Results of Surgical Treatment of Aortic Stenosis

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Surgical treatment of aortic stenosis at Guy's Hospital started in February 1952, when Sir Russell Brock's first closed transventricular aortic valvotomy on an incapacitated general practitioner was a striking success. Baker and Campbell (1956) reported the results of the first 16 operations which had been performed between February 1952 and December 1954. In this pioneer stage six of these patients died at operation and only five were considered to have good results. This early report emphasized the difficulties and initial disappointments of aortic valvotomy compared with mitral valvotomy, which had so rapidly established itself as a standard operation. As expected, the results in the next 50 consecutive patients operated on between January 1955 and May 1958 were far better (Baker and Somerville, 1959). The operative mortality was 18% and more than half the patients had good or excellent results.

Experience with transventricular closed valvotomy in young patients with uncalcified aortic valvar stenosis had shown that it was not a suitable operation for this group of patients, for catastrophic aortic regurgitation was too often and too easily produced. "Open" operation, using hypothermia to 30° C. induced by veno-venous cooling (Ross, 1954), was therefore introduced. This allowed surgery of the aortic valve under direct vision for a period of up to nine minutes and was used in nine young patients operated on between January 1955 and May 1958. The results were unsatisfactory, with a high operative mortality due to uncontrollable ventricular fibrillation and the frequent production of severe aortic regurgitation (Baker and Somerville, 1959). This technique was therefore abandoned. In December 1958 open operation with heart–lung by-pass, which allows adequate time for surgery under direct vision, was first used for patients with uncalcified valvar stenosis, and in October 1959 it was used for patients with calcific aortic stenosis. Hypothermia and coronary perfusion were later incorporated into the technique.

We now report the results on the next 134 patients operated on between April 1958 and June 1963 making up a total of 200 patients with aortic stenosis surgically treated since February, 1952. The proportion of open operations has steadily increased and has embraced a wider group of patients, but closed transventricular valvotomy is still performed where age, poor general state, severe heart failure, or impaired renal function constitutes too great a risk for the use of by-pass. There has been no fixed surgical policy in regard to "open" or "closed" operation, and the decision in each individual patient has been made on the background of past results and the current risk in this advancing method of treatment. We have not included patients who have been treated by insertion of a homograft aortic valve (Ross, 1962) at the end of this period.

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Method of Presentation

The composition of the series of 200 patients is shown in Table I. They have been primarily divided, according to the anatomy, into 179 patients with valvar stenosis, 20 patients with subvalvar stenosis, and one patient with supravalvar stenosis. The patients with subvalvar and supravalvar aortic stenosis are discussed separately as they present a different clinical entity and surgical problem. The group of 179 patients with valvar stenosis has been further divided according to the type of operation (Table I). Of the 90 patients who had closed operations, we have excluded from discussion the first 16 already reported (Baker and Campbell, 1956). We have also excluded two young patients with uncalcified valves who had transventricular valvotomy, as these would now be treated by open operation. The results of closed transventricular valvotomy in the remaining 72 patients with calcific aortic stenosis are fully discussed and compared with the results obtained by open operation using heart–lung by-pass. Eighty-nine patients with valvar stenosis had open aortic valvotomy, but nine patients in whom limited hypothermia alone was used, included in our previous report, are excluded, as this operation is now obsolete. Eighty patients had open operation with heart–lung by-pass; 29 had uncalcified valves and 51 had calcified valves, and these are discussed separately.

TABLE I.—*Analysis of 200 Patients to Show Type of Obstruction Present and Type of Operation Performed*

Type of Obstruction		
Valvar		179
Subvalvar		20
Supravalvar		1
Type of Operation		
For valvar stenosis		179
Closed transventricular valvotomy (90)		
Baker and Campbell (1956) (not discussed)	16	
Uncalcified valvar stenosis (not discussed)	2	
Calcified valvar stenosis	72	
Open aortic valvotomy (89)		
Hypothermia (not discussed)	9	
By-pass; uncalcified valvar stenosis	29	
" calcified valvar stenosis	51	
For subvalvar stenosis		20
Closed operation	9	
Open operation	11	
For supravalvar stenosis: open operation		1

General Details

All the early operations were performed by Sir Russell Brock. Mr. Donald Ross operated on 10 of the first 100

cases, and the second 100 operations were approximately divided between the two surgeons. The technique of transventricular valvotomy has been fully described (Brock, 1957a). Open aortic valvotomy using heart–lung by-pass was frequently combined with reduction of the temperature to 27° C. Full-flow normothermic by-pass with coronary perfusion is the method which is now preferred (D. N. Ross, personal communication 1963). The refinements of surgical technique employed are not described, but some understanding of the problems involved is necessary. In patients with uncalcified valves, myxomatous masses are removed. Judgment is needed in opening the fused commissures, for if this is too radical inadequately formed cusps are left which cannot support the diastolic pressure. Calcific valves are mobilized by removing the calcium, and commissurotomy is then possible. Prosthetic cusp material was not inserted in any of the patients, but occasionally pericardial patches were used to support cusps or repair holes made during débridement.

All patients had " pure " aortic stenosis, by which we mean that aortic stenosis alone was the lesion from which they suffered and which required surgical treatment. We have excluded patients with moderate or severe aortic regurgitation and those with associated significant rheumatic mitral valve disease. The distinction between mild rheumatic regurgitation and functional mitral regurgitation secondary to left ventricular failure was often difficult. Patients with additional complicating congenital lesions were also excluded, except one patient aged 43 with calcific aortic stenosis, who had a coarctation of the aorta successfully resected nine years previously. A number of the patients had mild aortic regurgitation, as evidenced by an immediate diastolic murmur at the left sternal edge but without widening of the pulse pressure. This was commonly present in the patients over 50 with calcific aortic stenosis and in those with congenital subvalvar stenosis.

A post-operative follow-up was obtained on all the patients who survived operation. Those who had transventricular valvotomy were followed for one to eight years and those who had open valvotomy have been examined from six months to over four years after operation.

Sex and Age, and Aetiology

The sex and age distribution of the 179 patients with valvar stenosis is shown in Fig. 1. There were 145 males and

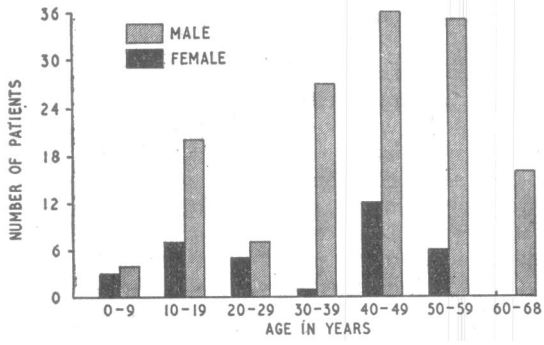

FIG. 1.—Sex and age distribution of 179 patients with aortic valvar stenosis.

34 females, a ratio of 4.3 : 1, which confirms the findings of others that aortic valvar stenosis is predominantly a disease of males. The age at operation ranged from 6 to 68 years, with a tendency to two peaks of maximum incidence; an early one below the age of 20 comprising the severe congenital group, and a later one between 40 and 50 where increasing calcification of the valve has intensified initially less severe stenosis which was either congenital or rheumatic. In this second group it is difficult to determine the aetiology when there is no evidence of rheumatic involvement of the mitral valve.

The majority of calcified valves at open operation or post-mortem examination look similar. There is fusion between the two coronary cusps, converting the valve into a rigid bicuspid mass with lumps of calcium in the cusps. The commissure between the two coronary cusps often appears as if it has always been rudimentary and has never properly separated the cusps by extending to the valve ring. Twelve of the 29 patients with uncalcified valvar stenosis had a basically tricuspid valve, so that the finding of this in the calcified group does not necessarily imply a rheumatic aetiology. We presume that the myxomatous masses of tissue present on the uncalcified valves provide the foundation for the exuberant calcification which ultimately distorts the anatomy and makes the cause so difficult to determine. Presumably the lesion is mild until progressive calcification, which increases with age, makes the obstruction severe, and causes symptoms. Similarly a mild rheumatic lesion may form the basis for later calcification (Lessof, 1958), but from the pathological anatomical appearance of the aortic valve it would appear that rheumatism is a less frequent cause of calcific aortic stenosis.

Evidence of Severity

All patients except one had severe stenosis, and it was considered that the prognosis without surgery was poor, and hopeless in those who had had left ventricular or congestive heart failure. We have previously described in detail the clinical features of severe aortic stenosis (Baker and Somerville, 1959) and have used the same five grades of disability.* Clinical evidence of left ventricular failure was found in 27 patients and 12 patients had been in congestive heart failure. The severity of the obstruction was primarily assessed on the clinical signs, in particular the pulse, the length of the systolic murmur, the delay in aortic-valve closure, and evidence of left ventricular hypertrophy. The finding of an anacrotic brachial pulse with prolonged upstroke time usually indicated severe stenosis in the patients over 30 with calcified valves, but the pulse was often so small that the delay in the upstroke was difficult to detect clinically. In the patients under 20 with uncalcified valves the pulse was often sharp and small but not necessarily anacrotic, and sometimes there was a marked difference between the two brachial pulses, the right pulse being sharp and the left delayed. In patients with uncalcified or lightly calcified valves where the aortic second sound (A_2) is audible, delay in aortic-valve closure can usually be heard and confirmed on the phonocardiogram. When this is delayed so that the second sound is single in all phases of respiration or split only in expiration—" reversed splitting "—stenosis is usually severe. Left ventricular hypertrophy was assessed by the thrust of the apical impulse, by the rounded contour of the chamber on the chest *x*-ray film, and by the electrocardiogram.

We have found that the electrocardiogram is the most useful single indication of severity, and the most reliable evidence of deterioration. The degree of left ventricular hypertrophy on the electrocardiogram has been graded 1 to 4:

Grade 1: Left ventricular hypertrophy indicated in chest leads (Sokolow and Lyon, 1949), but with normal ST segments and T waves.

Grade 2: Left ventricular hypertrophy, with ST segment depression or with flattened T waves in left chest leads.

*Grade of disability: (0) No symptoms. (1) Angina, syncope, or dyspnoea interfering with but not preventing normal activity. (2) Angina, syncope, or dyspnoea preventing normal activity and work. (3) Left ventricular failure. (4) Congestive failure.

Grade 3: Left ventricular hypertrophy, with ST segment depression and T inversion up to 5 mm.

Grade 4: Left ventricular hypertrophy, with ST segment depression and T inversion over 5 mm., or left bundle-branch block.

Pre-operative Investigation.—Confirmatory evidence of severe stenosis provided by left heart investigation, in almost all instances by left ventricular puncture (Brock *et al.*, 1956), was obtained in 80 patients. We think this is the safest form of left heart investigation in these patients, even when coronary disease is suspected or proved. Investigation of the haemodynamics of the left side of the heart is particularly indicated in three circumstances: in the young patient where symptoms are often absent and electrocardiographic evidence of severity is not so obvious as in adults; where subvalvar stenosis is suspected; and to assess the severity of the valvar stenosis when it is possible that coronary disease is an associated cause of disability. Angiocardiography was not often used, because withdrawal pressure records across the left ventricular outflow tract were usually adequate in establishing the site of obstruction when this was in doubt. Pressures and assessment or actual measurement of valve area at operation correlated well with findings obtained at pre-operative investigation. Patients were not investigated when the severity of the stenosis was obvious from clinical findings, particularly where the poor general state demanded valvotomy as an emergency and any investigation would delay this and carry an additional risk.

Results in Aortic Valve Stenosis

Criteria of Assessment

The results have been classed into three categories.

Operative deaths include those who died at the time of operation and those who did not survive to leave hospital.

Unsatisfactory results include those where stenosis was not satisfactorily relieved, where significant aortic regurgitation resulted, or where there was no distinct relief of disability. In many of these patients it would be misleading to call the result poor, for only partial relief of stenosis improves the prognosis, and regurgitation on the whole is better and longer tolerated than stenosis. The presence of significant regurgitation has been judged by a widening of the pulse pressure, and an increase in heart size of over 5% in the cardiothoracic ratio six months after operation. After open operation the result was judged to be unsatisfactory owing to regurgitation if the pulse pressure was over 50 mm. Hg, with a diastolic pressure below 70 mm. Hg, although both symptomatic and electrocardiographic improvement was often present. After closed operation in older patients significant aortic regurgitation was diagnosed if the pulse pressure was over 70 mm. Hg, with the diastolic pressure below 70 mm. Hg. Assessment of the degree of regurgitation is not considered to be reliable while the patient is still in hospital or early in convalescence, for the diagnostic signs may not appear until the patient resumes normal activity.

Good results, in which our criteria have differed according to the type of operation. When the surgeon is able to operate under direct vision with adequate time for reconstruction of the valve, it should be possible to achieve a better and more lasting result than with a closed procedure, and ideally the prognosis after operation should approach normality. Our assessment of a good result after open operation has therefore been critical. Clinical evidence of relief of symptoms was shown by the return of the pulse to normal, shortening of the systolic murmur, and an aortic second sound which became louder and less delayed. No significant aortic incompetence resulted from operation and the electrocardiogram improved within six to nine months. The sharp T-wave inversion in the anterior chest leads that occurs after valvotomy makes assessment difficult for at least six months. Milder changes (grades 1 and 2) of left ventricular hypertrophy have usually improved in this time, but with more severe changes (grades 3 and 4) improvement takes longer. We have found the ballistocardiogram a reliable guide in assessing the result early in the post-operative period (Deuchar, 1963). Our assessment of a good result after closed valvotomy has been less critical, for this is a palliative and emergency operation now reserved for those patients where the risk of surgery with by-pass is prohibitive owing to heart failure and a poor general state, particularly associated with impaired respiratory or renal function. The result is regarded as good if symptomatic relief of disability has been such that the patient was capable of normal activity or a return to work for at least one year. We have not been so critical of post-operative regurgitation and have not demanded electrocardiographic improvement.

Follow-up

The majority of patients have been examined at six-monthly intervals and the period of observation of good results is indicated in the tables of results. Confirmation of good results by post-operative investigation was obtained in a few patients but has been limited by the necessity of using this investigation for assessment of new patients or those with unsatisfactory results where a second operation was contemplated.

No patient who has had open operation for valvar stenosis has died during the follow-up period. A number of delayed deaths have occurred in patients who have had transventricular valvotomy and are included as "unsatisfactory" or "good" according to the post-operative assessment; these are mentioned separately in the text.

Open Operation for Uncalcified Valvar Stenosis

The pre-operative state of the 29 patients with uncalcified aortic-valve stenosis is summarized in Table II. Their ages ranged from 6 to 28 years, with the majority in age-group 10 to 20. Ten of the 13 patients who were asymptomatic had severe aortic stenosis and marked left ventricular hypertrophy. Elevation of the end diastolic pressure found at left ventricular puncture in some of these patients suggested a degree of impaired left ventricular function which in adults would be associated with considerable disability.

TABLE II.—*Pre-operative State of 29 Patients with Uncalcified Aortic Valvar Stenosis*

No symptoms	13
Symptoms (angina and syncope 4, angina 2, dyspnoea 4, syncope 2, minor syncope 4)	16

E.C.G. Changes	Grade 1	Grade 2	Grade 3	Grade 4
No. of patients	4	11	12	2

Fourteen patients had severe electrocardiographic changes of left ventricular hypertrophy (Table II). One of the four patients who were asymptomatic and had grade 1 electrocardiographic changes had milder aortic-valve stenosis than we would recommend for valvotomy at the present time. Left ventricular puncture in this patient revealed a peak systolic gradient of 35 mm. Hg, with a high cardiac output (cardiac index 3.7 litres/min./sq. m.). Severe obstruction may be present in these young patients in association with absent or minimal ST segment and T-wave changes, but these may rapidly worsen. We have also found that recently developed T-wave changes may regress with a period of rest before operation (Fig. 2).

The results of open operation on 29 patients with uncalcified aortic-valve stenosis are shown in Table III; the length of follow-up of the patients with good results is given in Table IV. Three (10%) died as a result of operation. One of these died from a fulminating chest infection, having been operated on too soon after influenza; the other two died from severe aortic regurgitation. A second operation to repair the aortic incompetence was performed on one patient who was in severe congestive heart failure for two months after the initial operation. He died with severe jaundice, which was attributed to halothane anaesthesia (Gordon, 1963). Unsatisfactory results, due to the production of significant aortic regurgitation, occurred in five patients (17%). In one a severe leak was satisfactorily repaired three years after the first operation. The other four patients with an unsatisfactory result have been followed for periods of six months to four years without the development of symptoms. These patients have been improved by operation, and it would be justifiable to claim them as good results from the electrocardiographic and symptomatic improvement. However, as we do not know the long-term prognosis, we consider that this degree of regurgitation must ultimately prejudice the result. Good results were obtained in 21 (72%) patients. The 16 who had symptoms pre-operatively obtained complete symptomatic relief, and the electrocardiogram improved within six months in all patients, and in six became normal. No evidence of deterioration from our strict criteria of a good result has occurred during the follow-up which extends to more than four years.

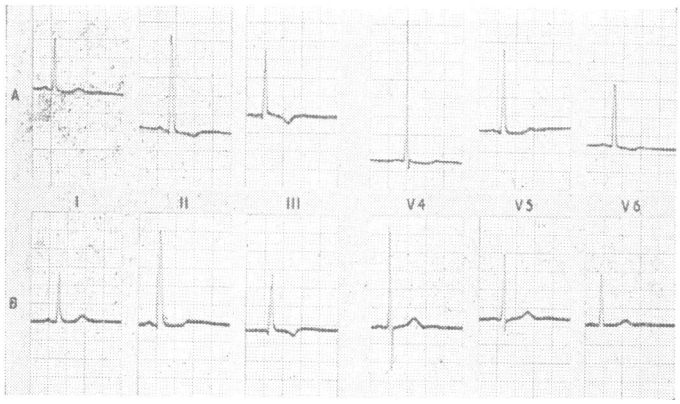

FIG. 2.—Pre-operative electrocardiograms from a patient with aortic valvar stenosis, showing improvement in T-wave changes with rest and restriction from athletics. A, 3 January 1963. B, 1 April 1963.

TABLE III.—*Results of Open Operation in 29 Cases of Uncalcified Aortic Stenosis*

No. of Cases	Age Range	Av. Age	Op. Deaths	Unsatis.	Good
29	6–28	13·7	3	5	21

TABLE IV.—*Follow-up Time in 21 Cases with Good Results*

Years	4	3	2	1	½
No. of cases	2	4	7	5	3

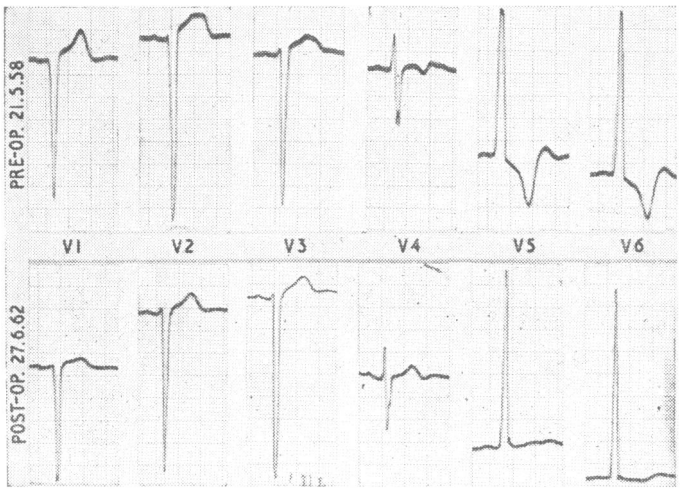

FIG. 3.—Electrocardiograms before and four years after open operation, showing marked improvement. The patient was a 19-year-old boy with very severe uncalcified aortic valvar stenosis.

The importance of relieving stenosis before severe electrocardiographic changes (grade 3 or 4) have occurred is illustrated in the case of a patient whose electrocardiograms are shown (Fig. 3). He has had an excellent symptomatic and electrocardiographic result, but the heart is still large, the apex beat diffuse in the anterior axillary line, and the pulse unusually small. There is no evidence of residual aortic stenosis, and it is thought that these clinical findings are due to impaired ventricular function resulting from an irreversibly damaged myocardium. Although no haemodynamic studies have been made on these patients it is likely that in some a persistently abnormal response to effort would be found, analogous to findings after adequate pulmonary valvotomy for severe pulmonary stenosis (Johnson, 1962). However complete the aortic valvotomy, left ventricular myocardial damage may persist if valvotomy is long-delayed and gross hypertrophy allowed to occur.

Open Operation for Calcified Valvar Stenosis

The pre-operative state of 51 patients with calcified valvar stenosis who had open operation is summarized in Table V, and the increasing severity of the disease with age is shown. Only 3 of the 20 patients under 40 years had been in left ventricular failure and none in congestive failure, while 11 of the 31 patients over 40 had been in heart failure. The electrocardiographic changes were not notably more severe in the older group, which suggests that their more marked deterioration was due to the general effects of increasing years and particularly to the development of associated coronary artery disease, which was unequivocally present in several patients.

TABLE V.—*Pre-operative State of 51 Patients with Calcified Valvar Stenosis Treated by Open Operation*

Age in Years	No. of Cases	Symptoms (Grade)				Electrocardiogram (Grade)			
		4 C.C.F.	3 L.V.F.	2	1	1	2	3	4
40 and under	20	—	3	11	6	0	2	17	1
Over 40 ..	31	2	9	17	3	1	4	21	5
Total ..	51	2	12	28	9	1	6	38	6

C.C.F. = congestive cardiac failure; L.V.F. = left ventricular failure. Electrocardiographic grades explained in text.

Severe symptoms and heart failure in an elderly patient with calcific aortic stenosis in the absence of severe electrocardiographic changes strongly suggests that coronary artery disease is present and may contribute or be largely responsible for their disability. It is, however, possible for stenosis to be wholly responsible for severe symptoms, with T waves in the left chest leads still upright; for this occurred in three patients—two aged 44 and one aged 45 who had been in left heart failure (Fig. 4). In all three an abnormally small pulse suggested severe aortic stenosis, and this was proved to be present at operation, and no evidence of coronary artery disease was found.

The results of open operation in 51 patients are shown in Table VI. The operative results when the valve is calcified

compare unfavourably with those of operations before calcification occurs (Table III). Sixteen patients died as a result of operation—an overall mortality of 31%. The age of the patients with calcific aortic stenosis influences the operative mortality, which is 42% in the patients over 40 and 15% in the younger group. Several factors account for this. Calcification increasing with age converts the valve into a rock-like mass which leaves little valve tissue for reconstruction, and this presents a difficult surgical problem necessitating a long period on by-pass. Age also increases the incidence of coronary disease, impaired renal function, respiratory

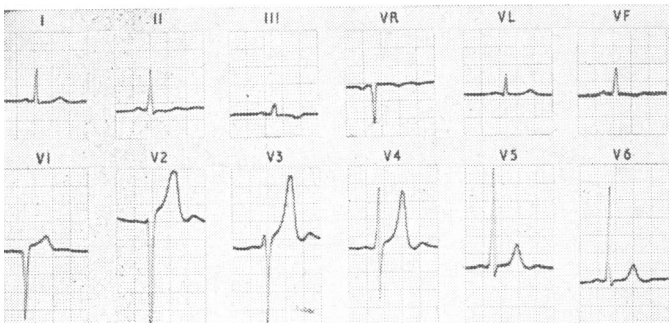

FIG. 4.—Pre-operative electrocardiogram from a patient with severe calcified aortic valvar stenosis showing upright T waves in the anterior left chest leads. He was a man aged 45 who had had angina and dyspnoea for eight years and two attacks of syncope. One attack of left ventricular failure was clearly documented. Pre-operative left ventricular puncture showed a peak systolic gradient of 180 mm. Hg. across the aortic valve. Open operation confirmed severe stenosis with aortic-valve orifice of 1 by 0.7 cm.

TABLE VI.—*Results of Open Operation in 51 Patients with Calcified Aortic Stenosis*

Age in Years	No. of Cases	Op. Deaths	Unsatis.	Good
40 and under	20	3	6	11
Over 40	31	13	2	16
Total	51	16 (31%)	8 (16%)	27 (53%)

insufficiency from chronic bronchitis and emphysema, and generalized arteriosclerotic changes. These factors not only add to the operative risk but must also influence the operative result. Irreversible ventricular fibrillation at operation or within the first 24 hours occurred in five patients and was associated with severe operative aortic regurgitation, long operating-time under by-pass, a poor myocardium, coronary artery disease, or a combination of these factors. This complication has become less frequent with increasing experience.

Anuria during the first week was responsible for three deaths in the first 20 cases, but the absence of this complication in the last 30 cases is probably due to a more conservative selection after assessment of renal function and greater care in pre-operative treatment, which includes a more restricted use of diuretics. It is relevant that four of the eight patients who died from these two complications had been in left ventricular failure. Four other operative deaths occurred, from haemorrhage in two, respiratory failure in one, and calcific cerebral embolism in the other. Four deaths occurred after the first week, in two due to ventricular tachycardia which occurred on the tenth and twelfth post-operative days, and in the third from endocarditis due to *Streptococcuus faecalis* probably secondary to unrecognized bilateral hydronephrosis. The fourth patient, aged 54, had complete heart-block and Adams–Stokes attacks for one year before operation, treated with steroids, and an internal pacemaker had been inserted. Open valvotomy adequately relieved his severe stenosis and sinus rhythm returned. He died in the post-operative period from perforation of small bowel and subphrenic abscess, presumably associated with continued steroid therapy. The operative mortality was, not unnaturally, highest in the early cases, but in the last 30 patients it has been 20%, which we regard as acceptable in a group of patients where the prognosis with supportive medical treatment is bad.

In the follow-up of the 35 patients who left hospital there have been no further deaths. The results in eight patients have been classified as unsatisfactory, two because relief of stenosis was not adequate, five because of significant post-operative regurgitation, and one because the patient is still incapacitated from a previous myocardial infarction despite good relief of aortic stenosis. The two patients with inadequate relief of stenosis were aged 22 and 39, and have undoubtedly been improved by operation: one of them, operated on during pregnancy, continued normally to delivery and has remained improved for three years; the other has returned to work without symptoms for two years. Of the five patients with regurgitation, one man aged 45 had post-operative endocarditis due to *Staphylococcus albus*; the other four patients (aged 34 to 39) have moderately severe regurgitation as the result of operation, but all have symptomatic relief and three have electrocardiographic improvement. As it is likely that the prognosis has been improved in this group of patients, it would not be unreasonable to regard them under good results, but we have classified them as unsatisfactory results in view of their relative youth and because we feel that future deterioration from either residual stenosis or the presence of regurgitation will occur, for which another operation will be needed.

We have no such reservations in the 27 (53%) patients whom we have classified under good results. Eleven of these patients were over 50 years and three were over 60. The pre-operative state and length of follow-up are shown in Table VII. Seven had been in heart failure, all but one had been disabled by angina, often with syncope, and one had in addition clear evidence of coronary artery disease. Although the follow-up period is of necessity short in some, the clinical and electrocardiographic improvement has been maintained in all.

TABLE VII.—*Follow-up Time and Pre-operative State of 27 Cases with Good Results*

	Follow-up Period in Years					Symptomatic State—Pre-operative (Grade)			
	4	3	2	1	½	4	3	2	1
No. of cases ..	2	5	9	7	4	2	5	19	1

Transventricular Valvotomy for Calcified Valvar Stenosis

The pre-operative state of the 72 patients who had closed transventricular valvotomy is shown in Table VIII. Congestive heart failure or a history of left ventricular failure was not common in the patients under 40 although the electrocardiogram was severely affected in 10 of the 14 cases. There was no evidence of coronary disease as judged by appearance of the coronary vessels and ventricle at operation in any of the younger group. These patients were all early in the series and would now be operated on with by-pass.

The 58 patients over 40 were in a more advanced stage of the disease. In many of these, closed operation was

TABLE VIII.—*Pre-operative State of 72 Patients with Calcified Valvar Stenosis Treated by Transventricular Valvotomy*

Age in Years	No. of Cases	Symptoms (Grade)				E.C.G. (Grade)			
		4	3	2	1	1	2	3	4
40 and under	14	1	—	12	1	1	3	9	1
Over 40 ..	58	9	15	32	2	1	5	44	8*
Total ..	72	10	15	44	3	2	8	53	9

* 4 of these patients had left bundle-branch block.

deliberately chosen because their poor general state constituted too severe a risk for open operation. Twenty-four had been in heart failure, a higher proportion than in the same age-group who had open operations (Table V). Thirty-two were considerably disabled by angina, syncope, or dyspnoea, often in combination, and symptoms were mild in only two patients. The electrocardiograms showed evidence of gross left ventricular hypertrophy (grade 3 and 4 changes) in 52 cases. Six patients had milder electrocardiographic changes, and in five of these macroscopic evidence of severe coronary disease in the vessels with infarction or fibrous patches in the myocardium was seen at operation, but in all of them significant aortic stenosis was present.

The results of closed valvotomy in 72 patients with calcified valvar stenosis are shown in Table IX. There were 12 (17%) operative deaths, either as a result of the production of aortic regurgitation or more often due to unrelieved aortic stenosis with a poor myocardium in the older group. Although adequate commissurotomy was often confirmed at necropsy, the petrified valves obviously continued to offer severe obstruction.

TABLE IX.—*Results of Transventricular Aortic Valvotomy for Calcific Aortic Stenosis. 72 Cases*

Age in Years	No. of Patients	Operative Deaths	Unsatisfactory	Good	Good : Det.*
30–40	14	3	4	7	5
41–50	24	3	12	9	4
51–68	34	6	12	16	4
	72	12 (17%)	28 (39%)	32 (44%)	13

* Good : Det. = Patients who had a good result and subsequently deteriorated.

The result was unsatisfactory in 28 patients (39%). Many of these obtained substantial clinical improvement for a time, but 21 died during the eight years of follow-up. Inadequate relief of stenosis was the main cause of an unsatisfactory result in 19 of the 28 patients; three of these died at subsequent open operation and one has had a good result from open operation. Significant aortic regurgitation occurred in nine patients; this was severe in five and moderate in four. In one other patient, aged 47, coronary artery disease was responsible for the continued symptoms and death one year after operation. Associated coronary disease contributed to poor myocardial function in at least three other patients. Post-operative complete heart-block added to the unsatisfactory result in one patient, and atrial fibrillation in six. Cerebral embolism at operation occurred in two patients; both made a complete recovery.

Thirty-two patients (44%) obtained a good result, and improvement in some was dramatic and maintained. Thirteen patients with good results deteriorated three to six years after operation and nine of these died, one from bacterial endocarditis, two following open operation, and six from heart failure. These patients who had good results usually remained well until left ventricular failure suddenly developed. In 19 patients a good result has continued for up to six years. Even when a good result is maintained, it is unusual for the electrocardiogram to show much improvement in patients who have had transventricular valvotomy, but this occurred in six patients (Fig. 5).

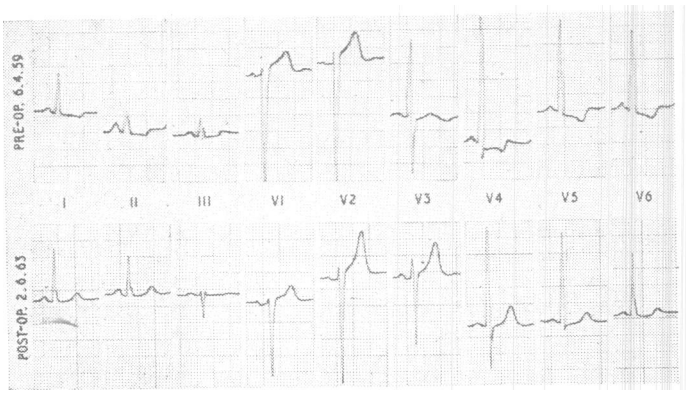

FIG. 5.—Electrocardiograms from a patient aged 44 years before and four years after transventricular aortic valvotomy for calcified valvar stenosis.

The operative results related to the pre-operative symptomatic state in the 58 patients over 40 are shown in Table X. The poor state of these patients is shown; 24 had heart failure, and in addition there were seven in this group with clear evidence of coronary artery disease. Despite this, 17 of 24 patients survived operation and 10 had good results. Transventricular valvotomy is surprisingly well tolerated in this group of patients, the majority of whom would not have survived open operation.

TABLE X.—*Results of Transventricular Valvotomy in Patients Over 40 Related to Pre-operative Symptomatic State*

Result	Symptomatic Grade			
	4	3	2	1
Operative deaths ..	6	1	2	—
Unsatisfactory	1	6	16	1
Good	2	8	14	1
No. of cases ..	9	15	32	2

Subvalvar Stenosis

General

Subvalvar stenosis was present in 20 of the 200 patients. All had severe obstruction of the outflow tract, and marked changes of left ventricular hypertrophy were present on the electrocardiogram in 18 patients. Disability was more pronounced with subvalvar stenosis than with valvar stenosis at the same age, and syncope was a more common and ominous symptom. Eleven patients were male and nine were female, a different sex incidence from the male predominance in valvar stenosis. This may suggest that different aetiological factors are present and that the two conditions should be clearly differentiated in any study of the genetic background of aortic stenosis. Only two of the patients were over 30, which demonstrates the rarity of subvalvar observation in the older patients with aortic stenosis and the relative frequency (over 50%) in patients under 30. Subvalvar stenosis is suspected when the brachial pulse is fast rather than slow rising, when an ejection click and post-stenotic dilatation of the ascending aorta are absent, when the systolic murmur is displaced towards the apex, and when no calcification of the aortic valve can be demonstrated in patients over 30 years. Investigation, by withdrawal tracings through the left ventricular outflow tract and sometimes also by angiocardiography, is indicated when the level of stenosis is in doubt. When the subvalvar obstruction is membranous and situated close to the attachment of the aortic-valve cusps, it may be difficult or impossible with pressure records to differentiate from valvar stenosis.

The exact type of subvalvar obstruction is important, for it influences the results of surgical treatment. We recognize three main types. The first is a thin membranous perforate diaphragm which is attached near the base of the aortic-valve cusps and is the most favourable for surgical treatment. The second is a fixed fibromuscular stenosis which usually occurs 1 to 2 cm. below the valve, where a fibrous ring obstruction protrudes like a shelf and appears as a thickened diaphragm surrounded by a muscular collar. Surgical relief of this obstruction is more difficult but should succeed, particularly if the muscular element is due to secondary hypertrophy of the outflow tract and there is no recurrence

of fibrosis. The third type of obstruction is due to a muscle mass that protrudes into the left ventricular outflow tract and causes a "functional" obstruction in systole (Brock, 1957b). This has also been described as pseudo-aortic stenosis (Berçu *et al.*, 1958), asymmetrical hypertrophy of the left ventricle (Teare, 1958), obstruction myopathy (Goodwin *et al.*, 1960), and hypertrophic subaortic stenosis (Braunwald *et al.*, 1960); it may occur as a familial disease. In this type, resection of the obstructing mass is difficult, and it is probable that the condition may recur through regrowth of muscle. Resection is feasible in the young, but in older patients the condition has usually been found to be inoperable and the operative risk is high.

Operative Technique

Eleven patients had open operation—two with limited hypothermia and nine with heart-lung by-pass. Three had a diaphragmatic type of stenosis near the aortic valve, and in two this was clearly interfering with complete valve-closure. Seven patients, including one woman aged 42, had a fibromuscular fixed stenosis with a shelf of fibrous tissue, 1 to 2 cm. below the valve, which was excised; this was followed by dilatation of the outflow tract with expanding dilators. One patient had an obstructive myopathy.

In the other nine patients closed transventricular dilatation of the outflow tract was performed and was often combined with infundibular punch resection of the muscle and fibrous collar in the outflow tract. The lesion was not, of course, seen at operation, but the type of obstruction was thought to be diaphragmatic in one patient and fibromuscular in eight patients; in no patient was it considered to be of the "functional" type.

Operative Results

The results are summarized in Table XI. There were four operative deaths: two patients who had closed operations died of unrelieved fibromuscular stenosis; in the third patient, a woman of 40, an attempt to resect a diffuse obstructive myopathy at open operation failed; in the fourth patient, a girl of 17, with severe left ventricular hypertrophy, there was a successful resection of a discrete fibromuscular stenosis under hypothermic by-pass to 28° C. without coronary perfusion, but she died three days later from ventricular fibrillation.

TABLE XI.—*Results of Operation on Subvalvar Aortic Stenosis*

Type of Operation	No. of Patients	Operative Deaths	Unsatisfactory	Good
Closed ..	9	2	7	0 (4†)
Open	11	2	3*	6 (1†)
Total ..	20	4	10	6

* One patient died a year after operation.
† Initially classed as good but subsequently assessed as unsatisfactory owing to deterioration in the electrocardiogram.

After closed operation none of the seven patients who have been followed up for four to eight years are now classed as good results. In six the electrocardiogram has deteriorated, while the seventh, who developed a left bundle-branch block, has shown a progressive increase in heart size; three of the patients have had a return of symptoms. The deterioration in four of these patients occurred after they had been critically classed as good results, having had marked reduction in their pressure gradients at operation and initial improvement in the electrocardiogram, particularly striking in two. In two of these, recent left ventricular puncture has shown peak systolic gradients of 22 and 44 mm. Hg, with normal cardiac output, and in the second of these angiocardiography did not demonstrate an abnormality in the outflow tract.

After open operation the results appear better, for in six out of eight patients these are considered to be good. Three patients with a membranous diaphragmatic stenosis have maintained symptomatic and electrocardiographic improvement for six and three years and one year respectively. The other three patients had fibromuscular stenosis; one, a woman aged 42, developed permanent left bundle-branch block at operation but is clinically a good result, while the other two have shown both clinical and electrocardiographic improvement. The period of follow-up in these three patients is only two years, which is short compared with two other patients who had open operation—a woman of 30 and a boy of 11, followed for two and six years respectively—who showed deterioration after initial improvement and are now classed as unsatisfactory results. The third patient classed as an unsatisfactory result was a 7-year-old boy with a Wolff-Parkinson-White syndrome who died in an attack of paroxysmal tachycardia three years after operation; necropsy showed only partial relief of the subvalvar stenosis with a fibrous obstruction 9 mm. across near the site of the original resection. We are particularly concerned about the boy aged 11, mentioned above, whose symptoms returned three years after operation and whose electrocardiogram deteriorated after initial improvement (Fig. 6). Left ventricular puncture five years after operation showed only a 27-mm. Hg systolic gradient at a subvalvar level, which is in keeping with that found in the two patients who were studied following deterioration after closed operation.

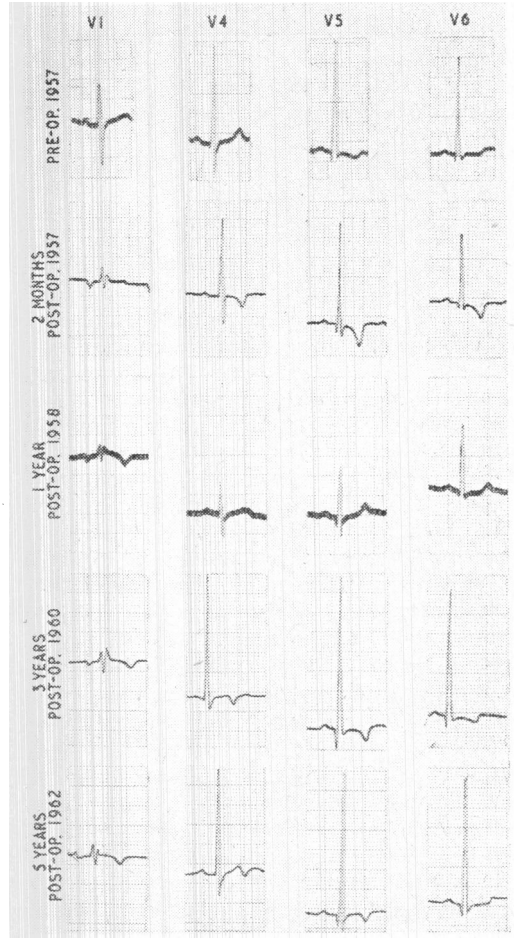

FIG. 6.—Serial electrocardiograms before and after open operation for fibromuscular subvalvar stenosis. The patient was aged 11 at time of operation.

It is difficult to explain these findings when it appears that stenosis has been relieved and yet the patient shows signs of deterioration. It is possible that fibrosis in the outflow tract may re-form ; this has in fact been proved in one patient, not in this series, in whom a second resection of a discrete fibromuscular stenosis was done four years after a previously successful open operation (Sir Russell Brock, personal communication 1963). It is possible that some of these patients have developed a functional obstruction which may only become severe with effort and is not apparent in haemodynamic studies in a resting and basal state. It may also be possible that this apparently discrete stenosis is part of a diffuse cardiomyopathy, whose relentless course is only temporarily arrested by surgery

Supravalvar Stenosis

One patient who had supravalvar stenosis had the same facial characteristics and mental retardation previously described (Williams *et al.*, 1961). Open operation with by-pass was used, but the stenosis could only be partially relieved owing to marked hypoplasia of the aorta.

Discussion

Aortic stenosis is by no means an uncommon form of heart disease and may escape recognition. It may present as a severe lesion at any age, and the prognosis is poor unless the obstruction to the circulation is relieved by operation. The surgical problem is a difficult one, but this critical review of the results over the last 10 years has shown a continued advance towards its solution. We think that this advance is now rapid and that in the future the proportion of good results will increase. This will depend not only on advances of surgical technique and experience but on recognition that this treatment is possible, so that patients are referred and selected for operation before the optimum time for surgery is already passed. It is therefore proper to state our present views on selection of patients, though these will certainly change with increasing evidence from the results of future treatment and a longer follow-up of patients already treated.

In young patients with uncalcified valvar stenosis the operative risk is small—currently 5%—so that we have no hesitation in advising operation if stenosis is severe. Good results are now obtained in at least 75% of these patients and the immediate improvement in prognosis is obvious. A much longer period of observation is needed to establish the long-term benefits of surgery, for the results will be influenced by the development of valvar calcification and restenosis ; the risk of bacterial endocarditis will still be present. In view of the uncertainty about the future and the danger of producing aortic regurgitation, particularly in the patient with a bicuspid aortic valve, we do not advise prophylactic surgery when the stenosis is not severe. Doubt about severity should always be resolved by left heart investigation. We have also stressed the importance of not delaying operation until severe electrocardiographic changes have occurred, for it is then possible that the left ventricular myocardium may be irreversibly damaged, resulting in continued impairment of function. We consider that it is important to restrict activities by stopping competitive sport in any patient who has significant aortic stenosis. Exercise causes further rise in pressure, which must provide a stimulus to develop left ventricular hypertrophy, for it is in these young patients who are allowed and even encouraged to be athletic that the most extreme left ventricular hypertrophy occurs, and this prejudices the result of good surgery.

In young and middle-aged adults with calcified valves the operative risk is greater but is diminishing, and the current mortality under the age of 40 is about 15%. Relief of stenosis is more exacting and reconstruction of the valve after removal of calcified tissue is more difficult. A diminishing incidence of unsatisfactory results in these patients shows that this technical problem is being solved. In view of the poor prognosis where stenosis is severe we advise open operation in most patients under 50 rather than a closed procedure, which is a palliative operation and cannot offer adequate benefits to these relatively young patients.

A more difficult decision arises with patients over 50, often in heart failure with heavily calcified valves, for the current mortality with open operation is about 35%. Very careful assessment, particularly of respiratory and renal function, is needed before a decision is made, and the risk can be reduced by a period of rest and medical treatment. Coronary artery disease is often present but is no contraindication to surgery provided severe stenosis is present, though it may limit the improvement and the life expectancy after operation. As surgical treatment advances it will be possible to offer a higher proportion of these patients open operation at a reasonable risk.

A direct comparison of the open and closed operations for calcific aortic stenosis cannot be made from the overall figures. Not only is the follow-up period after transventricular valvotomy much longer, which allows more time for cases to deteriorate, but also the number of patients who had been in heart failure is far higher in the group who had closed operation. We consider that there is still a place for closed transventricular valvotomy in selected cases with intractable heart failure, impaired renal function, or the degenerative changes of old age. Our results show that these patients may gain great symptomatic relief from this operation, with a lower operative mortality (18%) than open surgery (35%) in this type of case. This operation halts the downward course of the disease, and in some cases improvement may be sufficient to make open operation possible, with the prospect of a more lasting result.

Our views on the surgical treatment of subvalvar stenosis are unformulated. There is as yet insufficient knowledge of the disease, too small experience of open operation, and too short a follow-up to assess results in the variable type of obstruction found. It would seem at present that two factors —fibrosis and the muscular element—will determine the ultimate success of surgical treatment. Fibrosis in the outflow tract may recur and cause obstruction as a result of scar tissue forming at the site of previous resection. Muscular hypertrophy secondary to a diaphragmatic type of obstruction should resolve and good results should be expected, provided that fibrosis does not recur or the myocardium has not been irreparably damaged before relief is given. Obstruction due to a primary myopathy may well be a progressive disease, and in these cases surgical relief in the early stages may be of temporary benefit but in the later stages impossible.

Summary

The results of the surgical treatment of aortic stenosis at Guy's Hospital from February 1952 to June 1963 are reviewed.

The pre-operative state of the patients is outlined and the criteria for assessment of operative results are described.

In 29 patients with uncalcified aortic stenosis treated by "open" operation the mortality was 10% and good results were obtained in 72%, without subsequent deterioration in the follow-up.

In 51 patients with calcific aortic stenosis treated by open operation the overall mortality was 31% ; in the last 30 patients it was 20%. Good results were obtained in 53% without deterioration in the follow-up.

In 72 patients with calcific aortic stenosis treated by "closed" transventricular valvotomy the mortality was 17% and good results were obtained in 44%.

In 20 patients with subvalvar stenosis the operative mortality was 20% and initially good results were obtained in 55%, but deterioration in the follow-up reduced these to 30%.

The present position and future prospects of surgical treatment are discussed.

We are particularly indebted to Sir Russell Brock, who initiated the surgical treatment of aortic stenosis, and to him and to Mr. Donald Ross for co-operation and encouragement in assessing their results. We are grateful to all the physicians who have referred patients and helped us in the follow-up, and especially to Dr. Lawson McDonald, who referred 19 patients from the National Heart Hospital. We thank Mr. Frank Muir and Miss Sylvia Treadgold, of Guy's Hospital, and Miss Nicolette Larbey, of the National Heart Hospital, for their help with the figures.

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Relationship Between Aortic Plaques and Age, Sex, and Blood Pressure*

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The intimal surfaces of aortas removed at necropsy show a wide variety of disease patterns, and many attempts have been made to correlate these variations with such factors as the age, sex, and blood-pressure level of the patients. Widely divergent results have been obtained, but much of this confusion has arisen because of imprecise definitions of the various lesions observed, and because of the inaccuracy of visual grading methods (Cranston *et al.*, 1963). We have determined the extent and type of disease in the aortas of a sample of hospital necropsies by a tracing and planimetry method, and report here the relationship between these findings and the age, sex, and arterial pressure of the patients from whom the aortas had been obtained.

Material

Unselected Necropsy Sample.—During the period of study the aorta was removed from every fifth patient aged 35 and over and from every patient aged 15–35 on whom a necropsy was carried out at the Radcliffe Infirmary, Oxford. This unselected sample of the hospital necropsies comprised 336 patients, 195 men and 141 women. For each of these patients the age, sex, and blood-pressure were recorded from the case-notes. If the pressures thus obtained were of doubtful validity, as in cases of haemorrhage, cardiac infarction, or stroke, the patient's general practitioner was asked if the pressure had been measured by him or recorded by any other examining doctor (for life assurance or at hospital visits) in the 12 months before death. Patients with invalid case-note pressures, and with no pressure recordings in the year before death, were omitted from the studies on the relationship between disease and blood-pressure. There were 75 such patients—42 men and 33 women.

Patients with Cardiac Infarction.—During the period of study a consecutive sample of patients with cardiac infarction was being collected for studies on the heart muscle and arteries (Mitchell and Schwartz, 1963), giving 116 patients (82 men, 34 women) whose aortas could be compared with those of the unselected series. Of these, 47 men and 12 women had blood-pressure recordings which were considered to be valid for analysis.

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Methods

Preparation of Aortas.—Each aorta was removed, stripped of periadventitial debris, opened longitudinally along its anterior wall, and washed in 0.9% sodium chloride solution. It was then cut transversely at the level of the first paired intercostal arteries and at the bifurcation, the segment between these points being retained for assessment and fixed in 10% formalin.

Staining.—The segments were washed in tap-water, blotted dry, and immersed, intimal side upwards, for 15 minutes in a 0.5% solution of Sudan IV (Gurr), the solvent consisting of equal volumes of 70% ethanol and acetone. After staining, the segments were transferred to 80% ethanol for 25 minutes, then to fresh 80% ethanol until differentiation was complete, the normal areas of the aorta being unstained or only faintly pink, while the fatty lesions were deep red. The segments were then washed in running tap-water for an hour.

Tracing.—The aortas were placed on a wooden board and covered with a large sheet of waterproof tracing material which was completely transparent when wet (Kodatrace). This was pinned firmly to the board, thereby flattening the aortic segment, and the board with its attached paper and aorta was placed in a tray and covered with water. If the thoracic aorta was ballooned and would not readily flatten, a longitudinal midline incision was made in the expanded segment to enable it to be pinned out. The outline of the whole segment, and the boundaries of all the lesions were then traced with a pencil. Four types of plaque were recognized: (1) flat sudanophilic—fatty streaks; (2) raised sudanophilic; (3) raised non-sudanophilic—fibrous plaques; (4) complicated—plaques showing ulceration, thrombosis, haemorrhage, or calcification. Different symbols were used on the tracing to denote the four types of plaque.