INFUNDIBULAR RESECTION OR DILATATION FOR INFUNDIBULAR STENOSIS

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The relief of pulmonary valvular stenosis by valvulotomy was reported in 1948 (Brock, 1948) and the results in 33 cases have now been considered more fully (Brock and Campbell, 1950). Pulmonary valvular stenosis may occur as an isolated lesion (often with a patent foramen ovale) or as one of the components of the tetralogy of Fallot. In most cases of Fallot's tetralogy the obstruction is not at the valves but in the infundibular portion of the right ventricle and hence may conveniently be named infundibular. The Blalock-Taussig operation short-circuits the stenosis by anastomosing a systemic to a pulmonary artery; its brilliant success must not distract us from considering relief of the infundibular stenosis by direct operation, because if this could be achieved it would mean that the blood-flow to the lungs would be improved, without introducing the complications that may arise from the more complex procedure.

The arguments in favour of a direct attack on the obstruction, whether it be valvular or infundibular, have already been considered (Brock, 1948, 1949) and will not be elaborated here. In the second paper the problem of relieving the infundibular obstruction by operation was presented and brief mention was made of successful operations in 5 patients. The object of this paper is to record the results in the first 11 patients treated in this way; they were operated on before July 1949 after which the absence of one of us abroad caused a three month's hiatus that provides a convenient occasion for follow-up.

The nature of the obstruction in infundibular stenosis is not well understood and is generally assumed to be quite unfavourable for relief by operation. A matter of such importance should be settled by careful first-hand observation of the anatomical changes present: only in this way is it possible to decide whether direct operation is feasible and what form it should take. A brief account of the nature of the obstruction was given in the paper mentioned above and a fuller description will be published separately. This paper deals with the results of the operation.

The infundibular stenosis is usually strictly localized, often forming a thin annular constriction, sometimes almost diaphragmatic. The diagrams in Fig. 1 convey the general form of the most easily recognized types; the obstruction may be situated just below the valves (high infundibular) or at varying levels lower down. Dilatation occurs distal to the obstruction and, unless this is too near the valves, a chamber is formed which may be quite large; if the wall of this "infundibular chamber" is deficient in or quite devoid of muscle a more or less prominent bulge is formed on the surface of the ventricle, and may be of great value in diagnosis of the level of the obstruction. The muscle in the wall of the chamber is never as thick as that in the ventricle below the obstruction but when the muscle does extend to the valve level the chamber is less prominent on the surface of the heart (Fig. 1F), although it still forms a space within that may sometimes be quite large.

Direct operative relief of the infundibular obstruction serves a double purpose. It can certainly increase the flow of blood to the lungs along the pulmonary arteries; it may diminish the right-to-left shunt through the interventricular septal defect and into the over-riding aorta. With a high

FIG. 1.—Diagrams illustrating the commoner types of infundibular stenosis. In (A) there is a high degree of pulmonary hypoplasia with a bicuspid valve and stenosis lying just below the valve in a narrow muscular channel. In (B), the commonest type, there is a high infundibular chamber with a very thin fibrous wall. In (C) there is a small infundibular chamber with a very thin fibrous wall. In (D) the thin-walled infundibular chamber is large. In (E) and (F), two types of infundibular stenosis are shown, similar to those in (C) and (D), except that the outer wall of the infundibular chamber is muscular.

degree of obstruction to its outflow the powerful contractions of the obstructed right ventricle must force the blood via the alternative route into the aorta. If the obstruction is relieved more of the ventricular output should pass to the lungs and less to the aorta, as illustrated in the diagram in Fig. 2, and by the figures for the arterial O_2 saturation in Table II.

The feasibility of direct relief of the infundibular stenosis by open operation must be settled by practical experience: it is certainly possible for this is shown by the cases on which we have operated. Whether the good results that have followed will be maintained, time alone will tell. We report our experience in order to record the present position. Improvements in technique will no doubt enable the obstruction to be dealt with more efficiently, but so far, even in these few cases, the results have been good enough to encourage further efforts and trials.

FIG. 2.—Diagrams illustrating the importance of the degree of pulmonary stenosis in determining the amount of right to left shunting that occurs in the presence of an over-riding aorta. In (A) there is pulmonary atresia, and all the blood passes into the aorta. In (B) there is a high degree of pulmonary stenosis and most of the blood from the right ventricle enters the aorta. In (C), in which the pulmonary stenosis is less or has been relieved by operation, more blood enters the pulmonary artery and correspondingly less escapes into the aorta. In (D), in which there is no pulmonary stenosis, there is much less mixing.

THE DIAGNOSIS OF INFUNDIBULAR STENOSIS

Infundibular stenosis occurs, with a few exceptions, as a part of the tetralogy of Fallot or much less commonly with transposition of the great vessels. Both Peacock (1886) and Keith (1909) describe cases of pure infundibular stenosis with no septal defect; in all of these the obstruction was low and a chamber of considerable size was present. We have, so far, not encountered infundibular stenosis as an isolated lesion, though in Case 6 we thought it much the most important of the defects. The first step in its recognition is, therefore, the diagnosis of the tetralogy of Fallot. Differentiation from pure pulmonary valvular stenosis should not be difficult, and careful studies by cardiac catheterization and angiocardiology should confirm this: the post-stenotic dilatation of the pulmonary artery is one important diagnostic feature, although on occasions a high infundibular stenosis may mimic this.

FIG. 3.—(A) Teleradiogram, and (B) angiogram at 3 sec., from Case 2. In (A) there is some prominence in the pulmonary region and (B) shows that this is a large infundibular chamber above the stenosis, this chamber forming a considerable part of the left border of the heart shadow.

The diagnosis is made most easily when the stenosis is some distance below the valves and a large infundibular chamber is formed. This makes a projection on the left border of the heart (Fig. 3A and 4A) which can be brought into greater prominence in the right anterior oblique position (Fig. 8). Angiocardiology can display the chamber perfectly (Fig. 3B and 4B) even when it is not large enough or hardly large enough to show on plain radiographs (Fig. 6 and 7). As these illustrations show its size and shape are very varied, and other examples have been given by Campbell and Hills (1950). Cardiac catheterization may also provide valuable confirmation if the sudden drop in pressure occurs at a level below that of the valves and within the ventricle (Fig. 5). The greatest difficulty in diagnosis arises when no chamber, however small, can be recognized by angiocardiology, for the distinction between a very high infundibular and a valvular stenosis may then be impossible before the heart is displayed at operation. The final diagnosis must always be made or confirmed actually at operation, and with increasing experience we find that this is always possible when the heart and pulmonary artery are examined after opening the pericardium.

FIG. 4.—(A) Teleradiogram, and (B) angiogram at 3 sec. from Case 3. The infundibular chamber produces the smaller prominence on the left border in the teleradiogram. In the angiogram it is even more clearly separated from the other shadows and the shadow of the pulmonary artery can be seen above it.

FIG. 5.—Radiographs of catheter *in situ* during catheterization. (A) In the infundibulum, (B) just below this, in the right ventricle, where pressure recordings showed there had been a sudden increase of pressure. (Reference No. 0034).

FIG. 6.—(A) Teleradiogram, and (B) angiogram at 3 sec., from Case 1, where the infundibular chamber, well seen in (B), cannot be made out in (A), possibly because it is obscured by the severe scoliosis. The stenosis is higher in this case and the dilatation continues to affect the pulmonary trunk.

FIG. 7.—(A) Teleradiogram and (B) angiogram at 2 sec., from a boy with Fallot's tetralogy (Case P023) where the infundibular chamber was hardly visible on the teleradiogram, beautifully demonstrated on the angiogram, and confirmed post-mortem. The outflow tract of the right ventricle is often displaced to the left as in this case, so that it runs almost horizontally instead of more vertically, but the variations are very great.

FIG. 8.—Right anterior oblique views from the same patients as Fig. 3 and 4, showing that the prominence of the infundibular chamber can also be seen in this position. (A) Case 2, (B) Case 3. The prominence, especially in (B), might suggest the presence of mitral stenosis but the barium in the œsophagus shows there is no backward enlargement of the left atrium.

When the obstruction is low down, the post-stenotic chamber is clearly seen and the pulmonary artery, even though small in size, is normal in contour—a cylindrical tube with normal sinuses of Valsalva. Gentle palpation will confirm that the thrill originates well below the valves and actually within the cavity of the right ventricle.

When the obstruction is higher, e.g. 1–2 cm. below the valve level, there is again no difficulty because the small tense infundibular chamber usually has very thin walls and stands out prominently in systole; indeed, it can usually be seen and felt quite easily through the intact pericardium. The pulmonary artery presents normal sinuses of Valsalva and palpation confirms the level of the thrill well below the valves.

When the obstruction is a high infundibular one, immediately below the valve level, there may be more difficulty, and in one or probably two of our earlier cases a high infundibular was mistaken for a valvular stenosis. The most helpful feature is study of the sinuses of Valsalva; if these are present, even though dilated, an infundibular stenosis is almost certain. The sinuses and, indeed, the first part of the pulmonary artery may, however, share in the post-stenotic dilatation when the obstruction is just below the valve level, and the greater part of the pulmonary artery will be cylindrical, the bulge at its base resembling the swelling of a drum stick; careful inspection usually reveals slight indications of the separate sinuses.

When the stenosis is valvular, it is more common to observe the whole trunk of the artery dilated and its diameter smallest at its actual origin. This finding is constant when the valvular stenosis is pure but less so when it is part of Fallot's tetralogy. The final test comes by feeling lightly for the

valves; if the cusps are fused so as to form a conical projection or diaphragm, this structure can be felt with the finger tip in systole and the jet-like issue of blood is also felt to originate within the lumen of the artery from the summit of the cone or diaphragm, and it can be momentarily obliterated by pressure at the exact site of origin. Moreover, if the origin of the artery is lightly compressed between finger and thumb the conical projection itself can be easily and convincingly palpated. This, of course, allows a diagnosis of infundibular stenosis to be excluded, except as a concomitant lesion.

We have seen several cases in which valvular and infundibular stenosis co-existed and this must always be thought of. In one of two recent cases the diagnosis was suggested at cardiac catheterization by the finding of two levels at which the pressure dropped in two stages. In both the valvular stenosis was the more severe but the infundibular obstruction was severe enough to need relieving. Clearly a routine exclusion of a co-existing valvular and infundibular stenosis must be made: even if a severe and obvious infundibular stenosis is present, the valve level must be inspected and an instrument passed through into the pulmonary artery at cardiomy.

The final confirmation is made actually at cardiomy when the presence and level of the obstruction is verified by the passage of appropriate instruments or even by insertion of a finger into the heart.

OPERATIVE DETAILS

If a direct attack on the pulmonary stenosis is contemplated the operative approach should be from the front. It is, of course, possible by using an anterior incision to perform either cardiomy or Blalock's operation. Our own preference when a systemic-pulmonary anastomosis is planned, is for a long postero-lateral incision. We have, on nine occasions, performed right ventricular cardiomy (twice for infundibular, and seven times for valvular stenosis) through a postero-lateral incision, but this is not always possible and is liable, at the least to be awkward. On one occasion when a valvular stenosis was found, the postero-lateral incision was closed and anterior thoracotomy performed three weeks later for valvulotomy. In general, therefore, an important decision has to be made whether to use an anterior or postero-lateral approach.

The preliminary details are exactly as described for pulmonary valvulotomy. Intravenous procaine is given; a curved inframammary incision is used with detachment of the pectoral muscles from their lower costal attachment. The steps of injection of procaine into the pericardium and into the wall of the ventricle are just the same.

In all our earlier cases the right ventricle has been incised and entered *below* the level of the obstruction, that is below the limit of the infundibular chamber. There was no difficulty in recognizing this level because our earlier cases were selected in view of the easily demonstrated large chamber; it was felt that this allowed plenty of clearance to work below the valves so as not to endanger them. In these cases the wall of the chamber was extremely thin and nearly devoid of muscle so that the dark blood could easily be seen through it. The thinness of the wall did not invite interference and we were glad to avoid it and to enter the heart well below it where the muscle was thick. If the chamber is of large or moderate size a low incision has the disadvantage of making it necessary to introduce the instruments so that they curve abruptly round and forwards to engage in the ostium of the chamber; this is a difficult and unsatisfactory manœuvre. There is no doubt that if the thickness of the muscle wall of the infundibular chamber allows it the incision should be made *into the chamber itself above the stenosis* which is then approached from above. This, of course, is not possible if the stenosis is only a short distance below the valves. In a recent case we incised the chamber itself in this way and were able to relieve an infundibular stenosis below and then change direction and perform a pulmonary valvulotomy above.

Generally, the ventricular wall is incised and a small probe passed to confirm the presence and level of the obstruction. For this purpose we have also a special shouldered probe. A special punch is now inserted, opened and directed through the stenosis (Fig. 9). The fibrous ring

snaps back into the narrow part of the punch between the cutting edges and when the instrument is closed the resected portion of tissue is held secure and is withdrawn with the instrument. In this way we have been able to resect almost the whole circumference of the stenosed area (Fig. 10), or the resection has been made by a number of separate bites (Fig. 11). Three punches are available, their diameters being 0.7 cm., 1 cm., and 1.25 cm. The punch, when closed, can also be passed up to the valve level to ascertain the presence of a valvular obstruction or to demonstrate a free passage into the pulmonary artery. In several cases the little finger has been inserted and used to palpate the stenosed area and to dilate it further.

FIG. 9.—Curved infundibular punch that is inserted through an incision in the wall of the right ventricle; it is then opened and passed through the stenosis which engages in the recessed portion between the cutting blades. As the instrument is closed, all tissue between is punched out and is retained within the instrument as it is withdrawn. Three sizes are available (0.7 cm., 1.0 cm., 1.25 cm.).

The set of three sizes is made by Mr. R. Schranz of the Genito-Urinary Manufacturing Company Limited, 28a Devonshire Street, London, W.1.

In two patients (Cases 4 and 6) it was not possible to secure any tissue with the punch, which seemed to slip through the stenosis easily. Palpation with the finger confirmed a narrow almost linear fibrous ring that was only slightly raised; it had been readily dilated by the instrument and was further dilated by the finger without difficulty. In both, good results have followed and, indeed, in one of them (Case 4) the result is excellent and impressive. It is remarkable and, indeed, satisfactory that this can be achieved by simple *dilatation without resection*. Hence the title of this paper includes infundibular dilatation.

When one contemplates the morbid anatomy it is not so surprising that a good result should sometimes follow simple dilatation, at any rate in childhood. The infundibular portion of the ventricle, though small, consists of good muscle tissue with a certain amount of thickened fibrous lining in one place. This fibrous ring not only serves as an obstruction to the flow of blood but also tethers the ventricular wall. When one examines the ring in a child's heart, this is evident and, furthermore, the fixation of the ventricular walls may prevent their proper development as the

FIG 10.—Two views of the tissue resected from Case 1. Almost a complete circle has been removed round the small central ostium. The covering of shiny thickened endocardium is well shown. A long tag of muscle has come away with the circular punched-out portion. On the left, viewed from the side; on the right, viewed from above.

FIG. 11.—The five fragments of the infundibular obstruction removed from Case 2. The shiny white areas are covered with thickened fibrous endocardium, and the darker areas are muscle.

heart grows. If this fibrous ring is stretched and ruptured the muscle is freed and can function more normally; it can contract and relax and perhaps the raw surfaces formed by rupture of the fibrous ring may be rapidly endothelialized in their new and wider position. By liberating the walls it is possible that the continuous passage of blood will maintain the enlarged lumen and allow

normal growth and development to proceed unchecked. This observation would appear to be borne out by the steady progressive improvement noted in some of these cases.

Conversely it indicates that the time for infundibular resection or dilatation is in childhood and that its results are not likely to be so good in the late teens or twenties when growth has ceased and the wall of the infundibular portion of the ventricle and the whole outflow track has been prevented from developing properly with the rest of the body. Moreover, we know that as the years go by the normal wear and tear of the blood stream over the stenosis leads to progressive fibrous thickening and the formation of fibrous excrescences that project into and further obstruct the lumen; ultimately dense fibrosis extends over the endocardium around the area of maximum stenosis and also into the muscle underneath, and calcification also occurs. Experience in three cases has demonstrated that these changes render direct operation very hazardous in older patients (see later).

THE PATIENTS CHOSEN FOR OPERATION

The patients chosen for operation were all thought to have Fallot's tetralogy and were of the same type as those chosen earlier for systemic-pulmonary anastomosis (Baker *et al*, 1949). They were selected whenever an infundibular chamber could be demonstrated, indicating that the stenosis was infundibular. Perhaps their disability was a little less, on the average, as the more disabled had been chosen for earlier operation, but they were older as such patients were at this time being given preference for operation. Their disability and cyanosis were generally placed in Grade 3 (able to walk 50–200 yards only, and with moderately severe cyanosis at rest), though sometimes only in Grade 2 (able to walk a quarter of a mile, and with only slight cyanosis at rest). There was rather less polycythæmia than the average of the cases with Fallot's tetralogy chosen for operation, but even so it was considerable as the hæmoglobin averaged 132 per cent. The chief features of each case are given in Tables I and III.

All had a systolic murmur, and most a systolic thrill in the pulmonary area, but none had a diastolic murmur here or at the apex. The second sound in the pulmonary area was single and diminished unless otherwise stated. On radioscropy there was always some enlargement of the right ventricle. All the electrocardiograms showed right ventricular preponderance and the P wave was large and somewhat pointed in more than half of them: QRS was somewhat widened in Case 6.

TABLE I
CASES OF FALLOT'S TETRALOGY, SUBMITTED TO INFUNDIBULAR RESECTION OR DILATATION

Case No.	Reference No.	Age and Sex	Clubbing	Disability	Cyanosis	Onset of Cyanosis	Aortic Arch	Hæmoglobin, per cent	Red Cells, millions	Hæmatocrit	Hæmoglobin soon after operation	Hæmoglobin one year after op.
1	0080	13F	4	3—	3	1 yr.	L	128	6.4	62	110	110
2	CB11	20F	2	2	2	18 mo.	L	120	6.4	60	89	—
3	0185	19M	4	3+	3	2 mo.	L	130	7.1	60	112	107
4	P074	14M	3	3	2	2 yr.	R	132	6.7	59	103	88
5	P061	34F	4	3	3—	10 yr.	L	145	7.4	73	—	—
6	0263	14M	4	3	2	18 mo.	L	116	7.0	55	82	—
7	0089	12M	4	2+	3	2½ yr.	L	133	7.4	63	95	93
8	0102	20F	4	2	2	15 mo.	R	120	7.1	61	118	128
9	P063	28M	4+	4	4	6 yr.	R	172	10.0	79	—	—
10	P025	7F	4	3	3	3 mo.	L	130	6.2	54	92	85
11	0224	19F	4	2	3+	1 yr.	L	130	10.2	72	—	—

All patients had been cyanosed from infancy though sometimes not till after 18 months (details are given in Table I), except the two oldest where it was not noted till 10 years and 6 years respectively (Cases 5 and 9). These two differed from the classical picture of Fallot's tetralogy in this respect, probably because they had been slighter cases who had got on well for a long time and survived to 34 and 28 years respectively, though finally they had become gravely incapacitated.

All patients squatted habitually except these two, and Case 5 may have and Case 9 certainly had done so in childhood. The fingers were always clubbed, least so in Cases 2 and 4.

The clinical diagnosis of Fallot's tetralogy was, therefore, straightforward, except that in Case 7 the increased pulmonary shadows caused by the heavy collateral circulation raised some doubt as to whether the pulmonary blood flow was reduced, and in Case 9 the late onset of his cyanosis and even more of his disability presented the differential diagnosis of pulmonary valvular stenosis with a closed ventricular septum and a patent foramen ovale.

Angiocardiography was carried out in all except Case 5; it confirmed the diagnosis, but was done even more for the valuable help it gives as regards the size and shape of the infundibular chamber.

Cardiac catheterization was carried out in 6 of the patients and some of the results are shown in Table II. The pressure in the right ventricle was always raised, least in the first two cases; and in the

TABLE II
SOME RESULTS OF CATHETERIZATION IN SIX OF THESE CASES

Case No.	Pressure (mm. Hg.)			Pulmonary flow	
	R.A.	R.V.*	P.A.*	litre/min.	l/min/sq.m.
2	-5	20	-1	2.8	2.0
3	2	19	2	1.8	—
5	9	47	15	2.0	1.4
7	7	85/0	***	2.4	2.1
8	0	100/0	50/0	2.5	1.8
9	16/0	170/0	22/11	3.4	2.1

Case No.	Percentage O ₂ saturation					Systemic Artery	
	S.V.C.	I.V.C.	R.A.	R.V.	P.A.	Before	After
2	60	—	59	62	69**	88	93
3	—	—	—	—	—	76	93
5	57	58	63	61	62	75	—
7	56	51	55	62**	—	72	91
8	—	—	49	52	60**	74	—
9	61	53	61	64	63	75	—

* The single figures represent mean pressures and the double figures systolic and diastolic pressures.

** These increases of 1.7, 2, and 1.6 volumes per cent respectively, are thought to be significant.

*** The pulmonary artery could not be entered.

five where the pulmonary artery was entered there was evidence of obstruction between it and the right ventricle. The systolic pressure was very high (170/0) in Case 9: though this may have helped to overcome the obstruction for some years it was no doubt one of the features leading to his final deterioration. The figure for the pulmonary artery pressure in Case 8 (50/0), the patient who benefited least, was unusually high; either the left to right shunt was enough to cause some rise of pressure—a finding that is rare or absent in uncomplicated Fallot's tetralogy—or there was some independent cause for pulmonary hypertension which seems unlikely with the low diastolic pressure.

The arterial O_2 saturation was between 72 and 88 per cent, this providing further evidence of a right to left shunt. In Cases 2, 7, and 8 there was probable evidence of a much smaller left to right shunt as well as the main right to left shunt, but Holling and Zak (1950) have shown that this turbulence with left to right as well as right to left shunts is not uncommon in Fallot's tetralogy.

The pulmonary blood flow was considerably reduced, to between 1.8 and 3.4 litres a minute or to between 1.4 and 2.1 litres a minute per square metre of body surface.

RESULTS

The operation of infundibular resection was, not unnaturally, approached with considerable trepidation. We found, however, that it is, on the whole, well tolerated except for a short period during the most severe intracardiac manipulations. The alarming reactions of the heart are lessened by the adequate use of quinidine before, and of procaine during operation; and with our present technique the various manipulations are well borne.

The fatal cases. Three of the eleven died. They were older patients and we think this adds greatly to the dangers.

In Case 5, a woman aged 35, and in Case 9, a man aged 29, the circumstances were similar. It was very difficult at operation to decide whether the obstruction was valvular or infundibular, and after some deliberation it was decided to explore the lesion and to attempt valvulotomy. Both patients died and necropsy revealed a high, densely fibrous infundibular stenosis (in the older patient calcified as well) with the valves unaffected. Although infundibular resection was not performed but infundibular incision only, both have been included.

The third, Case 11, a woman aged 20 years, tolerated the infundibular resection well and gave no cause for anxiety until the chest was nearly closed. Her blood pressure and pulse then suddenly failed for 2-3 minutes and after some improvement for a few minutes, this recurred and death soon followed. Necropsy revealed that the infundibular stenosis had contained many rather exuberant fibrous vegetations; these had been dislodged and several were lying loose in the pulmonary artery. It seems possible that embolism had occurred and was responsible for the fatal collapse.

These three cases lead us to conclude that direct operation is best avoided in patients aged 20 or over, unless a large infundibular chamber is present (as in Cases 2 and 3). Indeed, patients of this age are a bad risk for any operation aiming at improvement of the heart condition, and a systemic-pulmonary anastomosis is wiser, when deterioration or the severity of the condition indicates operation.

The successful cases. The eight successful cases have now been seen for varying periods from 11 to 18 months after operation. Seven have been benefited greatly (Table III). In one, the improvement is as striking as in any case we have seen (Case 3): before operation he became extremely distressed after walking 25 yards, but within a short time could walk 4 miles and had taken on sedentary work; his arterial oxygen saturation had risen from 75 to 93 per cent.

In several others the result was nearly as good. One boy (Case 6) can walk 3 miles and is playing football. Another (Case 7) can walk 4 miles easily instead of half a mile very slowly; his arterial oxygen saturation has risen from 82 to 91 per cent: his heart has, however, increased more than any of the others. Another (Case 4) who underwent infundibular dilation only, became very distressed and squatted after walking 20 yards; he now walks about all day, climbing stairs without any difficulty, and is almost without cyanosis: whereas he used to spend almost all his days in the house, he is now at boarding school. The eighth patient was improved (Case 8) but much less than the others.

The improvement was generally noticed almost as soon as they got up after operation, and before leaving the hospital they could do much more than before. Often the systolic murmur became louder and rougher after operation and the thrill was more easily felt, but this was not always so: in no case was any diastolic murmur heard. The findings at operation and the condition before and after operation are described in the case notes that follow.

TABLE III
DETAILS OF 8 SUCCESSFUL CASES OF INFUNDIBULAR RESECTION OR DILATATION

Case No.	Sex	Age	Level of stenosis	Result*	Exercise tolerance	
					Before	After
1	F	13	Low	Good (18)	100 yards	1 mile
2	F	20	Low	V. good (16)	1 mile	4 miles
3	M	19	Low	V. good (15)	50 yards	4 miles
4	M	14	Moderate	V. good (15)	200 yards	2 miles
6	M	14	Moderate	V. good (13)	$\frac{1}{2}$ mile	4 miles
7	M	12	Moderate	V. good (12)	sometimes $\frac{1}{2}$ mile	3 miles
8	F	21	High	Fair (12)	$\frac{1}{2}$ mile	2 miles
10	F	7	High	V. good (11)	200 yards	2 miles

* The figure in brackets indicates the number of months after operation.

CLINICAL AND OPERATION NOTES OF SUCCESSFUL CASES*

Case 1 (0080), aged 13, was seriously disabled, walking only 100 yards without a rest and rarely attending school for long. Cyanosis and clubbing were both moderate and the hæmoglobin was 128 per cent. The heart did not seem enlarged but severe scoliosis made exact measurement difficult. There was a blowing systolic murmur in the pulmonary area without a thrill. Although no bulge indicating an infundibular chamber was seen on the plain radiograph, angiocardiograms revealed a typical oval chamber below the valve level (Fig. 6).

She was under observation for a year, and even with encouragement, never walked more than a quarter of a mile slowly with rests; and her mother thought that she was getting worse.

Infundibular resection, November 29, 1948. An obvious large infundibular chamber was displayed, measuring some 5×2.5 cm.; it was thin-walled and for the most part covered by a thin layer of muscle fibres, although dark blue blood could be seen through the most distal fibrous portions. A soft thrill originated from the base of this chamber and the jet could be felt impinging on the anterior wall. With the 7 mm. punch, almost a complete circle of the stenosed ostium was successfully resected. In the specimen (Fig. 10) the narrow, fibrous channel is well displayed; a small gap of about 2 cm. is missing to complete the circumference. After resection of the ostium a pair of dilating forceps was twice inserted and opened wide. All the manipulations were well borne and she made a smooth recovery. On discharge from hospital she was already improved; her arterial oxygen saturation was 85 per cent and the hæmoglobin had fallen from 128 to 110 per cent.

Four months later she was leading a normal quiet life and about all day except for breakfast in bed. She had walked half a mile more easily than 100 yards before, the colour was nearly normal and the fingers less clubbed: she was allowed to start school.

Eighteen months after operation her improvement was maintained and she was attending school regularly and was able to walk a mile without resting. She still seemed very frail and the improvement was good but not as good as in many cases. The heart did not seem any larger and the hæmoglobin had not risen again (110 per cent, average).

Case 2 (CB11), aged 20, could do little more than walk from one room to another, and always went about in a chair until she was 14 years of age. Between 14 to 18 she became able to do much more, and thought that it was real improvement. She was working as a student and was just able to walk a mile slowly. She squatted constantly. Cyanosis at rest and clubbing of the fingers were only slight (hæmoglobin, 120 per cent).

There was a rather loud systolic murmur in the pulmonary area with a systolic thrill. The

* To shorten the case notes, details given on page 412 and in the tables (blood counts, the size of the heart, etc.) are not repeated.

heart was enlarged; there was some prominence in the pulmonary region that was finally regarded as a dilated infundibulum beyond the stenosis (Fig. 3). Cardiac catheterization and angiocardio-graphy confirmed the diagnosis.

A year later she was losing ground; she could do less and was rather more cyanosed.

Infundibular resection, December 9, 1948. A large infundibular chamber was displayed, measuring some 6×3.5 cm., the proximal half covered with a thin and diminishing layer of muscle fibres. A powerful thrill could be felt at the base of the infundibulum and a fine jet-like stream of blood was evident. The sinuses of Valsalva were very large and well-formed; no thrill could be felt in the pulmonary artery, which above the sinuses was smaller than normal.

It was not possible to resect a circular fragment of the stenosed ostium, as was done in Case 1, but several bites were made and a number of segments obtained, each being characteristic of the fibrous, vegetated margin of the stenosed orifice (Fig. 11).

The character of the thrill completely changed after this resection from a high pitched fine one to one of lower intensity and greater volume. The operation was well-borne and she made a good recovery.

Two months later she was able to get about well and did not squat. Nine months after operation she was able to walk 2 or 3 miles, without dyspnoea even on hills, and was playing tennis and swimming, and had rowed a dinghy with three people in it two miles—all activities that would have been quite impossible before. The hæmoglobin had fallen from 120 to 89 per cent, and the arterial oxygen saturation had risen from 88 to 93 per cent. The heart had increased in size slightly, c.t.r. 61 instead of 56.

Sixteen months after operation she was leading a normal student life, walking 4 or 5 miles a day. She could dance all evening or even run on the level and noticed no symptoms except some dyspnoea if she ran up 2 or 3 flights of stairs. Her colour was normal except for slight cyanosis in the nails; the clubbing had disappeared. She had occasional paroxysmal tachycardia. There was no further increase in the size of the heart.

Case 3 (0185), aged 19, could not walk more than 100 yards on a good day, and in the ward only a few steps without great distress. There was moderately severe cyanosis and clubbing. His brother had died with Fallot's tetralogy.

There was a systolic murmur and thrill in the pulmonary area, getting rather louder lower down. The heart was not enlarged. On screening it was rather central with an obvious prominence due to an infundibular chamber of moderate size (Fig. 4). The pulmonary arteries were easily seen but there was no pulsation and the lungs were oligæmic. Angiocardiograms confirmed the early right to left shunt and the presence of the infundibular chamber.

Infundibular resection, March 3, 1949. The infundibular chamber measured 4.5×3 cm.; it was thin-walled and covered with muscle in its proximal part, and dark blue distally; the pulmonary artery was small with small sinuses of Valsalva.

Punch resection resulted in removal of 9 separate fragments of tissue from the stenosed area; most were covered with thickened fibrous endocardium. After resection the ostium was further enlarged by dilatation with forceps. The thrill became much more powerful, and the infundibular chamber could be seen to be distended freely with each heart beat. His condition was good at the end of operation.

Three months later his colour was good though cyanosis was just present; the clubbing of his fingers had improved. He could easily walk a mile and was getting about all day.

Nine months after operation he was walking at an ordinary rate up to 4 miles and did regular work; his colour was almost normal. The hæmoglobin was 112 instead of 130 per cent; the arterial oxygen saturation had risen from 76 to 93 per cent.

Fifteen months after, his progress was still excellent, but there had been no further improvement. The increase of heart size was hardly significant and the physical signs were unchanged.

Case 4 (P074), aged 14, had been diagnosed as Fallot's tetralogy by Dr. Shirley Smith when he was three years old. He had been able to walk 2 miles when 5 years old, but could now only

manage 200 yards in summer, and in winter rarely walked outside the house and had to be helped upstairs. He squatted frequently. Cyanosis was moderate (hæmoglobin, 132 per cent).

There was a rough systolic murmur maximal in the pulmonary area but audible as far down as the apex. A thrill was felt on occasions. The heart size was just within normal limits, with some prominence, probably due to a dilated infundibular chamber. Angiocardiography confirmed a large right to left shunt with poor filling of the lungs especially on the right side; the left pulmonary artery was large but the right pulmonary artery was not demonstrated.

Dilatation of infundibular stenosis, March 8, 1949. A left postero-lateral incision was made, with resection of the 5th rib, the intention being to do a systemic-pulmonary anastomosis. A well-marked infundibular chamber was present—thin-walled and about 2.5 cm. in length, with a typical thrill arising from its proximal portion. The pulmonary trunk was slightly smaller than normal and the sinuses of Valsalva were present.

In view of the absence of a right pulmonary artery of any demonstrable size, we hoped that it would be possible to use a large branch of the left pulmonary artery for anastomosis. Unfortunately none arose before the artery entered the lung and it was considered unsafe to occlude the left pulmonary artery itself to make an anastomosis. Fortunately, by prolonging the incision forwards, it was possible to gain good access to the right ventricle below the infundibulum.

A probe was inserted and confirmed a tight, small ostium, and the punch was next introduced but only a small fragment of tissue could be obtained; two further attempts failed to secure any tissue. The left little finger was now inserted; the infundibular orifice was located and firmly dilated so that the finger passed right through the pulmonary valves, which felt normal. The manipulation was well tolerated and his condition was satisfactory at the end.

After a short period of anxiety he did well and three weeks later was walking about freely without distress or cyanosis. The hæmoglobin had fallen to 103 per cent.

Six months after operation he seemed a different boy and had grown 2 inches and put on 12 lb. in weight. He was getting about all day without symptoms, and could walk 2 miles and run upstairs instead of being helped; he had lost all visible cyanosis even after exercise. The physical signs were not greatly changed though perhaps the systolic murmur was louder.

He was allowed to start school, which he had only attended one term previously, as it had been found that he had to rest the greater part of the time.

Fifteen months after operation his progress was equally satisfactory. He had been regularly at school and was playing cricket, and was able to get about all day and run upstairs. His colour was normal except for very slight cyanosis in the nails. His heart size was larger than before operation but almost identical with the size a few weeks after, and his hæmoglobin had not risen again.

Case 6 (0263), aged 14, had managed to walk a quarter of a mile in the last two years, though till 11 years he had generally been pushed about in a chair. Neither the cyanosis nor the clubbing, nor the polycythæmia were severe (hæmoglobin 116 per cent).

There was a rough systolic murmur and thrill in the pulmonary area with a pulmonary second sound that was louder than usual. Radiography showed the outline of an infundibular chamber; angiocardiography confirmed this and also a moderate infundibular stenosis and an aorta that was much less over-riding than usual, this agreeing with his relatively slight cyanosis and polycythæmia, but the arterial O₂ saturation was down to 84 per cent.

Infundibular resection, April 12, 1949. The infundibular chamber extended about 2 cm. below the level of the valves and was covered by a complete thin layer of muscle. The stenosed ostium was unusually firm and considerable pressure had to be exerted to pass the punch through it; a good portion of an extremely fibrous irregular margin was removed. His condition was poor for several days after operation but he then made a good recovery.

Six months after operation, his colour was just not normal and slight cyanosis could be seen in the nails. He had walked 3 miles and played football and his mother found it difficult to restrain his activity. The systolic murmur and thrill were striking and rather louder than before operation.

The heart was a little larger, the c.t.r. having increased from 48.5 to 52. There was possibly a

little more prominence of the infundibulum and the pulmonary circulation seemed to have increased on radioscopy.

A year after operation his progress was equally good.

Case 7 (0089), aged 12, was much disabled, though sometimes he could walk half a mile. The cyanosis, clubbing, and polycythæmia were moderate (hæmoglobin 133 per cent).

There was a rough systolic murmur in the pulmonary area and a thrill, with a normal pulmonary second sound. The heart was sabot shaped and not enlarged. Angiocardiography confirmed the over-riding aorta and an obvious infundibular chamber was revealed. Even after angiocardiography and cardiac catheterization, some doubt was felt as to whether the blood flow to the lungs was much reduced, but it was thought that the increased shadows were due to collateral circulation and that he would benefit from operation.

Infundibular resection, June 20, 1949. One month after operation the hæmoglobin had fallen from 133 to 95 per cent: the arterial O₂ saturation had risen from 82 to 91 per cent.

Six months after operation he was a changed boy. He was getting about all day with no symptoms and had walked four miles. His colour was almost normal and his fingers showed much less clubbing. The physical signs were the same except that the systolic murmur and thrill were much more obvious: the heart had become larger, c.t.r. being 52 instead of 48.

A year after operation his condition was equally satisfactory and there was no further increase in the size of the heart.

Case 8 (0102), aged 20, could walk half a mile without a rest or up to 2 miles slowly with rests, but had not been able to do more than helping her mother at home. She had been over-treated up to the age of 12 and taken about in a bath chair. Cyanosis was slight.

The heart was not generally enlarged but the prominence of the pulmonary region was at first thought to indicate Eisenmenger's complex and only later recognized as dilatation of the infundibulum beyond the stenosis. There was a fairly harsh systolic murmur in the pulmonary area with a slight thrill. Catheterization and angiocardiography confirmed a moderate overall right to left shunt and a high infundibular stenosis (see p. 413). She was dissatisfied with what she could do and was very anxious for help by operation.

Infundibular resection, July 7, 1949. The presence of a high infundibular stenosis with a well-marked thrill was confirmed. The punch resection cut audibly through firm fibrous tissue and four fragments were severed; a finger was then inserted and the canal dilated; the finger passed through into the pulmonary artery. The operation was well tolerated and her general condition was good until some four days after when she became blue and not so well. She improved before discharge from hospital but was not really satisfactory.

Four months after operation her cyanosis was hardly visible but it had always been slight. Her hæmoglobin was still 118 per cent. She thought she could get about more easily but had not really walked a greater distance and still noticed some tightness in the chest on exertion. The physical signs and the size of the heart were unchanged. She was advised to increase her activity and to try to get light work.

Twelve months after operation she was better, and had managed light work each afternoon for five months as well as more housework at home. The improvement has been classed as only moderate, though she could now walk 2 miles without resting.

Case 10 (P025), aged 7, could walk about 100–200 yards and play in the garden for half an hour or so. Up to the age of 2 she had many severe attacks, particularly after meals, but did not often go quite unconscious in them; these attacks continued but were less severe and less frequent. The cyanosis and polycythæmia were moderate (hæmoglobin of 130 per cent).

The heart was only slightly enlarged. The lung fields were light with a rather striking prominence of the left border, that was thought to be a high infundibular dilatation. Angiocardiography confirmed Fallot's tetralogy with a high infundibular stenosis.

Infundibular resection, July 18, 1949. The thrill was located about 2 cm. below the level of the valves, which seemed normal. The orifice of the infundibular stenosis felt very small when a

probe was passed and resection resulted in 3 fragments of the typical crenated edge of a diaphragmatic stenosis. The ostium was then dilated with forceps.

She did very well after operation with excellent colour from the start. Her return home was delayed by a low irregular fever for no obvious cause, but even before leaving hospital she was getting about better. Ten weeks after operation she was walking about much better and free from her attacks. The heart size was somewhat increased, c.t.r. 56 instead of 52. The hæmoglobin had fallen from 130 to 92 per cent.

Eleven months after operation the result was excellent. Her colour was almost normal and she was getting about all day. She could walk 2 miles with ease and could spend all morning in town with her mother; she had lost her attacks of faintness. The heart size had not increased further; the systolic murmur was rougher; and the hæmoglobin had not increased again. [Her father has written since to say that she won an obstacle race at a local show.]

ENLARGEMENT OF THE HEART AFTER OPERATION

The increase in the size of the heart after a successful systemic-pulmonary anastomosis has been looked on as one of the drawbacks of this operation. It seemed that direct operation would be less likely to be followed by this and might, in the course of time, lead to a reduction in the right ventricular hypertrophy. We were surprised to find that some cardiac enlargement followed in several cases, but perhaps we should have expected it. Heart size on radiology depends mainly on the size of the chambers rather than on the hypertrophy, and if the right ventricle is to pump more blood to the lungs it must have a greater capacity and may appear larger.

The increase in size is shown in Table IV and has not been great in any case, though a little more than we would choose in Case 2, as her heart was the largest before operation.

The average increase in maximum transverse diameter was a little less than 1 cm. but was just over this in 5 cases. A small part of this was due to the growth of the heart and chest as a whole. The average increase in the cardio-thoracic ratio was from 49.6 before to 52.6 per cent six to eighteen months after operation. This average figure after operation is just the same as in a much larger series of cases of Fallot's tetralogy after the Blalock-Taussig operation (Baker *et al.*, 1949), but the increase there was a little greater as the average c.t.r. before operation was only 48.1 per cent. As after the Blalock operation, the increase in size is generally found within a month or two and does not appear to be progressive.

TABLE IV
HEART SIZE BEFORE AND AFTER OPERATION OF INFUNDIBULAR RESECTION

Case No.	Reference No.	Cardiothoracic ratio		Maximum transverse diameter (cm.)		Diameter of chest (cm.)	
		Before	After*	Before	After	Before	After
1	0080	45	45 (18)	10.5	10.5	23.5	23.5
2	CB11	56	61 (16)	12.0	13.5	22.5	22.0
3	0185	47	48 (15)	12.0	12.4	25.5	25.8
4	P074	51	56 (15)	10.2	12.0	20.0	21.5
5	P061	50	—	11.75	—	23.5	—
6	0263	48.5	52 (6)	11.2	12.4	23	23.7
7	0089	48	53 (12)	11.5	13.0	24	24.5
8	0102	49	49 (12)	12.2	12.2	25	25
9	P063	52	—	13.2	—	25.5	—
10	P025	52	57 (11)	10.0	11.2	19	19.6
11	0224	49	—	12.0	—	24.5	—
Average (8 cases)		49.6	52.6	11.02	11.97	22.8	23.2

* The figure in brackets denotes the months after operation of the last available teleradiogram.

ELECTROCARDIOGRAPHIC CHANGES AFTER OPERATION

Changes in S-T and T waves, similar to those seen after muscle injury, have been found in all these patients for some weeks after section of the heart muscle at operation; they have not, however, been associated with pain or any symptoms similar to those found with coronary disease.

When continuous electrocardiograms are taken *during these operations*, and for this we are indebted to Dr. Geoffrey Reynolds, considerable changes take place in most cases. Nodal rhythm and other changes in the pacemaker are both seen frequently, but are not very uncommon in cases of congenital heart disease under normal conditions. When procaine is first injected into the ventricle, ventricular extrasystoles are generally observed. When the incision is made, these are more frequent and often occur in groups of two or three successive extrasystoles. These changes increase with the use of the punch and still more when the finger is passed through the stenosed region for dilatation, and S-T changes may appear at this time, but tend to be in the same direction in all leads, rather than reciprocal in leads I and III, and flat rather than of the cove-shaped coronary type.

These changes have in general almost if not quite disappeared within hours or a day after operation. A week or more *after operation* changes of quite a different type appear and develop and disappear again—a cove-shaped S-T with T inversion in lead I and a reciprocal rise of T in lead III. In the earlier cases the records after operation were at intervals of some weeks, so that one can only time the changes roughly, and can only say that they were present at 3 weeks (twice), at 4 weeks, (once), and at 5 weeks (once). More frequent records were therefore taken to time their onset and disappearance more precisely, and in these later cases the changes are shown about a week after operation. For example, in Cases 6, 7, 8, and 10 there was little or no evidence of a change in records taken 8, 5, 4, and 5 days respectively after operation, but changes had started at 12, 10, 8, and 10 days respectively, and were quite advanced in the last instance.

FIG. 12.—Electrocardiographic changes after infundibular resection in Case 6. (A) Before operation, (B) 1 day after, (C) 3 days after, (D) 11 days, (E) 15 days, (F) 20 days, (G) 28 days, (H) 36 days, and (J) 5 months after operation.

The changes were progressive for two or three weeks. In Case 6, for example, they progressed from 12 to 28 days (Fig. 12), and in Case 8, from 8 to 20 days at least (Fig. 13), in both these with little or no significant change during the fourth and fifth weeks: in Case 10 they progressed from 10 to 16 days at least (Fig. 14) and did not show much change from 4–8 weeks.

FIG. 13.—Electrocardiographic changes after infundibular resection in Case 8. (A) Before operation, (B) 4 days after, (C) 8 days, (D) 12 days, (E) 16 days, (F) 21 days, (G) 27 days, (H) 40 days, (J) 45 days, and (K) 4 months after operation. Size reduced by one-sixth.

FIG. 14.—Electrocardiographic changes after infundibular resection in Case 10. (A) and (B) before operation showing that some degree of T I inversion may occur from time to time in these patients, presumably when there is a greater degree of anoxæmia, (C) 5 days after, (D) 10 days, (E) 28 days, (F) 52 days, and (G) 6 months after operation.

In general, the changes in the V leads are more striking and T is generally more inverted in leads VL and VI to V3 or V5 than in lead I. In Case 10 they were deepest in leads V2 to V6. (Fig. 15).

Recovery generally started at from 6 to 8 weeks after the operation and was always complete as far as the standard leads were concerned by 7 months, and generally by 4 or 5 months, or perhaps sooner as we have relatively few records 2 or 3 months after operation. Thus, some degree of return to the levels before operation was seen at 7 weeks (Cases 3 and 6), at 6 weeks (Case 8), at 8 $\frac{1}{2}$ weeks

FIG. 15.—Unipolar chest leads, V1 to V6, from Case 10, showing the development of deep T inversion and its recovery. (A) (12/4/49) Before operation. (B) (26/8/49) Five weeks after operation, showing T inversion in all six leads and fairly deep inversion from V2 to V5. (C) (12/1/50) Six months after operation, showing that most of the inversion has disappeared though T is still inverted in V4 and slightly in V5 and V6 where it was not previously. Standardization is 1 MV.=0.5 cm. in (C).

(Case 10), and slightly (in Case 7) as early as 25 days. It was complete in the standard leads before 4 months (Case 1), before 5 months (Cases 3 and 6) and before 6 months (Case 6), but in the last three there was still some inversion of T in leads V2 and V3 that had not been present before operation.

The changes in the V leads generally last longer and are often present after 6 months, and in Cases 2 and 4 after 15 months, but had almost disappeared in Case 1 as early as 3 months.

These changes—the cove-shaped S-T and T inversion in lead I, with a reciprocal rise of T in lead III—are quite different from the changes observed during operation, and it seems that they are caused by the process of injury and repair in those parts of the muscle and its blood vessels that must be cut during operation, i.e. in the anterior part of the right ventricle. They are somewhat similar to the changes seen after cardiac infarction but are not associated with the development of Q waves; we have not seen these in any records except occasionally in leads III or VR, where they seemed to be normal waves without any progressive changes. This would suggest that the changes observed are due to injured muscle and not to dead muscle as in cardiac infarction. The possibility that they are due to pericarditis has also been considered, and some slight degree of pericarditis, even with a small effusion, may well have been present in some cases, though not to the extent that it has been diagnosed clinically. It is more usual for the changes of pericarditis to be visible in all leads and to be in the same direction, without the reciprocal relation observed here in leads I and III, and this is more in accordance with the electrocardiographic changes being due to injured muscle. They are not, however, associated with any particular symptoms and few patients have complained of more pain than would be expected after an operation on the chest, except Case 3, who was thought to have a small pulmonary infarct.

On general principles these patients have been kept in bed considerably longer than patients who had had subclavian-pulmonary anastomosis, usually for three or four weeks and rather more than this if there has been any significant post-operative pyrexia or other symptoms. As soon as they have got up they have been able to get about with less dyspnoea than before and with no signs of pain, and their progress subsequently has been satisfactory and in no case delayed by symptoms or pain in the chest. Case 8, who did complain of some sternal tightness on walking, had noted this symptom more severely before her operation.

In view of the absence of symptoms and the rapid improvement in these patients' condition we cannot think these electrocardiographic changes of serious significance. No similar changes have been found in cases of mitral stenosis where the surgical approach to the valve has been through the auricle.

SUMMARY

The pulmonary stenosis of Fallot's tetralogy may be valvular but is more often infundibular. Infundibular stenosis is generally localized and often recognizable by the dilated infundibular chamber beyond it, especially after angiocardiography.

As the results here reported show, infundibular stenosis can be relieved by direct operation and this should improve the condition of the patient without any corresponding drawbacks.

Eleven patients submitted to resection or dilatation of the infundibulum are reported. They were all thought to have Fallot's tetralogy of moderately severe degree and of the same type as those chosen earlier for subclavian-pulmonary anastomosis. They were rather older but perhaps a little less disabled as the more disabled and younger patients had been chosen for earlier operation. Even so, their disability and cyanosis were moderately severe. The polycythæmia was also moderate and the hæmoglobin averaged 131 per cent.

Three patients died after operation. They were all aged 20 years or more and this should probably be a contra-indication to direct operation unless a well-marked infundibular chamber can be demonstrated. In younger patients the operation does not seem to be as dangerous as might be expected.

The eight survivors have now been seen for varying periods from 11 to 18 months after operation. Seven have benefited greatly. In one, for example, a boy of 19, the improvement is as striking as in any cases we have seen. Within a short time he can walk four miles instead of 100 yards, and has taken on sedentary work. His arterial oxygen saturation has risen from 75 to 93 per cent and his heart size has hardly increased (Case 3).

In several of the others the results are nearly as good as this. One boy can walk three miles and is playing football (Case 6); another is getting about all day and walking four miles instead of half a mile very slowly (Case 7). The only one of the eight where the results are not so good, a girl, aged 19, can walk more quickly, but not much further, and has managed to start light work, which was the main purpose of her wanting an operation.

In general, the heart increases slightly in size, presumably with the extra output that is possible from the right ventricle. The average increase is of the same order as that found after a successful Blalock operation and the average cardio-thoracic ratio has increased from 49.6 to 52.6 per cent. The increase generally appears within a month or two and does not seem to be progressive.

In these operations, where the muscle of the right ventricle has been cut, certain electrocardiographic changes that appear to be due to injury of the muscle are seen during the following weeks. About 7–10 days after operation, there is a cove-shaped S–T and commencing T inversion in lead I with reciprocal changes in lead III; no Q waves have been observed. These changes increase in degree for about three weeks and the T inversion may be of considerable depth. During the fourth and fifth week these changes are generally stationary and thereafter in the sixth or eighth week gradually diminish and disappear in the standard leads by four months, though they persist longer in the unipolar chest leads.

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