CLOSURE OF DEFECTS IN CARDIAC SEPTA*

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THE HIGH INCIDENCE of defects in cardiac septa in 350 congenital hearts examined, about 50% being diagnosed as patent inverventricular or interauricular septa, stimulated my interest in the subject.

Only those defects in the septum which appear to be single lesions are included in this consideration. The perforated septum in tetralogy of Fallot, tricuspid atresia or patent ductus arteriosus and so on are not included and only those are considered when the septum is thought to be the predominant congenital defect and the one causing symptoms.

It is obvious that a small interventricular or interauricular septal defect, in the absence of infection, is of little or no significance. Cases are recorded where soldiers have gone through commando training and through the recent war with known congenital interventricular septal defects with no change in size of heart and no ill effects.

On the other hand, if the septal defect in either auricle or ventricle is large, it is possible that it may be the source of symptoms, and may be accompanied by cyanosis. The symptoms and the cyanosis may depend on several factors, but perhaps the size of the opening is one of the most important, which opinion is supported by Toussig[1] in her recent excellent book on Congenital Heart Disease.

The cases to be considered for operation in my view are those in which the heart is not excessively enlarged; the septal defect is not too large, such as occurs with a single ventricle, and before the patient has reached maturity. On the other hand, they may not be suitable for operation when there is evidence of an enormously enlarged heart with failure, and perhaps a single ventricle instead of a medium sized defect in the septum. I found on post mortem examination of congenital hearts, when a patient has survived to the age of medium childhood or the early twenties, has some cyanosis, has a moderate amount of energy, but with a moderately enlarged heart, that there has been an opening in the interventricular septum of perhaps one to two or more centimeters, in diameter.

In the few cases I have operated on, I was impressed with the high pressure in the pulmonary artery. This on measurement with a monometer was about equal to that of the pressure in the aorta. Whether that high pressure is the result of the septal defect or whether it is accounted for by some congenital anomaly in the pulmonary vascular tree, I do not know. Neither do I know whether this high pressure is reversible if the hiatus in the septum is closed. However, it seemed worth while to attempt to close the hiatus, presupposing that this might be the source of the high pulmonary artery pressure. I have a suspicion that there is some abnormal physiology

* Read before the American Surgical Association, Quebec, Canada, May 29, 1948.

in the pulmonary vascular tree which may not be remedied by closure of the septal defect alone. For this reason, the problem did not lend itself well to animal experimentation because the septal defects produced artificially in animals were not accompanied by long standing pulmonary hypertension.

Animal experimentation, however, did give us practice in operating on the heart. We learned how much the heart could be manipulated and displaced from its usual position, and its response to stimuli and to transfixion with foreign bodies. With practice, we were able to locate the position of the septum, from the surface markings on the anterior and posterior surfaces of the heart. Using this information we were able to pass needles and probes through the heart anteroposteriorly in the plane of the septum, and place ligatures, crossing artificially formed defects, in the interventricular and interauricular septa. We could see danger signs and learned to judge their significance, and how to relax and rest the heart so that its abnormal responses to stimuli were soon overcome and the circulation was maintained. We were able to proceed with what appeared to be relative safety.

Then came the problem of applying this principle to congenital septal defects in human hearts.

The problem resolved itself into:

(1) A consideration of the different reactions which might occur in the human heart when compared with an animal heart.

(2) Secondly, and probably most important, was an anatomic consideration of the area involved, to know what to do, what not to do.

My objective in the interventricular defect was to pass a suture, of considerable size on cross section, through the heart from front to back so that it would pass across the defect in the septum. It was hoped that by slight compression of the heart from before backwards, by this suture, the hiatus could be diminished somewhat in size. Secondly that the substance of the fairly massive living suture would in itself obstruct the hiatus to a degree. If one suture could be passed, then perhaps two or more could be passed in such a way as to interweave them and give fairly complete occlusion of the hiatus. This, accompanied by some local thrombosis, and healing of this area might, with good luck, cause sufficient obstruction of the hiatus to improve the function of the heart and relieve the patient of symptoms.

ANATOMIC CONSIDERATIONS

(1) The decending branches of both the right and left coronary arteries are described as passing down in the interventricular sulci anteriorly and posteriorly. These sulci are described in anatomy books as roughly outlining the anterior and posterior margins of the septum. Also, the transverse branches of both left and right coronaries run transversely in the auriculo-ventricular sulcus and these again, are in the field of operation. It was necessary then to go carefully into the anatomy of the heart to know more accurately what are the exact surface markings, of the anterior and

posterior margins of the septum, and so to know at what point in relation to the sulci and coronary arteries the septum can be approached with safety.

(2) The next anatomic structures in direct relationship to the operative field are the valves of the pulmonary artery and aorta anteriorly, and the tricuspid and mitral valves with their chordae tendineae more posteriorly. At the operation, it is necessary to pass the instrument and suture material down between these right and left series of valves so that none of them will be interfered with; so that the cusps are not caught in the suture material; so that the chordae tendineae and the papillary muscles are not caught in the sutures. Any serious interference with these structures would precipitate an immediate disastrous effect.

(3) The next structure to be avoided is the bundle of Hiss, or the conducting bundle which traverses the interventricular septum to reach the papillary muscles and ventricular walls.

These anatomic points will now be discussed in further detail.

The left coronary artery coming from the left sinus of Valsalva, courses toward the heart over a distance of about five-eighths to three-quarters of an inch. Reaching the anterior surface it divides into descending and transverse branches. The right arises from the right anterior sinus of Valsalva, courses distally to reach the posterior aspect of the heart, dividing into the right descending and transverse branches. In the books on the subject, these descending branches are placed in the anterior and posterior interventricular sulci.

To get more accurate information, Professor Grant and Dr. Mahanti dissected 15 hearts to determine the exact relationship of the septum to these surface markings. From within the heart, sutures were passed from both right and left surfaces of the septum, through the heart muscle, reaching the surface on both the anterior and posterior aspects. These sutures in a sense "staked-out" the margins of the septum as they reached the surface on both anterior and posterior surfaces and demonstrated the relationship of the attachment of the septum, to the anterior and posterior sulci, as well as to the descending branches of the coronary artery.

On the posterior surface, the interventricular sulcus corresponded to the attachment of the septum in six. The septum was attached to the left of the sulcus in nine and to the right in only one.

The descending vessels, both arteries and veins, were examined in relation to the septum. The septum was found to be attached to the left of the vessels in eight, over the line of the vessels in five and to the right of the vessels in two.

On the anterior surface, the descending branch appeared to lie more closely in relation to the sulcus than it did in the posterior, and the relationship to the septum was slightly more constant. It was demonstrated that if a point was taken to the right of the descending branch in front, and imme-

diately distal to the auriculo-ventricular sulcus, this fairly accurately marked out the attachment of the septum anteriorly. (Fig. 1)

If with an opaque medium, a defect in the interventricular septum should be demonstrated at a more distal point, such as occurs in the Rogere type, then suitable points in this corridor, both anteriorly and posteriorly would give a direct approach to the site of the defect.

Regarding the valve rings in the annulus fibrosis or skeleton of the heart, there are many diagrams in Quain's, Gray's, Cunningham's, Grant's

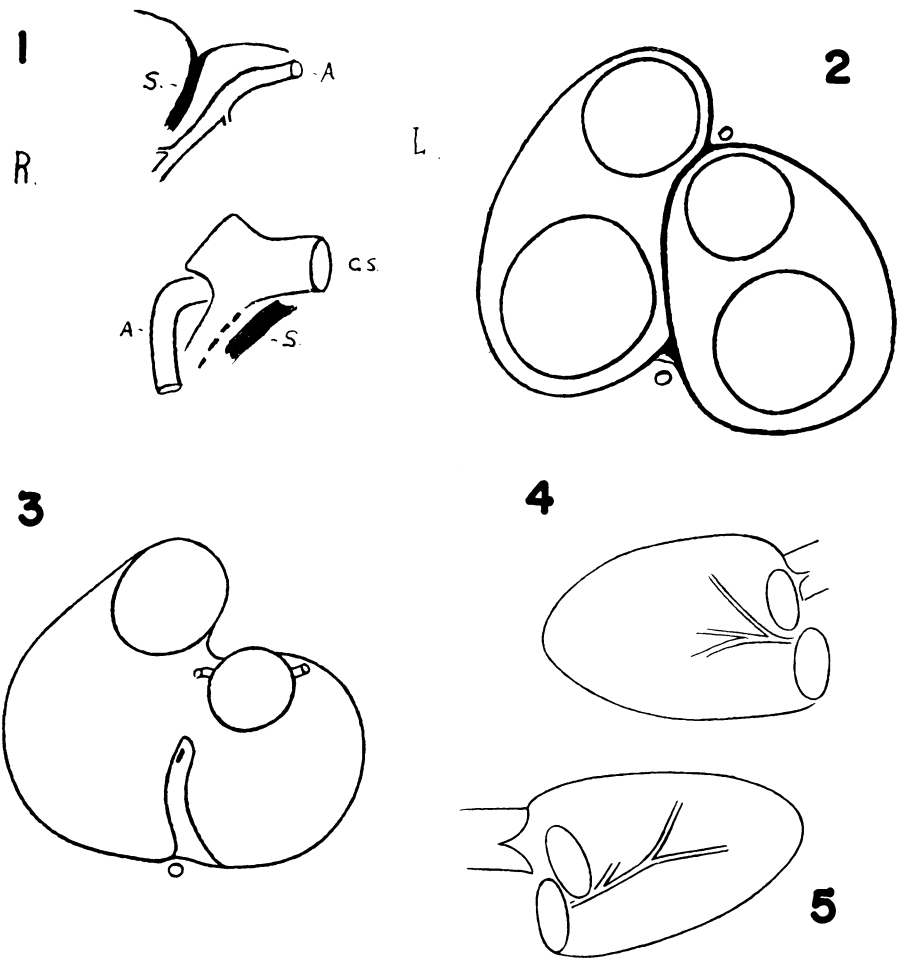

FIG. 1. *Top* S—septum, upper end seen from front and, A—coronary artery anterior descending branch. Showing relationship of upper end of septum to artery. *Bottom* S—septum A—descending branch right coronary, C S—coronary sinus. Showing relationship of septum to these structures on posterior surface of ventricles.

FIG. 2.—Diagram of annulus fibrosis with ventricles removed, showing valve seats and the relationship of the attachment of the base of the interventricular septum between the right and left groups.

FIG. 3.—Diagram of annulus fibrosis and the attachment of the base of interventricular septum in the presence of a patent septum.

FIG. 4.—Course of Bundle of Hiss seen from left ventricle.

FIG. 5.—Same—seen from right ventricle.

Atlas, Buchanan's and in many of the anatomies. To get further details, we did many dissections, again with the assistance of Professor Grant, as well as in the postmortem room, and Figure 2 represents our impression of what we found in relation to this. On looking at the diagram it is rather disconcerting to see that the attachment of the base of the septum to the annulus fibrosis, between the pulmonary and aortic valves anteriorly, and the tricuspid and mitral valves posteriorly, is curved. However, we have found practically, that to follow this line and place a foreign body or suture, in this line, is not as difficult as might appear, especially is this so when there is a hiatus and consequently the curves are not present. (Fig. 3.) The other problem which arose in placing such a suture was the possible presence of a dextraposed aorta. So far picking up the annulus fibrosis between the aortic and pulmonary rings in order to seal off completely the right margin of the dilated base of the aorta which is seen in Eisenmenger's disease has not been accomplished. However, with a suture well placed, it was hoped that it might provide useful occlusion.

There probably is more of a safety margin between the mitral and tricuspid valves than might appear on theoretical consideration. The septal cusp of the mitral valve when open, does not lie closely against the interventricular septum, but the septal cusp of the tricuspid lies more closely to the septum during diastole. (Fig. 2.) The attachment of the chordae tendineae to papillary muscles leaves a moderate space, probably up to half an inch, between them, through which there is room to work with little danger. We have had little difficulty in passing this area.

(3) Regarding the bundle of Hiss, there are many excellent dissections including those by Professor Grant and Dr. Mahanti, showing the course of this bundle. It arises posteriorly in the wall of the right auricle, traverses the annulus fibrosis and is directed forward and downward, posterior to, then below or, in the margin of, the membranous septum. In some congenital hearts, with a patent septum, the bundle was found to lie in the existing muscular portion posterior to the hiatus. At its origin it lies beneath the endocardium on the right side of the septum in the position indicated. As it passes distally beneath the pars membranacea septi, it divides into right and left bundles, the left passing through the substance of the muscular portion of septum to reach the plane beneath the endocardium on the left side of the septum from whence it courses to the musculature and papillary muscles of the left ventricle.

An instrument or suture passed through the heart, as described, necessarily crosses almost at right angles to the course of this bundle, and it, of course, must not be injured. The instrument and suture should pass in the direct line of the septum or slightly to its left to avoid the bundle as it lies beneath the endocardium on the right surface of the septum. Neither in our experimental work nor in the clinical patients operated upon, has there been evidence of ill effects produced by injury to the bundle of Hiss. Figure 4

shows and interventricular septum looked at from the left ventricular surface and No. V looked at from the right ventricular surface, indicating the course of the bundle of Hiss, in relation to the pars membranacea septi and the muscular portion of interventricular septum.

The interauricular septal defect also presents a challenge, but it is much less difficult to meet than is the interventricular defect, chiefly because the structures in relation to the field are easier to avoid.

Usually an interauricular septal defect is a persisting foramen primum and not foramen ovale. If giving symptoms or cardiac enlargement the defect is large. It causes ill effects by allowing left auricular blood which has just returned from the lungs to flow into the right auricle from which it again goes to the lungs with unsatisfactory completion of circulation. The ingenious method described by Cohn[2] of San Francisco has worked very well in experimental animals in their hands, and can be applied quite satisfactorily to small septal defects between the auricles. However, small septal defects probably cause few clinical symptoms, and their method would be difficult to apply in larger septal defects and in those in which the septum is practically missing.

In about 30 animals we have passed sutures through in the line of the interauricular septum beginning at the site of the transverse sinus behind the aorta, and coming out posteriorly between the superior vena cava and the right pulmonary veins. With two, three or four sutures through in this way, pulled taut, tied together posteriorly and then tied anteriorly, we have been able to compress the anterior to the posterior wall of the auricle in such a way as completely to occlude the defect. It has the other advantage of diminishing the size of the enlarged auricles. On examination of specimens, the anterior wall of auricles has healed to the posterior wall in such a way as to cause complete occlusion of the defect and construction of what appears to be another interauricular septum.

CASE REPORTS

Case 1.—C. G.: The first patient operated upon was a child of 17 months. There was fairly marked cynaosis and moderate clubbing. The child had not walked and had so little energy she would sit only when supported. The mother described a persistent cough and sputum, which was shown at operation to be related to atelectasis of the whole left lung. The heart was greatly enlarged. (Fig. 6.)

Operation. Cyclopropane was supplemented by continuous intravenous of one-tenth per cent novocaine solution. Exploration was made through the second left intercostal space down the middle of the sterum and out through the sixth space. On opening the pericardium one per cent novocaine solution was sprayed over the surface of the heart. A suture was passed through the apex of the left ventricle. Apart from extra systoles, there were no untoward effects. The heart was then dislocated forward and examination of the posterior surface carried out without difficulty. During this, the heart became more blue, and there seemed to be some embarassment of its action. However, on allowing it to return to its normal position, it recovered its poise and normal action. The heart was about two and one-half to three times normal size. It showed some cyanosis. The right

ventricle was enlarged and appeared to be roughly equal to that of the left. The pulmonary artery was greatly dilated and had high pressure; on palpation it felt equal to that of the aorta. The coronary vessels appeared normal.

A strip of fascia lata about three-quarters of an inch in width and six inches in length with a good blob of tensor fascia femoris muscle on the upper end, was removed. Through the other end a silk suture was attached. This was threaded on a straight sewing needle four inches in length.

A point was selected on the anterior surface of the heart, above and slightly to the right of the descending branch of the left coronary artery, just distal to the annulus fibrosis. Here, one per cent novocaine solution was injected, making

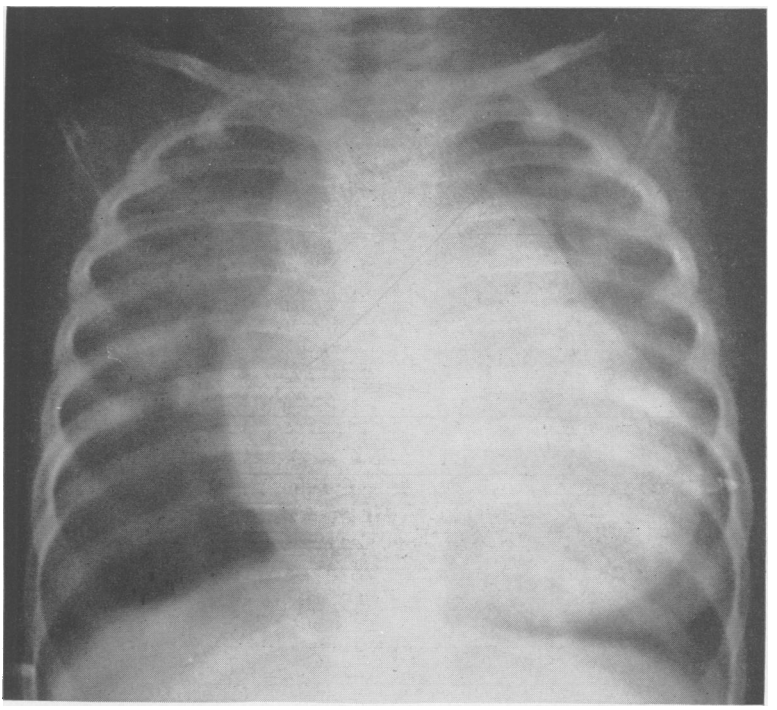

FIG. 6.—Rontgenogram showing size and shape of heart in child 17 months of age.

a bleb beneath the epicardium. With the threaded needle reversed, it was passed through the anterior wall of the heart, at the point mentioned. There were some extra systoles, but no other disturbance of the heart action. When the blunt end of the needle had passed through the wall of the heart, it felt as if it were in a cavity and not in the substance of the septum. On palpation with this needle, as with a probe, it was found to be in a fair sized hiatus measuring about 1.5 cm. It was passed across the hiatus until an obstruction was met at the posterior surface. Then on swinging the heart forward, by traction on the apex, and with the finger posteriorly, the end of the needle could be felt, like the end of a probe through the heart muscle posteriorly. The right position was then selected and the needle passed on through the posterior wall appearing through the epicardium. There was no injury to coronary vessels or coronary sinus. By the time this was completed, the heart became moderately cyanosed and showed some irregular action. However, on allowing it to go back into its normal position, with the needle

still through the heart, the heart regained its regular action and poise. The cyanosis which had appeared, diminished and the blood pressure remained normal. The needle was left in situ, through the heart for several minutes, to see if there was any interference with mitral or tricuspid valves, or any other ill effect. The cardiac conduction appeared to be normal. The needle was then drawn through posteriorly and with it the silk and living suture. Again this was held lightly in position, by slight traction on the posterior end, to observe any ill effects. If necessary we could, at any moment, remove the suture. However, there were no ill effects. Traction on the suture was increased, causing it to tighten across the hiatus, and almost immediately there was some improvement in the appear-

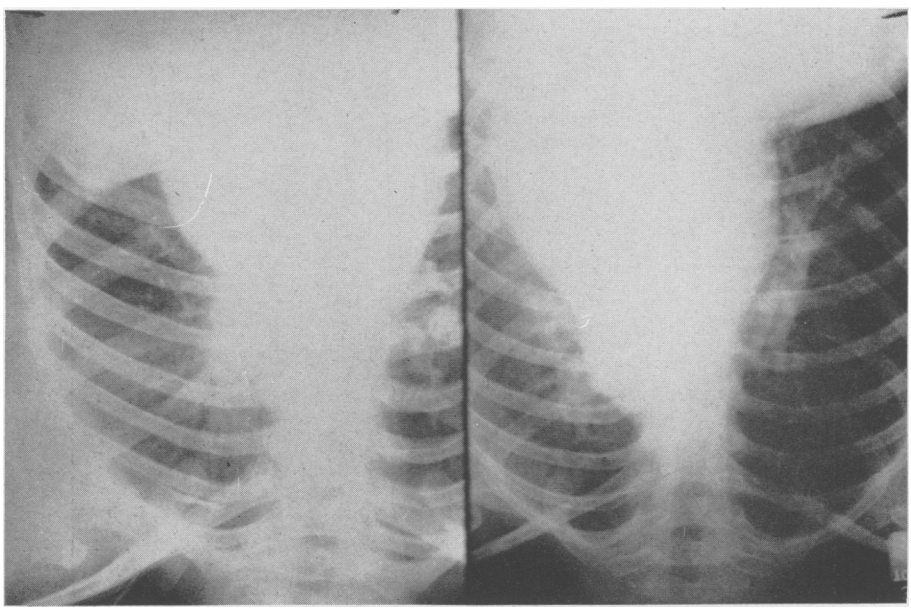

FIG. 7. Age 11—Patent interventricular septum.
On left—before operation.
On right—ten days post operation shows some inflammatory oedema at lung hilus, also change in size and shape of heart.

ance of the heart. Its size, particularly of the right ventricle, diminished quite considerably. The color of the heart improved and there seemed to be no ill effects. The anesthetist found no change in the patient's condition or blood pressure. It was thought, therefore, that perhaps the suture was in a satisfactory position and was performing some useful function. While moderate traction was applied to the posterior end of the suture, it was stitched to the epicardium at several points, avoiding branches of the coronary artery. This moderate tension caused some anteroposterior compression of the heart at the site of the hiatus. The mass of muscle in the anterior end of the suture, plugged the anterior opening in the heart satisfactorily. There was practically no hemorrhage and the patient stood the operation very well. The pericardium was repaired and the chest closed.

Case 2.—W. L., age 11: The patient was not cyanosed but had little energy. Examination showed an enlarged heart. He was operated upon through an exposure similar to the above. The heart was about three times normal size. A

living suture was passed through in a fashion similar to that described. The patient stood the operation very well. There were no ill effects whatever. On tightening the suture in position, there was marked diminution in size of the heart with improvement of its color. Blood pressure which was 120 systolic at the beginning, during the operation fell to 108, but by completion of the operation had returned to 120.

The patient made an uninterrupted recovery. On the fourth day he was given heparin for a period of seven days, keeping his clotting time between eight and 14 minutes. The result seemed to be quite satisfactory, although the late result cannot be determined as yet. Figure 7 shows the heart roentgenograms before and 10 days after operation.

Case 3.—BB., age 13: This patient was operated on quite satisfactorily with similarly good results.

Two other patients were explored hoping to carry out a similar procedure. However, in both of these, transposition of great vessels was discovered which had not been revealed with certainty by clinical, radiographic evidence or by catheterization of the heart. In these no interferenc with the heart was carried out.

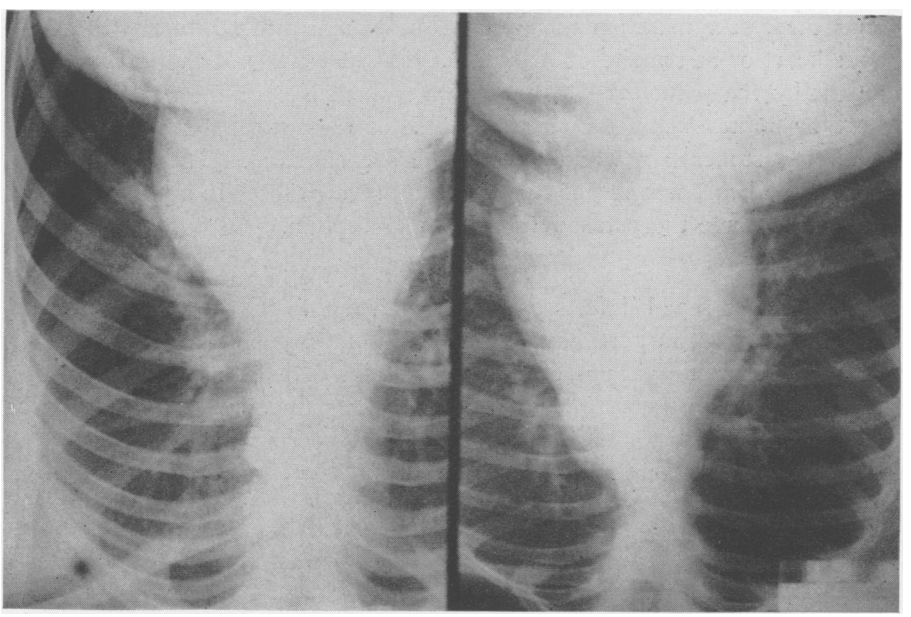

FIG. 8.—Patent interauricular septum.
On left—before operation.
On right—Two weeks following operation showing change in size and shape of heart.

INTERAURICULAR SEPTUM

Case 4.—C. W., age 12: This patient was operated upon through a similar exposure, for a patent interauricular septal defect as well as what was thought to be a smaller patent interventricular septal defect. At operation the right auricle was found enormously enlarged, probably ten times the size of the left. The auricular appendage was at least ten times as large as that on the left side. The ventricles, while enlarged, were small in comparison with the enormously enlarged right auricle. By means of the enlarged right auricle, the heart was already rotated very much to the left so that the aorta appeared on the right

side of the pulmonary artery. It was decided, therefore, to place our sutures of silk, in this case, beginning to the right of the aorta and pulmonary artery and emerging posteriorly through the area between the superior vena cava and the right pulmonary veins. Two sutures were passed through without difficulty. (It is the plan in future cases to pass more than two sutures.) These sutures were tied together posteriorly and were drawn taut from the anterior end and compressed with the finger. This caused a very great change in the size, shape and color of the heart. The right auricle diminished to at least one-half its size within about two minutes. The patient's general condition was good. The blood pressure remained normal. The sutures, after experimenting with this for some time, were tied down firmly, compressing the anterior and posterior walls of the auricles. This caused continued improvement in the patient's condition. The chest cavity was then closed without drainage. (Fig. 8.)

The patient made an uninterrupted recovery. From the fourth to the 11th day she was given heparin[4] to prevent propagating thrombosis from the area of suture. She made a good recovery and her general health is much improved. As there was very little cyanosis before, there was little improvement on this account.

One of these patients undergoing operation for interventricular septal defect died. Examination showed that the patient died not of any ill effects in the heart or at the site of operation. The atelectasis of the left lung was thought by the pathologist to have been responsible for the death, and this would be borne out by the clinical course of the patient toward the end of the first postoperative week, which time she survived. The suture going through the heart was in good position and seemed to be in a position to occlude to a degree the patent interventricular septum.

CONCLUSIONS

The cardiac septal defects present a challenge to the surgeon. Attempts at closure, at least in part, have been carried out experimentally, and in clinical patients resulting in moderate improvement. This would suggest further work which might go on to produce better effects anatomically and clinically. The demonstration that this can be done with safety is probably the chief feature of the present work.

REFERENCES

[1] Taussig, H. B.: The Surgical Treatment of Congenital Heart Disease; Commonwealth Fund; 1947.

[2] Cohn, Roy, Experimental Method of Closure of Interauricular Septal Defects in Dogs; Am. Heart J. **33**: 453, 1947.

[3] Murray, Gordon; F. R. Wilkinson, R. MacKenzie: Reconstruction of the Valves of the Heart; Canadian M. A. J. **38**: 317-319, 1938.

[4] Amer. Jour. Med.

DISCUSSION.—DR. ARTHUR H. BLAKEMORE, New York: I certainly enjoyed this presentation. I heard via grapevine what was going on in Toronto and I congratulate Dr. Murray. Some years before the war, I think in 1939, we did some experimental closures of the septa in dogs, that we had made by a punch. We were rather interested in seeing how well simple inversion of the auricular appendage worked when pushed through the opening and, after getting it in there, packing in some fascia lata to make it a self-retaining ball on the other side of the septum.

I should like to ask Dr. Murray what kind of needle he used and also would like to know how tight he drew the interventricular septal sutures.