The Use of Cardiopulmonary Bypass for the Repair of Atrioseptal Defects and Pulmonary Stenosis*

ALVIN A. BAKST, M.D., F.C.C.P., PHILIP CRASTNOPOL, M.D., F.C.C.P.,
and IRVING KROOP, M.D., F.C.C.P.
Brooklyn, New York

With the advent of extracorporeal circulation and the subsequent extension of surgery to defects within the heart, many lesions have become the subject of study and controversy. Several intracardiac lesions are accepted as being best repaired by open cardiotomy. In inter-atrial septal defect and pulmonary stenosis, however, there is still some controversy as to whether the best technique is closed, open using hypothermia, or under direct vision using cardiopulmonary bypass.

There are those clinics in which these lesions are repaired using closed, blind techniques. The difficulty with complicated lesions and the uncertainty of complete repair precludes the acceptance of this approach. This procedure is mentioned only for historical purposes.

Gross and Kirklin have used a semi-closed approach to atrio-septal defects using an atrial well. This requires the defect to be blindly palpated and sutured beneath a pool of blood. It doubtless permits associated smaller lesions to be missed. Gross has subsequently discarded this technique for open atriotomy using cardiopulmonary bypass.

Several clinics have effectively utilized hypothermia as a means of effecting a direct vision repair. This technique emphasized the advantage of repairing an intracardiac lesion under vision, and therefore, was a giant step in intracardiac surgery. However, it has the disadvantage of imposing a time limit upon the surgeon. Although simple foramen ovales defects can be repaired within the accepted limit, there are many complicated lesions which cannot. These include transposed pulmonary veins, transposed inferior vena cava, transposed superior vena cava and high septum secundum defects. It goes without saying that the more complicated ostium primum defects and atrio-ventricular canal cannot be repaired by this technique. Lewis, who has had a considerable experience with hypothermia, has reported a rather high mortality and morbidity with the high septum secundum defects associated with transposed upper and middle lobe pulmonary veins.

We have used extracorporeal bypass with a pump oxygenator for the repair of atrioseptal defects over the past two years, during which time 31 defects were repaired with one mortality. Of these, 16 presented complicated lesions which probably could not have been corrected under a hypothermic technique. There were three high septum secundum defects associated with transposed upper and middle lobe pulmonary veins. One of these presented a transposed superior vena cava requiring a complicated correction, which has been reported. There were two with transposition of the inferior vena cava; two with transposed right pulmonary veins; five with multiple defects; two with cribiform septa; one ostium primum, and one in which a pulmonary valvular stenosis was associated with a transposed pulmonary vein without an associated

*From the Jewish Hospital of Brooklyn.
atrioseptal defect. In all, a complete closure was effected using an accurate meticulous repair. The most complicated lesions were repaired without difficulty. To eliminate unnecessary periods of cardiopulmonary bypass, the atria were first explored digitally so that the lesions could be accurately assessed and the technique of repair decided upon. This maneuver led to an expeditious, carefully planned and accurate repair. However, in several cases, although the major defect was palpated by blind digital exploration, multiple smaller lesions were not recognized until the visual inspection. This we believe to be the factor responsible for persistent postoperative arterIALIZATION of the right atrium reported by those using closed and semi-closed techniques.

Embryology

At approximately the fifth week of embryonic life, the primitive common atrium begins its separation into right and left chambers. This involves the formation of two septa. The septum primum starts as a crescentic ridge on the dorsocephalic aspect of the atrial wall, and grows toward the atrioventricular canal. Simultaneously, two endocardial cushions, one dorsal, the other ventral, appear in the walls of the atrioventricular canal. These ultimately fuse to divide the atrioventricular canal.

As the septum primum grows toward the atrioventricular canal cushions, the opening known as the interatrial foramen primum, or the ostium primum diminishes in size. At approximately the time that the closure of the ostium primum would have completely divided the atria, a secondary opening develops in the septum primum. This new aperture first appears as multiple small perforations, which subsequently coalesce to form a single, large opening referred to as the ostium secundum.

At the end of the sixth week, a second septum forms which lies just to the right of the septum primum. The ventro-caudal limb of this septum sweeps caudally and merges with the A-V canal cushion to the right of the septum primum. As it grows, its concave margin progressively cuts into the atrial lumen. Its extension gradually ceases and leaves the characteristic oval shaped apperture of the foramen ovale.

The secondary opening in the septum primum was formed so near the cephalic wall of the atrium that the unresorbed lower part of the septum line has a loose flap which covers the oval opening in the septum secundum on its left atrial side and, thereby, forms a one-way valve permitting filling of the left atrium from the right but not vice versa.

Surgical Anatomic Aspects

A. Septum secundum defects are characterized by the fact that the anterior-inferior margin of the defect is formed by a remnant of atrioseptal tissue. These defects may vary in size and location.

B. Septum primum defects are those in the lower portion of the atrial septum in which there is no atrio-septal tissue between the atrioventricular valve ring and the defect.

C. High defects in the septum secundum are located just inferior to the superior vena cava. The superior edge is a sharp crescent which
forms the inferior margin of the defect. Superiorly, the defect has no margin since there is no remnant of septum above it. The defect is superior to, and separate from, the site of the foramen ovale.

Some believe this defect to be due to an abnormal entry of the superior vena cava into both the right and left atria. However, it is probably due to an improper development of the septum secundum which does not cover the resorbed portion of the septum primum. The defect is invariably associated with a partial anomalous pulmonary venous drainage of the right upper and middle lobes. These enter with separate openings into the lower part of the superior vena cava just above the atrioseptal defect.

In our series, the atrial septum has been repaired under direct vision using cardio-pulmonary by-pass. The right atrium has been approached through a right anterior, inframammary incision through the fourth intercostal space with transection of the sternum. The left pleural space has usually not been entered unless the preoperative catheterization suggested the presence of a combined lesion. Early in this series, when complicated lesions were suspected, the heart was approached through a bi-lateral transpleural incision. However, over the past six months, complicated lesions have been approached through a midline sternal incision.

The uncomplicated atrioseptal defects are routinely repaired through a right transpleural approach with transection of the sternum in line with the fourth interspace. The pericardium is opened widely by a longitudinal incision anterior to the phrenic nerve. The femoral artery is cannulated, to receive the arterialized blood from the pump. The cavae are cannulated through separate incisions in the atrial wall and the auricular appendage. A purse-string suture is placed around the base of the right auricular appendage and an exploring finger is inserted into the right atrium prior to cannulating the heart. At the time of digital exploration, the lesion is assessed, and the technique for the repair is outlined. The finger is then withdrawn and the superior vena caval catheter is inserted through the tip of the appendage. A second catheter is inserted into the inferior vena cava through a small incision in the wall of the atrium. These catheters are attached to the venous limb of the heart pump.

The patient is then placed on cardio-pulmonary by-pass, the atrium is opened and the repair effected in the beating heart. Cardiac arrest is never used for the repair of atrioseptal defects. Coronary sinus return is aspirated by a low pressure intracardiac suction unit. Before the last sutures are placed in the septal defect, the atrium is allowed to fill with blood and all air from the left atrium is evacuated. The last sutures are then ligated beneath a pool of blood to prevent the collection of a pocket of air in the left atrium. The right atrium is then carefully inspected for the presence of arterialized blood. The presence of arterialized blood at this time indicates the existence of an associated defect. After the defect is repaired, the lips of the atrial incision are grasped, and the inferior caval tape opened. The atrium fills with blood, air is evacuated, and the incision is clamped with a non-crushing clamp. The superior
caval occluding tape is opened, and the patient removed from cardio-
 pulmonar y by-pass. The atrial incision is closed, after which the patient
 is decannulated. The patient is heparinized with 1.5 mg. of heparin
 per kilo of body weight prior to being placed on cardio-pulmonary by-
pass. Upon completion of the procedure, the clotting mechanism is
 restored by Polybrene administered in double the heparin dosage.

The heart pump used at this institution consists of a Kay-Cross
 oxygenator with a DeBakey-type pump. Blood flows from the patient
to the oxygenator by gravity. It is then pumped into the femoral artery
by a non-occlusive DeBakey-type pump. In this way, the patient is
allowed to set his own flow rate. We have found that the flow rates are
high and exceed 2400 cc. per meter square per minute. Only at these
rates are blood pressures above 80 systolic maintained throughout the
periods of perfusion.

In this series of 31 patients, 16 had a simple septum secundum re-
paired. In this lesion, (Fig. 1) a suture was placed at the upper and
lowermost margins of the defect, which was then closed with a running
#00 atraumatic silk suture. The line of repair was reinforced with several
interrupted figure of eight #000 atraumatic silk sutures.

There were two patients having high septum secundum defects asso-
ciated with transposed right upper and middle lobe veins into the supe-
rior vena cava immediately above its entrance into the right atrium.
In these, there was no uppermost margin to the atrioseptal defect and
the superior vena cava seemed to straddle both the right and left atria.
To properly repair this lesion, an uppermost margin to the defect had
to be first created. This was done by running a suture from the upper-
most portion of the defect, along the wall of the left atrium, and then
into the posterior segment of the superior vena cava just above the
transposed veins (Fig. 2). By ligating this suture, an uppermost margin
to the defect was created and the transposed veins were redirected into
the left atrium. The defect was then closed with a running silk suture.
In neither case was it necessary to use a prosthesis, although in one

![FIGURE 1: The superior and inferior cavae are cannulated. The lesion is closed with a running #00 atraumatic silk suture. The suture line is reinforced with several figure of eight #000 atraumatic silk sutures.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21344/ on 04/28/2017)
case, the orifice of the superior vena cava into the right atrium was somewhat narrowed.

In one patient, a high septum secundum defect was associated with transposition of the right upper and middle lobe veins into a superior vena cava which itself was transposed, and emptied into the left atrium. In this patient, there was a superior rim to the septal defect. When the defect was closed, the superior vena cava was totally diverted into the left atrium. The right atrium was closed and the superior vena cava was transected proximal to the entrance of the transposed pulmonary veins. This, then, allowed the upper and middle lobe veins to empty into a blind stump of superior vena cava which then emptied into the left atrium. The proximal segment of the superior vena cava was anastomosed to the tip of the right auricular appendage thereby redirecting its blood flow into the right atrium, and effecting a complete repair of the lesion.

In two patients, the atrioseptal defect was associated with a transposition of the inferior vena cava. This lesion was created by a prominent eustachian valve. On palpating the rim of the defect, the finger passed from atrial septum to eustachian valve and then to posterior atrial wall. With a closed technique, one author reported that the vena cava was erroneously directed into the left atrium. Under direct vision, the inferior caval catheter was retracted, thereby enabling the left atrial wall to be visualized. The inferior margin of the septum was sutured, and the suture line then carried across the wall of the left atrium posteriorly to the wall of the right atrium. When this stitch was tied, an inferior rim to

**FIGURE 2:** An uppermost margin to the lesion is first created. This is done with a continuous suture from the uppermost portion of the defect along the wall of the left atrium and into the posterior portion of the superior vena cava above the transposed veins. When the suture is ligated an uppermost margin to the defect is created and the transposed veins are redirected into the left atrium. The defect is then closed with a running silk suture.
the septal defect was created and the inferior cava was redirected into the right atrium. The atrioseptal defect was then closed by a running suture (Fig. 3). In neither case was it necessary to use a prosthesis for the closure of the defect.

In two patients, there was a transposition of the right pulmonary veins into the right atrium. The lesion was corrected simply by transposing the anterior margin of the atrial septum in the region of the septal defect to the posterior wall of the right atrium, to the right of the pulmonary veins. This type lesion did not present a posterior rim of septum and it was necessary to suture the anterior margin of the septum to the posterior wall of the right atrium. In this way, the pulmonary veins were redirected into the left atrium and the septal defect was totally closed (Fig. 4).

In four patients, multiple defects were found. In each, there was one major defect associated with two or three smaller ones. In two others, the septum was cribiform in nature. In all six, the lesions were closed by a continuous suture to each defect. The cribiform septum was treated as though it were one large defect and was closed with a continuous, running suture. In one, after the cribiform lesion was corrected, arterialized blood continued to emerge into the right atrium. An additional, one cm. defect was visualized anteriorly and inferiorly, well away from the major lesion. This was then closed with a continuous silk suture. In none of these lesions was it necessary to use a prosthesis.

There was one in whom a right pulmonary vein was transposed into the right atrium, and was associated with a small patent foramen ovale in addition to a valvular pulmonic stenosis. In this patient, the pulmonic valvular stenosis was corrected by an open technique, after which the transposed pulmonary vein was corrected under direct vision. This
repair necessitated the creation of a septal defect at the site of the patent foramen ovale. The septum was then sutured to the posterior wall of the atrium, to the right of the pulmonary veins, which retransposed them into the left atrium, with the complete correction of the lesion.

In this series, many complicated lesions were corrected under direct vision using open atriotomy under cardio-pulmonary by-pass. This technique enables the surgeon to repair these defects using an unhurried, meticulous repair. Since these lesions can be completely corrected using open atriotomy without cardiac arrest, the risk is extremely low.

**Pulmonary Stenosis**

Pulmonary stenosis, too, has been the subject of much recent controversy as to its best method of repair.

Originally, Brock and Potts led the way in describing a closed technique for the correction of a pulmonary valvular stenosis. This necessitated the introduction of a special knife through the right ventricular wall, into the pulmonary artery. It consisted of incising the valve cusps, thereby converting a pulmonary stenosis into a pulmonary insufficiency. Although it was originally believed that a pulmonary insufficiency seemed not to impose too severe a burden on the right ventricle, it was noted that the surgical procedure was usually followed by an enlargement of the right ventricle during the postoperative course. Moreover, recently Potts has described several cases of re-stenosis following this blind pulmonary valvulotomy. At most clinics, when the pre and postoperative ventricular and pulmonary artery pressures were monitored, the cardiologists recognized that the right ventricular-pulmonary artery pressure differential was frequently not corrected after the blind tech-

![FIGURE 4: The anterior rim of the atrial septum is transposed to the wall of the right atrium, to the right of the aberrant pulmonary veins. This redirects the aberrant veins into the left atrium, with complete closure of the defect.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21344/)
niques. Swann and others recognized the necessity for repairing this lesion under direct vision and demonstrated the safety of the technique.

Usually a stenotic pulmonary valve is tricuspid. The valve cusps are thickened, and the commissures fused. In some cases, the valve is bicuspid. Invariably, however, the stenotic valve is supported by either two or three commissures. When the repair is effected under vision, the pulmonary artery is opened and the valve leaflets inspected. The stenotic valve is opened accurately and meticulously by incising the fused commissures to the annulus of the pulmonary artery (Fig. 5). The leaflets are thus completely freed, thereby creating a functioning tricuspid valve. In addition, a finger is inserted into the ventricle for the evaluation of the right ventricular outflow tract and to explore for an infundibular stenosis, or a septal defect.

Because of the relative frequency of associated lesions, and, because of our familiarity with the heart pump for cardio-pulmonary by-pass, we have elected to perform these procedures, using an open technique, under cardio-pulmonary by-pass.

We have felt more secure in the knowledge that the heart pump was present to support the circulation in the event of a catastrophe, or cardiac arrhythmia. We have not regretted choosing this technique. We have now surgically corrected eight uncomplicated pulmonary valvular stenoses, without mortality. A ninth was associated with an interventricular defect and a tenth was associated with transposed right upper lobe veins and a patent foramen ovale. In the latter case, an atrioseptal defect was created and the septum moved to the right to retranspose the pulmonary veins into the left atrium.

A few years ago, cardiac surgery was unheard of. Over the 15 years, many cardiac lesions were successfully attacked using blind, closed techniques. It was apparent that, if the interior of the heart, itself, were to be inspected and repaired under vision, the heart and lungs would
have to be bypassed. It seems obvious that only, under direct vision, can the various lesions be repaired safely and accurately. In addition, the presence of a dependable cardiac pump to support the circulation in the event of a catastrophe lends added safety to the patient, and confidence to the surgeon.

**SUMMARY**

1. Extracorporeal circulation with the pump oxygenator has been used for the repair of 31 atrioseptal defects with one mortality. Of these, 16 presented complicated lesions which probably could not have been corrected using a hypothermic technique. In all lesions a complete repair was meticulously effected without difficulty. To eliminate unnecessary periods of cardiopulmonary bypass, the lesions were assessed by a preliminary blind digital exploration.

2. In several cases, although the major defect was palpated by the blind exploration, multiple smaller lesions were not recognized until inspected visually. This, we believe to be responsible for the persistent postoperative arterialization of the right atrium reported by those using closed and semi-closed techniques.

3. In all cases the repair was effected in the beating heart, without arrest.

4. It is believed that congenital pulmonary valvular stenosis, too, is best repaired under direct vision using extracorporeal circulation. The stenotic valve is supported by either two or three commissures. When the repair is effected under vision, the fused commissures can be incised accurately and meticulously, with the creation of a functioning tricuspid valve. In addition, the right ventricular outflow tract can be explored.

5. Eight uncomplicated pulmonary valvular stenoses have been corrected without mortality. A ninth, associated with an interventricular septal defect, and a tenth, associated with transposed right upper lobe veins, were also corrected without mortality.

**Addendum:** Since submitting this report 33 additional atrioseptal defects have been operated upon.

**RESUMEN**

1. Se ha usado la circulación extracorpórea con el oxigenador de bomba en la reparación de 31 defectos atrioseptales con mortalidad de un caso. De estos, 16 tenían lesiones complicadas que probablemente no hubiesen podido corregirse usando técnica de hipotermia. En todas las lesiones se llevó a cabo una meticulosa reparación sin dificultad. Para eliminar los innecesarios periodos de desviación cardiopulmonar, las lesiones se estimaron previamente por una exploración digital ciega.

2. En todos los casos, aunque el defecto mayor fue palpado por la exploración ciega, múltiples lesiones más pequeñas no se reconocieron sino hasta que se hizo la inspección visual. Esto según creemos es responsable de la arterialización postoperatoria del atrio derecho que se ha relatado porque usan la técnica cerrada y la semi-cerrada.

3. En todos los casos la reparación se llevó a cabo con el corazón latiendo, sin paro cardíaco.

4. Se cree que la estenosis valvular congénita también es mejor corregida bajo visión directa usando la circulación extracorpórea.

La válvula estenosada es soportada ya sea por dos o tres comisuras. Cuando la reparación se hace bajo la vista, las comisuras unidas pueden ser seccionadas exacta y meticulosamente creando así una válvula tricúspide capaz de funcionar. Además, el tracto del flujo ventricular derecho puede explorarse.

5. Se han corregido ocho estenosis valvulares complicadas sin mortalidad. La novena, que tenía asociado un defecto septal y la décima asociada con transposición de las venas lóbulares superiores también se corrigió, siendo ambas sin mortalidad.

**RESUMÉ**

1. La circulation extra-corporelle avec oxygénateur à pompe a été utilisée pour opérer 31 cas de communication auriculaire. Il n'y eut qu'un décès. Sur ces cas, 16 présentaient des lésions compliquées qui n'auraient probablement pas pu être corrigées en utilisant le simple procédé hypothermique.

Pour toutes les altérations, la réparation complète fut méticuleusement effectuées sans difficulté. Pour éliminer des périodes inutiles de circulation artificielle, les lésions furent repérées par une exploration préliminaire aveugle au doigt.

2. Dans plusieurs cas, bien que l'altération principale fût perçue par l'exploration aveugle, de multiples lésions plus petites ne furent pas reconnues tant qu'elles ne furent pas inspectées par vision directe. Les auteurs pensent que c'est là que réside la cause de l'arterialisation post-opératoire persistante de l'oreillette droite, rapportée par ceux qui utilisent des techniques à cœur ouvert ou semi-ouvert.
3. Dans tous les cas, la réparation fut effectuée sur cœur battant, sans arrêt.

4. Les auteurs croient que la sténose congénitale de valves pulmonaires est également mieux réparée sous vision directe en utilisant la circulation extra-corpoorelle. La valve sténosée est soutenue par deux ou trois commissures. Lors l'intervention est effectuée sous vision directe, les commissures soudées peuvent être incisées avec précision et méticuleuse. Ainsi est créée une valve tricuspid aplé et fonctionner. De plus, le flux sanguin du ventricule droit peut être exploré.

5. 8 sténoses de valves pulmonaires non compliquées ont été corrigées sans aucun décès. Une neuvième, associée à une communication interventriculaire, et une dixième, associée à une transposition des veines du lobe supérieur, furent également traitées sans mortalité.

**ZUSAMMENFASSUNG**


2. Obwohl die größeren Defekte mittels blind Untersuchung in mehreren Fällen, zupalpieren waren doch multiple kleinere Veränderungen nicht anders als durch visuelle Inspektion feststellbar Wir glauben, daß dieser Umstand verantwortlich ist für das Fortbestehen der Arterialisation des rechten Vorhofes nach der Operation, die von denjenigen angegeben wird, die von der geschlossenen oder halbgeschlossenen Technik Gebrauch machen.

3. In allenen Fällen wurde die Besetigung des Defektes am schlagenden Herzen ohne Stillstand erzielt.


5. 3 unkomplizierte Pulmonal-Klappen-Stenosen wurden korrigiert ohne einen Todesfall. Ein neunter Fall, bei dem gleichzeitig ein Kamerscheidwanddefekt bestand, sowie ein zehnter, bei dem außerdem noch eine Transposition der rechten Oberlappvenen vorlag, wurden ebenfalls ohne Todesfall korrigiert.

**REFERENCES**
