SURGICAL TREATMENT OF FORTY-SIX INTERATRIAL SEPTAL DEFECTS BY ATRIO-SEPTO-PEXY*

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IN PREVIOUS COMMUNICATIONS,[1, 2, 19] the concept and technic of atrio-septo-pexy for the closure of interatrial septal defects has been presented. These described clearly the principle of suturing an invaginated portion of the redundant right atrial wall to the periphery of the defect. This completely closes the defect with a superimposed patch of normal atrial wall at the expense of converting the dilated globular right atrium into a doughtnut-shaped chamber (Fig. 1).

However, subsequent and increasing experience with these defects has impressed us with the fact that the defect may not be surrounded by a complete rim or margin of septal tissue. Indeed, such tissue is frequently missing in the upper and ventral portion of the septum. Even when a complete peripheral rim is present, complete circumscription by suturing may not be feasible when the defect is large because of the required extreme sacrifice of effective right atrial lumen. Practically, the problem has been solved in a number of cases by simply suturing the redundant atrial wall to the free edge of the posterior septal remnant (Fig. 2 A and B). This results in conversion of the globular right atrial cavity into a U-shaped chamber which lies posterior to the defect. One might say that the right atrial blood passageway had been displaced posteriorly to and below the defect.

Consideration of this change in the basic principle of the operation led to a re-evaluation of our objectives. While we had previously considered actual mechanical closure of the defect to be the primary objective, here it was obvious that the physiological abnormality had been corrected completely, without any actual closure of the defect which still remained in free communication with the left atrium. All we had accomplished was complete separation of the systemic and pulmonic venous systems.

On reconsideration of the functions of the right atrium, we determined them to be:

(1) Initiation of the contractile impulse of the heart and transmission to the ventricles—pacemaker function.

(2) Conduction of the vena caval and coronary sinus blood to the tricuspid valve without admixture with the pulmonary venous blood.

(3) A reservoir function in order to provide more rapid right ventricular filling during diastole.

(4) Propulsion of its contents through the tricuspid valve during the proper phase of cardiac contraction.

It was evident immediately that the last two functions are subsidiary or minor, as illustrated by the excellent ventricular filling

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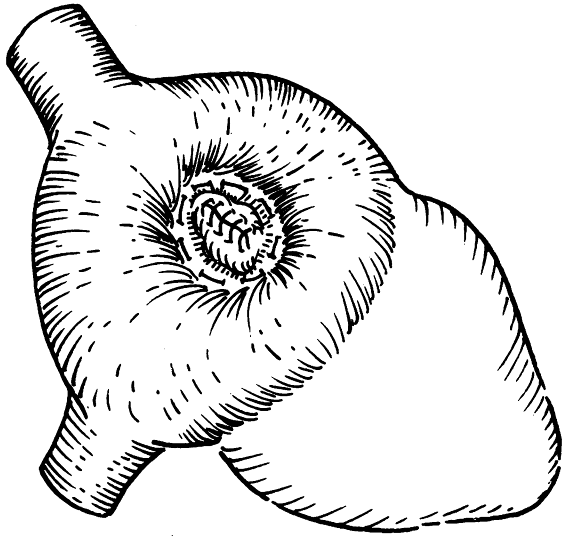


FIG. 1. Classical atrio-septo-pexy. Invagination of the redundant right atrial wall and suture approximation to the periphery of the defect. Suitable for moderate-sized central defects.

obtained in well-controlled atrial fibrillation in which co-ordinated atrial contraction has been lost, and by the good cardiac action observed after removal of a large portion of an atrium, a procedure carried out not infrequently during radical pneumonectomy for cancer.

The pacemaker function is centered in the sino-auricular node located in the crista terminalis at the junction of the right atrium with the superior vena cava. However, it is mediated diffusely through the atrial wall to the atrioventricular node rather than through a definite pathway, and scarcely can be interrupted by any surgical technic short of complete transverse interruption of the continuity of the right atrium. However, the atrioventricular node or the common conduction bundle (of His) might well be injured by sutures with production of complete atrioventricular block.

Obviously that function of the right atrium which is significantly disordered in atrial septal defects is the second one. Whether there is a right-to-left shunt or a left-to-right shunt, this function of flow from venae cavae to the tricuspid valve is disturbed. An admixture with the pulmonary venous blood is prominent in all cases except those in which a congenital or acquired increase in the pulmonary vascular resistance or some impedance in the passage of blood through the right ventricle or pulmonary artery prevents a significant shunt through the defect. Therefore, we may say that our primary objective in corrective surgery for atrial septal defects is complete separation of the two venous systems to the respective atrioventricular valves rather than anatomical closure of the defect.

In some cases with increased pulmonary resistance, the defect performs an important compensatory function which may not be safely interrupted until after the associated lesion has been corrected. When the increased vascular resistance of the pulmonary arteries is of fetal or vasospastic (compensatory) origin, the effect will subside after surgical correction of the disturbed function of the right atrium. However, if it is due to degenerative (arteriolosclerotic) changes in the lung, perhaps induced by long-continued excessive blood flow through the pulmonary vessels (left-to-right shunt) and associated spastic hypertension, no improvement can be expected after surgery and, conceivably, the patient would be rendered significantly worse by it. Kay and Zimmerman[4] have reported a high postoperative mortality in a

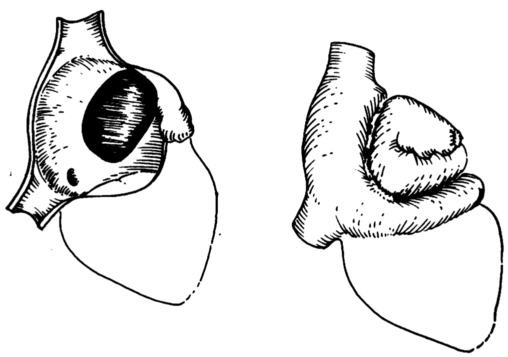
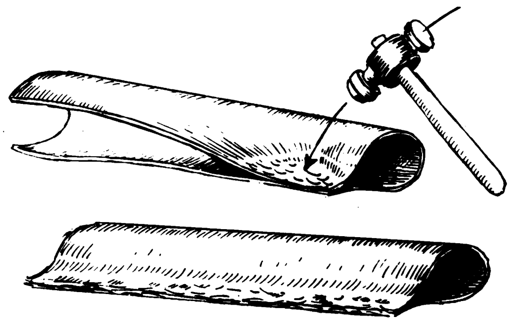


FIG. 2. (A) Large defect with incomplete septal margin. (B) Atrio-septo-pexy which displaces the effective right atrial chamber posterior to and caudal to the defect which remains anatomically existent.

A



B

FIG. 3. (A) Ancient Pompeian (or Roman) method of manufacturing water pipes. (B) Final eccentric cross-sectional lumen of pipe (after heat treatment).

small series of patients who preoperatively presented a right-to-left shunt.

In June, 1953, when one of the writers (C. P. B.) visited the ruins of Pompeii, he was impressed by the method of construction of the waterpipes used in ancient Roman days. Apparently the construction of round pipes was not technically feasible, so eccentric-shaped pipes were created by longitudinally folding long strips of lead sheeting. The approximated edges were sealed together by heat. This produced a conductive pipe with a teardrop-shaped cross section (Fig. 3).

Immediately, this author realized that a superficially similar technic might be employed in patients with very large atrial defects, perhaps amounting nearly to a state of a single atrial chamber. By compressing the redundant anterolateral wall of the right atrium against the posterior wall of the common atrium by the thumb and finger, keeping to the right of the entrance of the mouths of the right pulmonary veins, mattress sutures could be placed to maintain this approximation, thus creating a new intracardiac passageway for the flow of the vena caval blood (Fig. 4).

This passageway would begin at the mouth of the superior vena cava just to the right of the *crista terminalis* and would continue down to the region of the ostium of the coronary sinus. At this point the blood flow from the inferior vena cava and the coronary sinus would join that from the superior vena cava.

Now, if a remnant of the *septum primum* persisted between and above the tricuspid and mitral valves, it would be easy to align the construction of the intracardiac vena caval channel toward the ventral aspect of the heart by approximating the lateral wall of the atrium to this lower remnant of the septum all the way to the anterior wall of the heart. Thus would be created a channel for the flow of systemic venous blood to the tricuspid valve, entirely separated from the pulmonary venous blood. This would accomplish our fundamental and primary objective even though the defect were not attacked directly. Even if no septal remnant persisted except the one between the atrioventricular valves this technic is applicable. This operation has come to be known as the Pompeian version of atrio-septo-pexy.

However, while this procedure is very satisfactory in those patients who have a persistent remnant of lower septal tissue, it obviously is not complete applicable in those in whom the *septum primum* is totally absent (persistent *ostium primum*), whether or not a *septum secundum* is present.

An attempt to apply this technic in such a patient (persistent *ostium primum* with nearly complete absence of the *septum secundum*) by placing the lower sutures between the right atrial wall and the raphe of tissue lying between the mitral and tricuspid valves, really the upper margin of the interventricular septum, has caused complete interruption of the common conduction bundle of His and atrioventricular dissociation. The subsequent death and certain preceding ones due to such interruption of the conduction bundle have emphasized that this insult often is intolerable and must be prevented at all costs. We were faced, therefore, with the possibility of having to accept the apparent necessity of permitting

A B

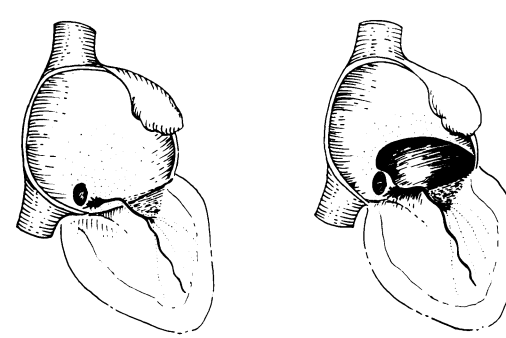
FIG. 4. (A) Pompeian type of atrio-septo-pexy—creation of an eccentric luminal intracardiac passageway for vena caval flow. (B) Cross sectional relationships of new intracardiac passageways above level of transverse portion of passage.

some residual interatrial communication to remain in patients with defects of the *ostium primum* type. However, since this would imply a failure of accomplishment of our objective of separation of the two venous systems, we were not willing to accept this conclusion.

After careful review of the anatomy pertinent to this problem, the following points became clear. The ostium of the coronary sinus is located just ventral (anterior) to the entrance of the inferior vena cava. Normally it lies in the atrial septum, but in the absence of atrial septal tissue in this area it stands up independently just cephalad to the interventricular septum. It is a landmark readily recognizable by intracardiac digital palpation. If in doubt, the operator may reassure himself of its location by inserting the Bolton cardioscope[4] to visualize this region.

The atrioventricular node is found just ventral, and somewhat caudal, to the coronary sinus, usually being located in the interatrial septum. In these cases of persistent *ostium primum*, it lies upon the right aspect of the surface of the upper edge of the interventricular septum. The common conduction bundle extends from it, usually under the epicardium of the right side of the lower atrial septum just above the interventricular septum, and proceeds forward to the junction of the membranous and muscular portions of the interventricular septum. It then deviates toward the ventricle, running on the right side of the junction of these two portions of the ventricular septum. At the lower margin of the membranous portion of the interventricular septum, it divides into two branches, of which the right continues down the right aspect of the muscular portion of the interventricular septum, while the left divides into several rami which pierce the septum and spread out along its left surface.

In a defect of the *ostium primum* type, since there is no lower atrial septal tissue, the common conduction bundle runs along the free upper margin of the muscular por-



A B

FIG. 5. (A) Normal anatomical relations of atrioventricular conduction system. (B) Relations of atrioventricular conduction system in persistent ostium primum.

TABLE I. *Defects of Atrial Septum Secundum.*

	Initial	Case No.	Age	Sex	Operative Date	Associated Venous Anomaly	Lutem. Synd.	Preoperative Catheterization Shunt	Preoperative Catheterization Amount	Post-operative Catheterization	Transp. of Veins	Clinical Result
1	P. F.	65121	38	WF	1-11-52	No	No	L-R	13.2L/min.	Defect closed	No	Good
2	M. S.	73901	41	WF	8-4-52	R. Pulm. V. entered rt. atrium	No	L-R	4.3L/min.	Defect closed	Yes	Good
3	B. C.	74855	40	WF	8-25-52	No	No	L-R R-L overall L-R	1.3L/min. 0.7L/min. 0.6L/min.	No	No	Death in operating room.
4	J. S.	75971	11	WF	9-19-52	R. Pulm. V. entered rt. atrium	No	L-R	26.0L/min.	Defect closed	Yes	Good
5	J. C.	77508	35	WM	10-27-52	No	No	L-R	1.8L/min.	Shunt greatly reduced	No	Good
6	R. B.	78217	44	WF	11-10-52	No	Yes		At. defect Dx at surgery	Defect closed	No	Good
7	T. S.	81647	6	WM	1-29-52	R. Pulm. V. entered rt. atrium	No	L-R		Defect closed	Yes	Good
8	C. M.	Brazil	8	WF	2-12-53	No	No	L-R	6.0L/min.	Defect closed	No	Good
9	J. R.	Brazil	31	WM	2-13-53	No	Yes	L-R	6.0L/min.	No	No	Good
10	H. N.	Chicago	39	WM	3-5-53	P. inf. Pulm. V. entered rt. atrium	No	L-R	6.0L/min.	No	Yes	Good
11	M. K.	Doctors' Hosp., Phila.	24	WF	3-6-53	No	No	L-R	13.0L/min.	Defect closed	No	Good
12	Y. N.	83452	35	WF	3-9-53	Sup. pulm. v. entered superior vena cava	No	L-R R-L	0.35/Lmin. 0.3L/min.	—	Yes	Death in O. R.
13	J. B.	83639	22	WF	3-16-53	No	No	L-R	8.7L/min.	Defect closed	No	Good
14	C. F.	83640	22	WM	3-19-53	No	No	L-R	4.5L/min.	Defect closed	No	Good
15	A. B.	85007	50	WF	4-20-53	No	Yes Some thickening of valve	L-R R-L overall L-R	4.3L/min. 0.54L/min. 3.76L/min.	No	No	Good
16	M. F.	86415	49	WF	5-8-53	No	No	L-R	3.8L/min.	No	No	Good
17	R. F.	84961	39	WF	4-13-53	No	No	L-R	3.7L/min.	No	No	Good
18	M. J.	85625	40	WF	5-4-53	No	No	L-R	4.6L/min.	No	No	Good
19	G. C.	87122	51	WM	6-1-53	No	No	L-R	5.3L/min.	Defect closed	No	Good
20	C. M.	89178	11	WF	7-10-53	No	No	L-R	3.6L/min.	No	No	Good
21	N. N.	Paris	12½	WF	7-21-53	No	No	—	—	—	No	Good
22	M. P.	London	30	WF	4-7-53	No	No	—	—	—	No	Death 2 weeks postoperatively
23	H. V.	Holland	10	WM	6-18-53	No	No	—	—	—	No	Good
24	J. R.	90456	37	WF	8-13-53	No	No	L-R R-L	6.1L/min. 6.1L/min.	No	No	Good
25	C. S.	92381	18	WM	10-2-53	No	No	L-R	3.9L/min.	Shunt reduced	No	Good
26	L. M.	Army Hosp.	20	WM	11-2-53	No	No	L-R	22.3L/min.	Defect closed	No	Good
27	L. C.	Army Hosp.	35	WF	11-2-53	No	No	L-R	4.2L/min.	Defect closed	No	Good
28	D. O.	94009	38	WF	11-5-53	No	No	L-R	14.3L/min.	No	No	Good
29	B. S.	Army Hosp.	35	WF	11-3-53	No	No	L-R	3.1L/min.	Defect closed	No	Good
30	N. H.	1954959	27	WM	2-12-54	No	No	L-R	5.5L/min.	Defect closed	No	Good

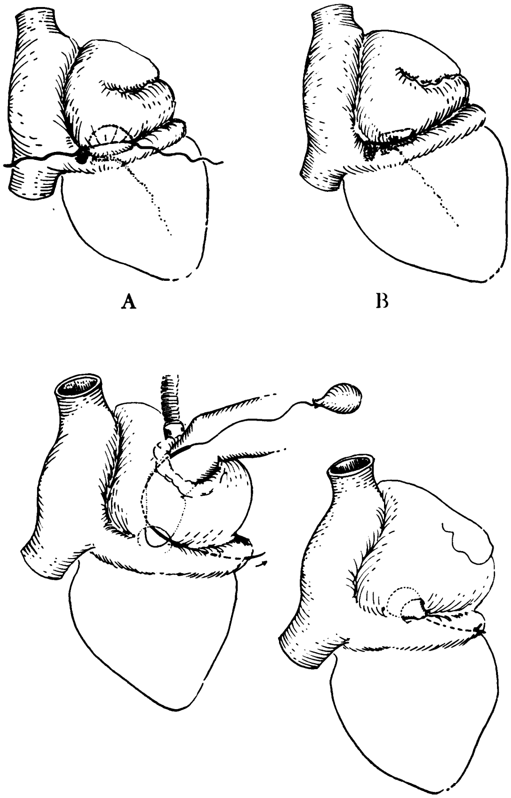


FIG. 6. (A) Placement of large mattress suture through the safe points anterior and posterior to the course of the atrioventricular conduction system. (B) Tying down of mattress suture reduces but does not obliterate residual communication between venous systems. (C) Passage of large needle through residual communication from the left to emerge from anterior and lateral portion of newly created passageway. (D) Fat-bag drawn into position completely blocking residual communication from the left side.

tion of the interventricular septum to the line of its junction with the membranous portion (Fig. 5 A and B).

It is obvious, therefore, that sutures placed in the edge of the muscular portion of the interventricular septum ventral (anterior) to the coronary sinus ostium must usually encircle completely the common conduction bundle. However, a suture can be placed safely in the upper lip of the ostium of the coronary sinus. Furthermore, sutures can be placed with safety in the most ventral (anterior) portion of the interventricular septum, which is the membranous part. Thus, it is safe to complete an intracardiac channel of the Pompeian type in these cases except for the short interval between these two points of safety in the lower or transverse portion of its course. Intracardiac exploration with the finger then will reveal this residual communication to the left atrium to be large enough to permit the passage of the operator's terminal phalanx. While a communication of this size is preferable to persistence of a very large defect (perhaps amounting physiologically to a single atrium), such an end result obviously leaves much to be desired.

Consideration of possible methods by which this residual opening might be closed leads to two applicable approaches. In the first, a suture on a large curved needle is passed through the most posterior safe point of the anterior segment of the interrupted suture line. This pierces the right atrial wall, and the membranous part of the interventricular septum, to enter the left atrial chamber. Then, the needle is redirected in such a way that it pierces the previously sutured upper lip of the ostium of the coronary sinus, emerging through the now adjacent suture-approximated wall of the right atrium. This suture is really a large encompassing mattress suture which, on being tied down, will reduce the size of the residual communication (Fig. 6 A and B). The exploring finger now will usually find an opening just large enough to engage the finger tip. However, the opening will not be completely abolished by this suture.

In order to block completely this final communication, we have adopted a modification of Kiriluk's[6] method of plugging a small interatrial septal defect with a small bag of pericardial fat prepared from an excised patch of pericardial tissue. This fat tampon is placed on the left atrial aspect of the residual opening by traction of a suture which is passed by the use of a curved probe or needle through the right atrial appendage along the intracardiac finger to traverse the residual "defect" and to emerge from the ventral portion of the lateral wall of the defective portion of the newly created intracardiac passageway. By a combination of these methods it therefore is possible to separate completely the two venous circulations even in cases in which there is a total absence of atrial septal tissue. Donald[7] has recently suggested a modification of Kiriluk's technic, consisting in the use of polyvinyl plastic enclosed in a pericardial bag. Whether this would offer any advantages over the method described above remains to be seen (Fig. 6 C and D).

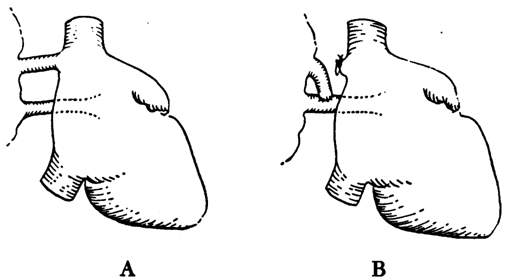


Fig. 7. (A) One right pulmonary vein anomalous (into superior vena cava) the other normal, no septal defect. (B) Surgical correction by implantation of end of divided abnormal into side of normal vein.

It is realized that many other ingenious methods of closure of interatrial septal defects have been suggested and tried clinically, notably by Murray,[18] Swan,[22, 23] Gross,[8–10] Sondergaard,[21] Björk and Crafoord,[3] Gibbon,[7] Lewis,[15] Shumacker,[20] Kirklin[14] and Dodrill.[5]

ASSOCIATED ANOMALOUS PULMONARY VENOUS DRAINAGE

We have encountered clinically seven cases in which there was anomalous drainage of one or more pulmonary veins. Discussion of the surgical correction of such anomalies by Muller,[17] by Neptune *et al.*,[19] and by Bailey *et al.*,[2] would seem to justify the simultaneous management of such abnormal venous drainage at the time of surgical treatment of coexisting septal defects. While this would seem to be adequate, it may be well to summarize briefly the treatment of the various combinations encountered.

When one right pulmonary vein is anomalous and the other empties normally, there may be no coexistent interatrial septal defect. Whether the anomalous vein drains into the superior vena cava or into the right atrium, it is probably best handled by simply dividing it at its termination between Potts toothed clamps and reimplanting it in end-to-side fashion into the main trunk of the normally draining right pulmonary vein (Fig. 7 A and B).

When both right pulmonary veins drain into the right atrium, there usually is an associated interatrial septal defect located posteriorly in close proximity to the mouths of these vessels. The unusual location of these defects suggests that the formation of the septum in this region during embryonic life may have been impaired significantly by the direct transseptal flow of blood from these veins. At any rate, they are ideally located from the surgeon's standpoint, since simple approximation of the lateral atrial wall to the entire margin of the defect (there being no posterior edge to the defect) results in conversion of the right atrial chamber into two compartments, a small posterior one which, from this point on, drains the right pulmonary venous blood directly into the left atrium, and a larger anterior one which continues to communicate the venae cavae with the tricuspid valve (Fig. 8 A and B). Again, it will be noted that the atrial defect will not have been closed anatomically, since it still exists as a passageway for blood to flow from the right pulmonary veins to the left atrium. Physiologically, the two venous systems have been completely separated. In those rare individuals in whom the atrial defect initially is small or absent, it will be necessary to incise the septum, perhaps with the cardioscope,[4] before placing the sutures into its anterior edge. Otherwise, the residual pas-

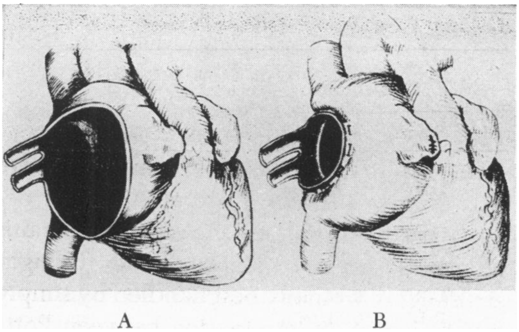


FIG. 8. (A) Anomalous drainage of both right pulmonary veins (into right atrium) in association with classically posteriorly located and contiguous septal defect. (B) Correction by suturing redundant atrial wall to anterior margin of defect. Veins become re-transposed and venous circulations completely separated. These pictures are reproduced with permission of J. Thor. Surg. (C. V. Mosby Co.).

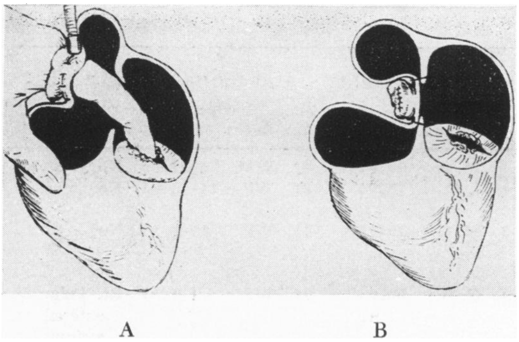


FIG. 9. (A) Performance of digital commissurotomy *via* right atrial appendage and septal defect in a case of Lutembacher's syndrome. (B) Correction of the defect by atrio-septo-pexy. These pictures are reproduced with permission of J. Thor. Surg. (C. V. Mosby Co.).

sageway for right pulmonary venous flow might be inadequate or lacking.

In patients in whom there is total anomalous venous drainage, the exact operative procedure depends upon the particular anatomical variant encountered. These have been adequately described[19] in a previous communication. Usually a two-stage operation is necessary, the first of which is performed on the left side to anastomose the left pulmonary venous trunk with the stump of the amputated left auricular appendage. The second stage is performed at a later time to close the defect and to re-transpose the right pulmonary veins if that has not been accomplished at the first operation.

COEXISTENT MITRAL STENOSIS

Lutembacher's syndrome[16] (interatrial septal defect plus significant mitral stenosis) was encountered three times in our series. In one case, undiagnosed atrial septal defect was encountered unexpectedly during the performance of commissurotomy, via the usual left thoracic approach, for the coexisting mitral stenosis. After closure of this wound, the right fourth intercostal space was opened, and a standard atrio-septo-pexy was performed with success. In the other two patients, accurate preoperative diagnosis permitted performance of a digital commissurotomy *via* the right auricular appendage and the septal defect prior to the closure of the latter by the standard technic of atrio-septo-pexy (Fig. 9 A and B). Since all these patients did well, we believe that this combination of lesions is a favorable one for corrective surgery.

MULTIPLE SEPTAL DEFECTS

In a certain number of these patients one will encounter multiple septal openings. This may amount to a lattice-like septum (Fig. 10) in which one may consider that the major portion is replaced by a large defect through which the string-like remnants happen to course. They are treated as single large defects. In other cases, several small defects may be closely aggregated so that they, too, may be considered as a single larger defect and so managed (Fig. 11). Occasionally, widely separated individual defects will be encountered (one was present in our series). These must each be treated individually by localized invagination of a portion of the redundant atrial wall. Attempts at closure of such defects by direct suturing are likely to fail both for technical reasons and because the delicate muscular structure of the septum tends to permit the sutures to cut through the tissue if they are

TABLE II. *Persistent Ostium Primum.*

	Initial	Case No.	Age	Sex	Operative Date	Associated Venous Anomaly	Lutem. Synd.	Preoperative Catherization: Shunt	Preoperative Catherization: Amount	Post-operative Catheter-ization	Transp. of Veins	Clinical Result
1	M. S.	74754	44	WM	5–22–52	No	No	L-R	2.4L/min.	No	No	Good
2	I. D.	78294	27	WF	11–10–52	No	No	L-R	3.3L/min.	—	No	Death day of operation
3	M. G.	79415	11	WF	12–8–52	No	No	Done elsewhere		—	No	Death 2 days postoperatively
4	G. H.	80193	27	WF	1–5–53	Rt. Pulm. V. entered rt. atrium	No	L-R R-L overall R-L	0.2L/min. 0.5L/min. 0.3L/min.	—	Yes	Death day of operation
5	M. K.	82658	25	WM	2–27–53	Rt. Pulm. V. entered rt. atrium	No	L-R	5.5L/min.	—	Yes	Death 42 days postoperatively
6	D. M.	Calif.	21	WM	3–27–53	No	No	L-R		No	No	Good
7	E. T.	89039	39	WF	7–9–53	No	No	L-R	4.5L/min.	—	No	Death 1 day postoperatively
8	A. C.	84126	17	WM	3–24–53	No	No	L-R	13.7L/min.	Defect Closed	No	Good
9	M. T.	84737	31	WF	4–14–53	No	No	L-R R-L overall L-R	5.3L/min. 0.9L/min. 4.4L/min.	—	No	Death 21 days postoperatively
10	J. P.	86586	23	WM	5–16–53	No	No	L-R R-L overall L-R	5.7L/min. 0.3L/min. 5.4L/min.	Defect Closed	No	Good
11	A. P.	89008	36	WF	7–13–53	No	No	L-R R-L overall L-R	8.9L/min. 0.6L/min. 8.3L/min.	—	No	Death 1 day postoperatively
12	L. W.	Germany	33	WF	6–17–53	No	No	L-R R-L overall L-R	5.4L/min. 0.4L/min. 5.0L/min.	—	No	Death 3 days postoperatively
13	J. W.	Holland	23	WM	6–19–53	No	No	L-R	30.6L/min.	—	No	Death 1 day postoperatively
14	J. C.	90211	5	WF	8–4–53	No	No	L-R		—	No	Death 1 day postoperatively
15	S. M.	Army Hosp.	4	WM	11–3–53	No	No			Shunt reduced	No	Unchanged
16	L. S.	Havana	14	CF	11-20-53	No	No			—	No	Death day of operation

applied under any tension, as is usual if the defect is over a few mm. in diameter.

There is appreciable risk of missing a second smaller interatrial septal defect or of failing to recognize the peripheral extent of grouped multiple fenestrations if only the palpating finger is relied upon for recognition. The Bolton[19] examining cardioscope has proven particularly valuable in this respect, since it permits accurate visualization of all parts of the interatrial septum.

SELECTION FOR SURGERY

At the present time, as might be expected, there are no clear-cut and well-established criteria for the surgical selection or rejection of patients with interatrial septal defects. Whether we should limit the operation to patients who present serious symptoms of cardiac insufficiency, or whether we should consider the anatomical existence of the lesion as an indication for correction remains to be seen. For the most part, patients in

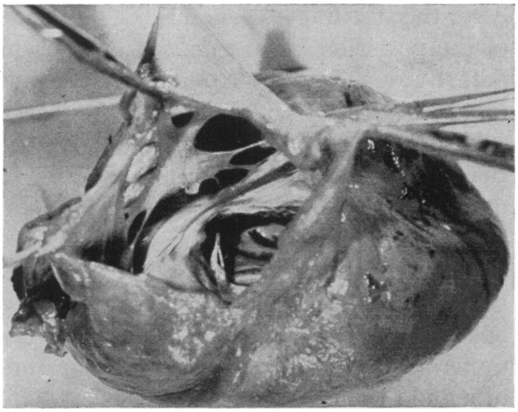


FIG. 10. Lattice-like remnants of atrial septum in a case with a very large defect. This picture is reproduced with permission of J. Thor. Surg. (C. V. Mosby Co.).

the former group apply to us for relief, while the asymptomatic group usually is not even recognized. It is our general belief that if cardiac catheterization reveals a pulmonary blood flow in excess of twice the systemic blood flow, the left-to-right shunt is of sufficient size eventually to destroy myocardial compensation. In many patients with serious symptoms the shunt is of lesser magnitude, presumably because of increased pulmonary vascular resistance. Surgery might tend to overcome this abnormality if irreversibility had not yet taken place. Whether surgery should be performed in patients with a right-to-left shunt is uncertain, since the defect may have a partially compensatory effect. Of our 13 deaths, seven patients had been in a fairly desperate clinical condition preoperatively. This would lead us in the future to be more conservative in recommending surgery when the patient has advanced so far.

SURGICAL TECHNIC

The patient is anesthetized by the usual combination of intravenous procaine and pentothal with the administration of endotracheal oxygen which has been recommended by Keown and associates.[12] The patient is placed in the supine position and a right anterolateral inframammary incision is made. The right fourth intercostal space is opened widely with division of the internal mammary vessels between clamps. The costal cartilages are divided at their sternal junction. The lung is compressed posteriorly. Before the interior of the right atrium is explored an electrocardiograph of the direct writing type is attached in order promptly to recognize any arrhythmia or conduction disturbance which may develop.

It is especially important for the surgeon or an assistant to refer constantly to the electrocardiogram while the sutures are being placed in the portion of the atrial septum lying between the mitral and tricuspid valves lest the common conduction bundle be encircled inadvertently. The risk of such a catastrophe, of course, is even greater in patients with persistent *ostium primum* during the placement of sutures in the midventral (junctional) portion of the interventricular septal edge. Should evidence of irritation of the conduction bundle appear during placement of one of these sutures, the suture should be cut and gently removed at once.

The pericardium is incised anterior to, and parallel with, the right phrenic nerve for its full length. At the level of the diaphragm, the pericardial incision is angulated forward in "hockey-stick" fashion. The anterior pericardial lip is suspended medially with weighted sutures. After inspection of the atrium and the great veins, a purse-string suture of No. 2 braided silk or nylon on an Atraumatic® curved needle is placed about the right auricular appendage, the ends of the suture being placed at a point between the superior vena cava and the aorta. This keeps the Rumel-Belmont tourniquet, in which they are incorporated, out of the line of probable suturing. The appendage is clamped with Satinsky forceps and its tip is incised for 2 cm. parallel to the clamp. All obstructing trabeculae are divided. The operator's ungloved left index finger tip is

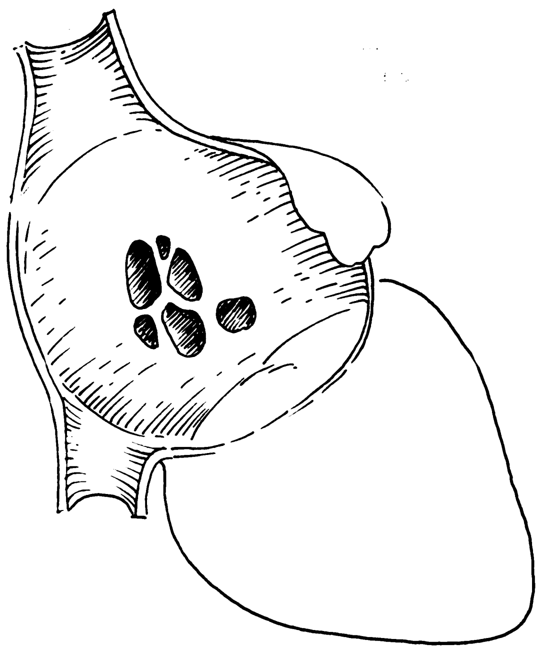


FIG. 11. Aggregation of several small septal defects. These should be treated as a single large defect.

placed in the appendageal opening and, as the clamp is removed, is passed well into the atrial chamber. Hemostasis is maintained by tension applied to the purse-string suture.

Methodically, the operator examines with his finger tip the superior vena caval orifice, the ***crista terminalis,*** the inferior vena cava, and the tricuspid valve orifice, and then slips it medialward and cephalad in order to pass it through the interatrial defect. By a circular motion of the inserted finger the approximate size of the defect can be estimated, and absence of a septal remnant in any quadrant is recognized. The finger is now directed posteriorly and to the left to enter the mitral valve orifice and to recognize any coexisting stenosis or regurgitation. In very low defects the septal leaflet may be congenitally cleft and, therefore, incompetent. The finger tip now explores the left side of the posterior septal remnant in order to recognize the ostia of the pulmonary veins, especially those from the right lung. After this, the finger examines the right side of the posterior septal remnant in order to detect any anomalous mouths of right pulmonary veins.

The finger now returns to the region between the tricuspid and mitral valves in order to determine whether any atrial septal tissue remains between them. If it does, the case is one of septum secundum defect. If the only tissue between these valves is a heavy muscular ridge, it represents the upper margin of the interventricular septum and the case is one of persistent *ostium primum*. After this determination, the finger tip seeks for the ostium of the coronary sinus which should lie just anterior to the site of entrance of the inferior vena cava. Great care should be taken in exploring the posterior inferior margin of the septum, since a hypertrophied inferior vena caval valve may lie in such a position as to be mistaken for the lower margin of the septum. This is particularly likely if the inferior vena cava is directed more toward the left atrium than toward the right. In one of our patients undergoing surgery, the "atrio-septo-pexy" was performed in such a way that the lower portion of the invaginated atrium was secured to the lateral margin of the valve of the inferior vena cava, permanently directing all inferior vena caval flow into the left atrium. This type of accident occurs more readily than one would imagine, since the inferior vena cava frequently seems to empty more directly into the left atrium than into the right in cases of persistent *ostium primum*. It can be avoided easily by remembering this possibility.

Having determined the size, location, and type of the defect by palpation, the operator confirms this by removing the finger and replacing it with the largest-sized examining cardioscope which can be inserted. All aspects of the septum then are visually inspected. The operative plan now may be formulated logically.

If mitral stenosis is present, the finger is reinserted after removal of the cardioscope.

It is passed through the defect and an attempt is made to perform a digital commissurotomy. If this proves impossible or unsatisfactory, the appropriate mitral guillotine may be inserted into the heart along the finger for instrumental division of the commissure. Then, the defect is closed in the appropriate manner.

If the defect is a small to moderate-sized central one, it may be closed by the originally described technic of invagination of the redundant atrial wall and circumferential peripheral suturing to the edge of the defect (Fig. 1). If the defect is somewhat larger but presents a good posterior septal ridge and sufficient septal tissue above the two atrioventricular valves, the effective atrial chamber may be "displaced backward" by suturing the lateral atrial wall to these margins. This results in a U-shaped or C-shaped residual right atrial chamber posterior and inferior to the septal defect (Fig. 2 A and B). It is preferable to start the suture line in the anterior and caudal part of the right atrium, because this technically is the most difficult portion for the placement of approximating sutures. Since there is some danger of using the available excess atrial wall wastefully during the placement of the first few sutures, it is preferable that this region should be closed securely before the available reparative tissue becomes scanty. One way in which the available atrial wall may be used economically is by the reversal of the needle once its "heel" has fully traversed the septum but before it has emerged from the heart, so that the "heel" penetrates the atrial wall fairly close to the point of atrial puncture. Usually this blunt end of the needle and the attached suture will produce a small tear in the atrial wall which should be repaired immediately with fine arterial silk. Then, when the suture is tied, only the narrow intervening portion of atrial tissue will be approximated to the septal edge (Fig. 12 A, B, C, D). Otherwise, the use of a large curved needle implies the tying down of a large amount of intervening

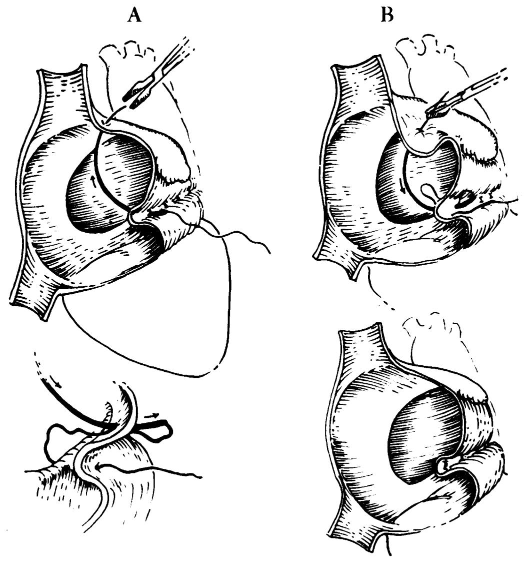
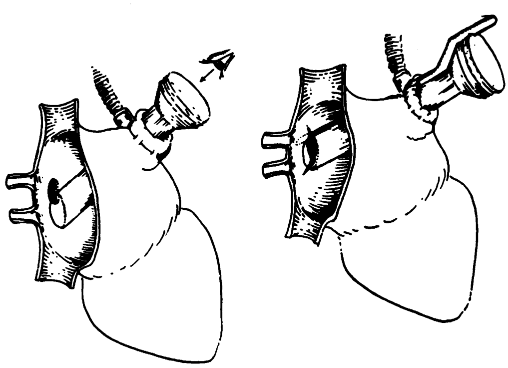


Fig. 12. (A) Most convenient and economical method of placement of large suturing needle in closure of a large low defect. The ventral and caudal portion of the suture line should be established first. (B) Showing method of reversing direction of needle without removing it from the heart. (C) Showing exact relationship of this retrograde suture passage to septal edge. (D) Final tying down of sutures to create an intracardiac passage for vena caval blood flow.

atrial wall between the sites of entrance and exit. Furthermore, by the recommended technic the needle point may be permitted to emerge initially from any part of the atrial chamber which its curve and the direction of passage make convenient. This lessens the risk of tension upon the often very fragile tissue of the septal remnant. By this suturing technic, even patients without a greatly dilated right atrium may be successfully "cured."

When there is no posterior septal remnant and when the defect is very large, perhaps approximating a condition of single atrium, one must determine whether there is any residual septal tissue between the atrioventricular valves. If so, the construction of the intracardiac channel is begun in this area by the placement of sutures between the lateral atrial wall and this rem-



A B

FIG. 13. (A) Inspection of periphery of septal defect by use of Bolton examining cardioscope. (B) Enlargement of small defect by use of Bolton operating cardioscope.

nant of the *septum primum*. In order to obtain secure closure in the most anterior or ventral portion of this channel, it is well to place the initial sutures in such a way that the large curved needle in passing from the lateral atrial wall to the ventral portion of the septal remnant first picks up whatever tissue is attached to the intracardiac portion of the aorta. The needle tip then will emerge from the cephalic portion of the right atrium close to the ascending aorta. The operator will pick up the needle point and will withdraw the needle until its "heel" is completely free of the septum and periaortic tissue. The direction of the needle is then reversed so that the "heel" emerges from the atrial wall near the original site of entrance. Sometimes several such sutures are necessary to close securely this natural weak point in the construction of this portion of the channel. The suture line is carried posteriorly, usually without any attempt at mattress suturing of the septal edge until the region of the coronary sinus ostium is reached. Now, the remaining three fingers of the left hand of the operator are placed beneath the posterior wall of the atrium, while the thumb compresses the lateral wall down to meet them. This accomplishes an approximation of the posterior and lateral atrial walls comparable to the construction of the Pompeian pipe. It is preferable that direct contact be maintained between these atrial walls while the approximating overlapping mattress sutures are placed. Smaller curved needles are preferable at this time, since they "waste" less of the available atrial wall. This suture line is continued in this manner, with progressive formation of a posterior channel all the way to the entrance of the superior vena cava (Fig. 3 A and B, and Fig. 4 A and B).

Treatment of true absence of the entire interatrial septum or of a large persistent *ostium primum* is the same as that just described except that in the preparation of the transverse (anteroposterior) portion of the intracardiac channel, the suture line is interrupted when the operator feels he has gone backward as far as the membranous portion of the interventricular septum extends. The suture line begins again in the upper lip of the ostium of the coronary sinus and then is continued on in the previously described manner up to the entrance of the superior vena cava. Then, the previously mentioned large mattress suture is placed to include the two points of suturing at either extremity of the residual interatrial communication (Fig. 6 A and B). After this is tied down, a Kiriluk "fat bag" is prepared. A threaded probe or a large curved needle is passed through the appendage along the intracardiac finger to traverse the residual communication and to emerge from the lateral aspect of the newly created intracardiac channel. After removing the probe or needle from the heart, the operator attaches the trailing end of the suture to the "fat bag." By traction upon the lead end of the suture, the bag is caused to enter the auricular appendage as tension on the purse string is relaxed, and to enter and "plug" the remaining communication between the two venous circuits (Fig. 6 A, B, C, D).

When anomalous pulmonary veins are to be "transposed" at the time of correction of the defect, palpation and examination with the cardioscope will have revealed whether the defect is of sufficient size to provide an

TABLE III.

	Ostium Primum		Ostium Secundum	
	No. of Cases	Percentage	No. of Cases	Percentage
Total Cases	16		30	
Associated Mitral Stenosis	0	—	3	10.0
Associated Anomalous Pulmonary Venous Drainage	2	12.5	5	16.7
Mortality	11	68.7	3	10.0
Clinical Improvement in Surviving Patients	4	80	27	100
Clinical Result Unchanged in Surviving Patients	1	20	–	–
Postoperative Cardiac Catheterization	3	60	16	59.2
Complete Abolition of Shunt in Those Catheterized	2	66.7	14	87.5
Great Reduction of Shunt in Those Catheterized	1	33.3	2	12.5

adequate passageway for the flow of blood from these veins. If it is not, it is enlarged incisionally by the use of the operating cardioscope (Fig. 13 A and B). The lateral atrial wall is attached by overlapping mattress sutures to the anterior edge of the defect, beginning at the most caudal and posterior extremity of the suture line. When the sutures have reached the most cephalic extremity, the atrium will have been divided into two compartments, with complete separation of the venous systems (Figs. 8 and 14).

After completion of the appropriate intracardiac surgery, the finger is removed from the appendage, the purse string is tightened and tied, and the cut end is oversewn. The pericardium is flushed with saline solution and the sac is reconstructed partially. A large inferior pericardial aperture, as well as a large upper drainage site, is left. The pleura is drained by a multiwindowed catheter inserted through a stab wound in the right eighth intercostal space in the posterior axillary line. This is connected to a water-seal drainage bottle. The ribs are approximated, using pericostal sutures of chromic catgut. The incision in the muscles and fascia is closed with a single layer of chromic catgut. The skin is closed with continuous wire.

RESULTS OF SURGICAL TREATMENT

When an atrial septal defect is anatomically closed or when the systemic and pulmonary venous systems are separated by the technic previously described, the mechanical efficiency of the heart is restored. The heart size becomes reduced and the pulmonary vascular congestion diminishes. Signs of congestive failure subside and, except for those with severe myocardial damage or irreversible pulmonary vascular changes, physical activity becomes normal. In practically all of our patients the sense of well-being and marked increase in activity have been most dramatic. This has been true to only a slightly less degree in those in whom we have accomplished a great reduction in size but incomplete closure of their defects.

Unfortunately, however, some patients did not survive the operation (Table III). In 30 patients with *septum secundum* defects, there were three operative deaths, an operative mortality of 10 per cent (Table I). One of these patients (Y. N.) was an extremely bad surgical risk with recurring bouts of heart failure and associated bouts of cyanosis. Another patient (B. C.) had a preoperative thrombosis of the left main pulmonary artery which was discovered at autopsy; she developed a cardiac arrest on the operating table. The third death (H. S.) occurred two weeks after operation. This patient had done well except for the postoperative development of auricular fibrillation. Her death was attributed to the toxic effects of quinidine being used in an attempt to convert the fibrillation to a normal sinus rhythm. At autopsy it was found that her interatrial septal defect had been completely closed.

Postoperative catheterization studies have been completed in 16 of the 27 surviving patients in this group (Table III). Fourteen have shown that the defect was completely closed, and the other two have shown a marked reduction in their interatrial shunt.

Our results have not been so gratifying in those patients with *ostium primum* defects. There have been 11 deaths in 16 cases operated upon (Table II).

Two patients died in congestive failure and apparently did not have sufficient myocardial reserve to withstand the operative procedure. One (L. S.) was in intractable failure at the time of surgery and died a few hours after her defect had been completely closed. The other (G. H.) had been in marked failure with a gallop rhythm for four months prior to operation. Surgery had been refused this patient on a previous admission. Three patients (M. G., A. P., J. C.) died on the first day following surgery with heart block, apparently from interruption of the bundle of His. It is our present feeling that this hazard can be greatly reduced if not entirely eliminated by the technic described in this article.

One patient (M.K.) died 42 days postoperatively in congestive failure due to an aortico-atrial fistula produced at operation. Suturing into the adventia of the intracardiac aorta is a hazardous procedure because of the possibility of fistula production by penetration of the needle into the aortic lumen.

One patient (E. T.) died on the first postoperative day in congestive failure, and at autopsy it was found that the sutures at the caudal end of the defect had cut through to re-establish her interatrial defect. She was a bad-risk patient and apparently could not withstand the operative trauma, especially since she did not receive maximum improvement in the mechanical efficiency of her heart.

One patient (M. T.) died 21 days postoperatively and was cyanotic throughout her postoperative course. At autopsy it was found that the inferior vena cava had been shunted into the left atrium by mistaking

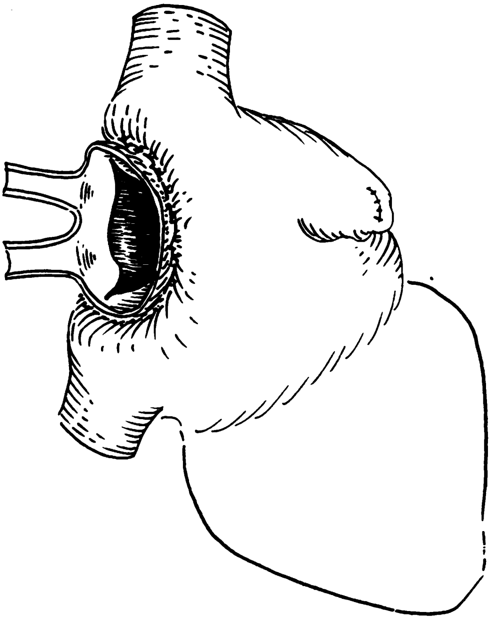


FIG. 14. Atrio-septo-pexy for retransposition of anomalous right pulmonary veins after enlargement of septal defect. If none exists, one may be created by the use of the cardioscope or by a bistoury knife and scissors (guided by the intracardiac finger).

the Eustachian valve edge for the lower margin of the defect. Awareness of the possibility of such a technical error plus use of the Bolton cardioscope should prevent a recurrence of this tragedy.

Two patients (J. W., L.W.) died on the first and third postoperative days, respectively, due to distortion of the septal leaflets of the mitral valve, producing mitral insufficiency. Awareness of this possibility should likewise help prevent its recurrence.

The remaining death (I. D.) occurred early in our series of cases. At that time we felt that an *ostium primum* defect would necessitate an "open technic" approach, and preliminary hypothermia was established in order to render it possible. Her death was apparently related to myocardial depression due to the application of hypothermia as an adjunct to surgery. At the present time we feel that the "closed technic" is the one of choice, and that hypothermia gives no added advantage, especially in adults.

SUMMARY

A new concept has been presented for the surgical separation of the systemic and pulmonary venous systems in cases of interatrial septal defects. The technic has been presented in detail and we believe it offers a technical advantage in some cases where anatomical closure of the defect itself would be difficult or impossible. In both technics the prime objective of physiological defect closure (separation of the two venous systems) is accomplished.

An analysis of 46 cases of interatrial septal defect who have been operated upon is presented with a discussion of the associated mortality.

We feel that the 90 per cent survival with marked clinical improvement in our 30 cases with *ostium secundum* defects justifies continuation of the use of the closed method of atrio-septo-pexy for these lesions. The fact that complete abolition of the shunt was accomplished in 14 of 16 patients studied postoperatively by catheterization technics confirms this clinical impression. To date no other proposed method for the correction of interatrial septal defects has proven successful in an equivalent percentage of a sizable series of patients.

The high mortality experienced in those cases with *ostium primum* defects seemed to be closely associated with the fact that they were much poorer surgical risks as a group, in comparison with the *ostium secundum* group of patients. Also technical errors relevant to overcoming a more formidable group of anatomical obstacles contributed greatly to the mortality. We feel that these technical errors largely can be prevented. Rejecting the poorer surgical risks also undoubtedly would lower the mortality, but in doing so one should remember that he is dooming these patients to inevitable downhill course and death. It might well be worth while to consider these individuals for surgical intervention on a calculated-risk basis if they insist even after being fully informed of the great dangers involved.

CONCLUSIONS

The surgical logic, the technical simplicity, the relative safeness of clinical application, and the high percentage of proven complete separation of the venous systems associated with atrio-septo-pexy commend its widespread application in these patients. This is primarily true with defects of the *ostium secundum* types.

It is felt that correction of an interatrial communication is not indicated in patients with a right-to-left shunt since, in them, the defect has come to have a partially "compensatory" function.

It is urged that these patients be diagnosed and treated in early childhood before irreversible myocardial deterioration, pulmonary vascular changes, or general impairment in physical development have taken place. It is thought that the age range of four to six years is the optimal one both surgically and physiologically. In these patients, the right atrium is sufficiently dilated to permit technically effective surgical treatment at one year of age.

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