associated with valvular heart disease. *Am J Cardiol* 1972; 30: 319–26.

7 Morgan JJ. Hemodynamics one year following mitral valve replacement. *Am J Cardiol* 1967; 19: 189–95.

8 Björk VO, Böök K, Cernigliaro C, Holmgren A. The Björk-Shiley tilting disc valve in isolated mitral lesions. *Scand J Thorac Cardiovasc Surg* 1973; 7: 131–48.

9 Kappagoda CT, Linden RJ, Newell JP. Effect of the Canadian Air Force training programme on a submaximal exercise test. *Q J Exp Physiol* 1979; 64: 185–204.

10 Kappagoda CT, Stoker JB, Linden RJ. A method for the continuous measurement of oxygen consumption. *J Appl Physiol* 1974; 37: 604–7.

11 Royal Canadian Air Force. *Physical fitness.* Harmondsworth: Penguin Books, 1964.

12 Snedecor GW, Cochran WG. *Statistical methods.* 6th ed. Ames, Iowa: Iowa State University Press, 1967: 432–6.

13 Åstrand PO. Quantification of exercise capability and evaluation of physical capacity in man. *Progr Cardiovasc Dis* 1976; 19: 51–67.

14 Gilbert R, Auchincloss JH Jr. Cardiac and pulmonary function at the exercise breaking point in cardiac patients. *Am J Med Sci* 1979; 257: 370–81.

15 Patterson JA, Naughton J, Pietras RJ, Gunnar RM. Treadmill exercise in assessment of the functional capacity of patients with cardiac disease. *Am J Cardiol* 1973; 30: 757–62.

16 Cotes JE. Rational exercise testing: the case for simple indices of submaximal exercise: ventilation, tidal volume and cardiac frequency. *Scand J Respir Dis* 1971; 77, suppl: 223–7.

17 Spiro SG, Juniper E, Bowman P, Edwards RHT. An increasing work rate test for assessing the physiological strain of submaximal exercise. *Clin Sci Mol Med* 1974; 46: 191–206.

18 Raffo JA, Luksic IY, Kappagoda CT, Mary DASG, Whitaker W, Linden RJ. Effects of physical training on myocardial ischaemia in patients with coronary artery disease. *Br Heart J* 1980; 43: 262–9.

19 New York Heart Association. *Nomenclature and criteria for diagnosis of diseases of the heart and blood vessels.* 5th ed. Boston: Little Brown, 1953; 112.

20 Nylin G. More recent developments of heart function tests. *JAMA* 1937; **109:** 1333–7.
21 Wyndham CG, Ward JS. An assessment of the exercise capacity of cardiac patients. *Circulation* 1957; **16:** 384–93.
22 Bergy GG, Bruce RA. Discrepancies between subjective and objective responses to mitral commissurotomy. *N Engl J Med* 1955; **253:** 887–91.
23 Gilmour DG, Spiro SG, Raphael MJ, Freedman S. Exercise tests before and after heart valve replacement. *Br J Dis Chest* 1976; **70:** 185–94.

Requests for reprints to Professor R J Linden, Department of Cardiovascular Studies, University of Leeds, Leeds LS2 9JT.