EXPERIENCES WITH THE PEMCO AUTOMATIC HEART-LUNG APPARATUS

A REPORT ON 22 PATIENTS

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This report deals with the first 22 patients operated on for intracardiac defects with the aid of the Pemco Heart-Lung Apparatus* at the Karl Bremer Hospital. The reliability of this automatic apparatus has been proved in this series of patients. There have been 4 deaths. These 4 patients were in severe cardiac failure before operation, and in 2 it was not possible to correct the defect at operation.

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THE HEART-LUNG APPARATUS

The Pemco Heart-Lung Apparatus in use at the Karl Bremer Hospital has 2 roller pumps as arterial and venous pumps and a corrugated disc oxygenator of the Björk type, modified by Kay and Cross. The corrugated stainless-steel discs have the advantage of increasing the oxygen-uptake

capacity of the oxygenator by 25%. In operations on patients weighing less than 50 lb. the 13-inch oxygenator with 70 discs is used. For patients weighing between 50 and 100 lb., the 17-inch oxygenator with 90 discs, and for those over 100 lb. the 21-inch oxygenator with 110 discs are used. The 25-inch oxygenator was not used in this series, but, for patients weighing over 180 lb., 2 oxygenators, connected in parallel, are used. The second oxygenator is then driven by a sewing-machine motor which has a variable speed control, matching the built-in control of the first oxygenator.

The pumps are standard roller types working on silicone rubber tubing. The heart-lung apparatus in use at the Karl Bremer Hospital has a few special features:

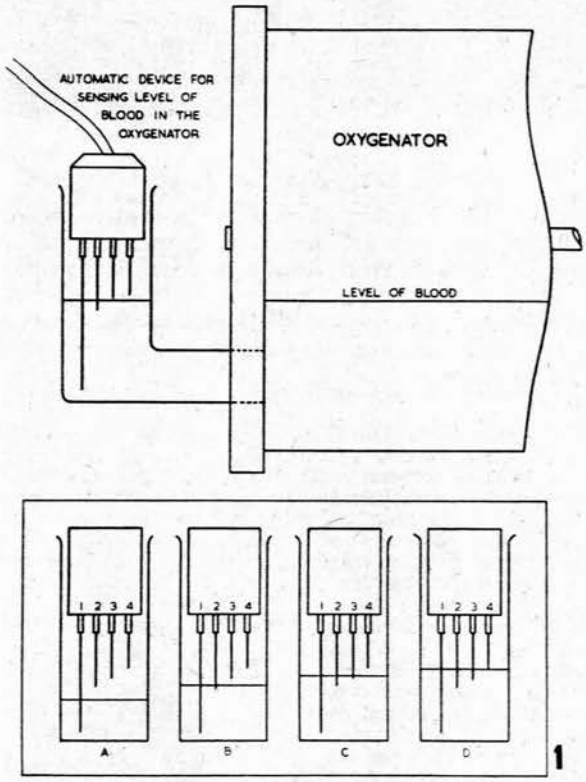

Fig. 1. Diagram of the device for sensing the level of blood in the oxygenator. The inset shows the blood at 4 different levels. In A the level is too low: only electrode 1 touches the blood, and the venous pump works and the arterial pump is stopped to prevent air embolism. In B the level is low-normal: electrodes 1 and 2 touch the blood, and both pumps work — the venous one slightly faster. In C the level is high-normal: electrode 3 now also touches the blood, and both pumps work — the arterial one slightly faster. In D the level is too high: all 4 electrodes touch the blood; the venous pump is stopped and only the arterial pump works. Normally the level of blood in the oxygenator stays constant between the tips of electrodes 2 and 3.

1. An electronic control unit keeps the level of blood in the oxygenator constant (Fig. 1). This has the following advantages:

(*i*) The volume of blood in the heart-lung apparatus remains constant. Any blood lost during operation is measured and replaced. The patient cannot lose blood into the heart-lung machine.

(*ii*) There is no danger of air embolism, since the pumps are stopped if the level of blood in the oxygenator drops too low.

(*iii*) During the run of the machine the technician does not have to watch the blood level in the oxygenator, and he can give more attention to other aspects of the machine, making control of the apparatus fairly simple. Only one technician is in the operating room during an open-heart operation. Although the electronic control is not an essential part of this type of heart-lung apparatus, it makes the procedure safer for the patient.

2. Although loss of heat from the circulating blood in the oxygenator is prevented by direct, controlled heating of the oxygenator, the patient's temperature is controlled during the use of the machine by a heat exchanger. In addition to this a precision rotameter flow meter is connected in the circuit. The volume of blood pumped by the machine is not judged by the rate of rotation of the arterial pump, which may be misleading when complete occlusion is not maintained by the rollers, but directly by the flow meter. The flow meter does not appear to do any damage to the blood elements.

3. A third feature of this apparatus is the coronary sinus reservoir. Two roller pumps suck the blood by means of 2 coronary sinus suckers from the opened heart and pump it into a reservoir. From here it flows by gravity directly into

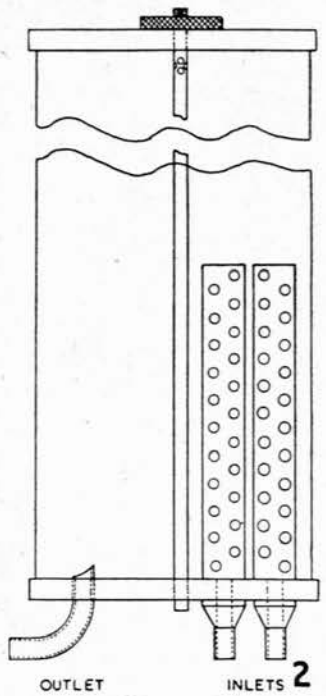

Fig. 2. Diagram of coronary sinus reservoir. Blood and air flow in through the multiple perforations of the inlets which extend into the chamber. Foam collects on top, and the blood automatically flows through the outlet to the oxygenator when the level in this reservoir rises above the oxygenator level. The chamber is 9 inches high and 3½ inches in diameter. The perforated parts of the inlets are one inch in diameter, and the internal diameter of the in- and outlets is ¼ inch.

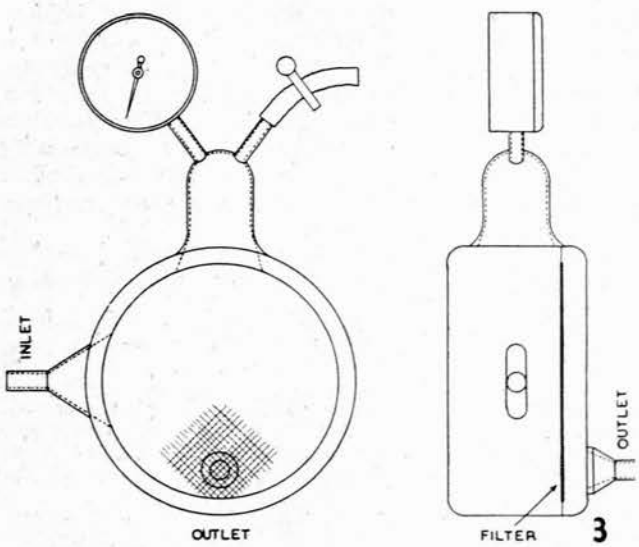

Fig. 3. Diagram of arterial filter-bubble trap. The blood flows through the inlet, passes the stainless steel filter and flows through the outlet which lies at a low level. The top part of the chamber traps any air that might escape from the blood. The gauge registers the arterial pump pressure of the heart-lung apparatus. The diameter of the chamber is 3½ inches and its width is 2 inches. The internal diameter of the in- and outlets is ¼ inch.

the oxygenator. The level of blood in the reservoir is such that foam cannot reach the oxygenator. A diagram of this coronary sinus reservoir is shown in Fig. 2. This system can handle blood flows of up to 4 litres a minute with little foaming. No defoaming sponge is used, nor is air suction applied. This set-up requires minimal attention, and all the technician has to do is to adjust the speed of the 2 coronary sinus pumps to instructions given by the surgeon during the open-heart procedure.

4. Another special feature of this apparatus is the arterial filter-bubble trap unit which was made to specifications by Pemco Inc. (Fig. 3). This unit is connected to a manometer which registers the pressure of the arterial pump, and thus the resistance of the arterial inflow catheter. Any obstruction of the arterial inflow will immediately be indicated by a sudden rise of arterial-pump pressure. The filter consists of stainless-steel mesh of 100 squares to an inch. Although minimal fibrin is deposited on this filter during perfusion, it is regarded as an essential part of the heart-lung apparatus.

Connection of the Heart-lung Apparatus to the Patient

In all the patients except 2 the standard method of inserting the superior and inferior vena caval catheters through the wall of the right atrium into their respective veins, and the arterial catheter into the right common femoral artery, after incising the lower part of the inguinal ligament, was used. One of the 2 exceptions was a patient with an ostium primum septal defect and a complete situs inversus. In this patient a left thoracotomy was done, and the venous catheters were placed through the left atrium into left superior and inferior venae cavae; the left common femoral artery was used for arterial inflow. This operation was therefore a mirror image of the usual right-sided approach.

In the other patient a new approach to the mitral valve was used: This patient was positioned on her right side with her chest rotated 30° backwards and the pelvis 45° backwards. A left antero-lateral thoracotomy was made through the fifth intercostal space. The arterial catheter was inserted into the left common femoral artery and the venous catheter was inserted through the outflow tract of the right ventricle so that the tip of this catheter lay low in the ventricle immediately distal to the tricuspid valve. This patient was put on total bypass by clamping the pulmonary artery. The right ventricular catheter also drained the coronary sinus blood. An excellent exposure of the mitral valve was obtained by an antero-posterior incision, parallel to the circumflex artery, in the left atrium. This approach to the mitral valve was good and is one that can be recommended.

The following approaches to the heart are now used:

1. For mitral-valve surgery a left antero-lateral thoracotomy, with connections as described above, is used.

2. For operations on the right atrium a right anterior thoracotomy is made through the fifth intercostal space, with the right side of the patient raised to an angle of 20° with the horizontal (Fig. 4). The right internal mammary artery is ligated and cut, but the sternum is not transected. The venous catheters are inserted near the entrances of the superior and inferior venae cavae through the wall of the right atrium, so that when the right atrium is opened they lie out of the operative field.

3. For all other operations, i.e. operations on both ventricles and on the large vessels at the base of the heart, a vertical, midline, trans-sternal incision is used. The 2 venous catheters are inserted through the appendix of the right atrium. In all patients the right common femoral artery is used for the inflow of arterial blood, except when a left antero-lateral thoracotomy is made — when the left common femoral artery is used.

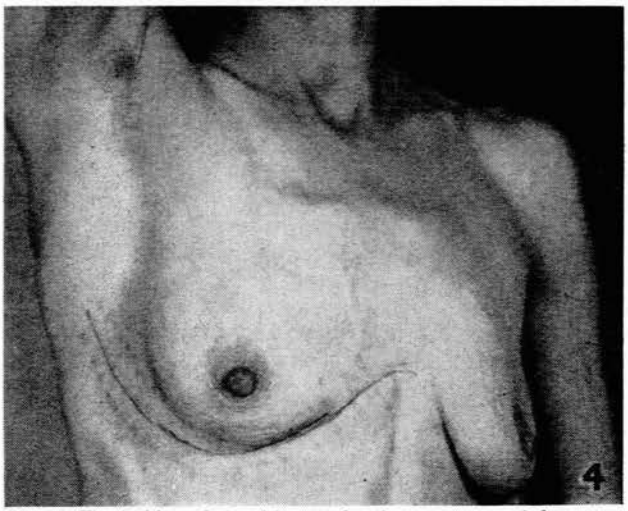

Fig. 4. The incision of the right anterior thoracotomy, used for open operations on the right atrium.

REPORT ON 22 PATIENTS

Information on the first 22 patients operated on with the heart-lung apparatus at the Karl Bremer Hospital is shown in Table I. There were 4 postoperative deaths in this series; these will be discussed. Another patient died 4 months after operation. Of the 18 patients who recovered, a few merit discussion because of the interest of the operative findings:

Case 4

This was a White female of 28 years who was known to have a cardiac murmur since childhood. Examination revealed a harsh systolic murmur, heard maximally over the base of the heart. The electrocardiogram showed right ventricular hypertrophy, and right heart catheterization showed a high atrial septal defect with anomalous right-sided pulmonary venous drainage. The diagnosis of a sinus venosus defect with anomalous venous drainage of the whole of the right lung into the right atrium was confirmed at operation (Fig. 5). The sinus venosus defect measured 4 x 2 cm. It was closed without a patch of teflon so that the right inferior pulmonary vein opened into the left atrium, but the superior pulmonary vein still drained into the right atrium (Fig. 5). This appeared to be a safer procedure than closing the septal defect so that the right superior pulmonary vein also drained into the left atrium, since serious narrowing of the superior vena cava would have resulted. Thrombosis of the superior vena cava following such a procedure has been reported in the literature. The anomalous venous drainage of the right upper pulmonary vein remaining after operation, does not appear to be harmful.[1]

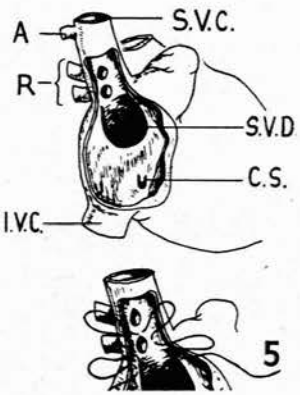

Fig. 5. Drawing of sinus venosus defect found in case 4. The right pulmonary veins open into the superior vena cava. The lower drawing shows the first part of the stitch used for closing the defect, so that the inferior pulmonary vein drained into the left atrium, but not the superior vein. A = Azygos vein. R = Right pulmonary veins. S.V.C = Superior vena cava. S.V.D. = Sinus venosus defect. C.S. = Coronary sinus. I.V.C. = Inferior vena cava.

TABLE I. SUMMARY OF CASES

Patient	*Age*	*Diagnosis*	*Length of perfusion*	*Remarks*
1 White male, J.S.	21	Ostium primum septal defect with a left superior vena cava	40 min.	Recovery. No complications
2 White male, C.S.	19	Ostium secundum septal defect. Patient also had Marfan's syndrome	24 min.	Recovery. No complications
3 White male, C.K.	12	Ventricular septal defect with pulmonary valvular stenosis	42 min.	Recovery. Patient was treated for bacterial endocarditis pre-operatively. No complications
4 White female, J.S. ..	28	Sinus venosus septal defect with anomalous venous drainage of entire right lung	28 min.	Recovery. No complications
5 Coloured female, M.J. ..	9	Ostium secundum septal defect with pulmonary valvular stenosis	30 min.	Recovery. No complications
6 Coloured female, S.K. ..	18	Ostium secundum defect	26 min.	Recovery. No complications.
7 Coloured male, C.D. ..	33	Mitral incompetence following an earlier mitral valvotomy	46 min.	Mitral valve approached through right atrium and atrial septum. Severe aortic incompetence also present. Initial recovery. Died 4 months after operation from cardiac failure
8 White male, G.L.	12	Ventricular septal defect	30 min.	Recovery. No complications
9 White female, E.R. ..	43	Ostium primum septal defect and complete situs inversus	50 min.	Patient was in severe cardiac failure pre-operatively. Died 12 hours after satisfactory closure of septal defect
10 Coloured female, S.S. ..	10	Ostium secundum septal defect	16 min.	Recovery. No complications
11 Coloured female, C.H. ..	29	Ostium secundum septal defect	23 min.	Recovery. No complications
12 White female, A.S. ..	8	Ostium secundum septal defect and pulmonary valvular stenosis	28 min.	Recovery. No complications
13 White female, J.R. ..	43	Mitral incompetence	50 min.	Mitral valve approached through right atrium and atrial septum. Patient was in severe cardiac failure before operation and died 6 hours after operation. It was technically impossible to repair the defective mitral valve
14 White female, J.N. ..	33	Congenital sub-valvular aortic stenosis	16 min.	Heart was stopped by cooling. Patient was in severe cardiac failure pre-operatively and died of cardiac failure on fourth postoperative day
15 White male, S.B.	34	Pulmonary valvular stenosis	8 min.	Recovery. Patient developed bacterial endocarditis with septic emboli to lungs post-operatively. Responded to treatment
16 White female, E.V. ..	33	Ostium secundum septal defect	14 min.	Recovery. No complications
17 White female, E.J. ..	19	Sub-valvular pulmonary stenosis and aortic sinus of Valsava fistula with right ventricle	18 min.	Recovery. Anoxic rest of the heart was used. Patient bled in the immediate post-operative period from a coronary artery, and had to be re-opened. She developed an empyema, but responded well to treatment. She was 3 months pregnant at time of operation. The pregnancy continued normally afterwards.
18 Coloured male, B.P. ..	6	Ostium secundum septal defect with severe mitral incompetence from ruptured chordae tendiniae	58 min.	Patient was in severe cardiac failure pre-operatively. Died on the seventh day after operation from cardiac failure in spite of immediate good response
19 Coloured female, S.F. ..	39	Mitral stenosis and severe mitral incompetence	42 min.	Recovery. The mitral valve was approached through the left atrium with the patient lying on her right side. Patient was in cardiac failure pre-operatively, but did well after operation. She lost 1,650 ml. of blood postoperatively and was the only other patient in this series who lost more than 700 ml. of blood postoperatively
20 Coloured female, A.A. ..	12	Ventricular septal defect	44 min.	Recovery. No complications
21 White female, W.N. ..	28	Ostium secundum septal defect	20 min.	Recovery. At operation a valve of Chiari made insertion of the inferior vena cava catheter difficult. The patient did well postoperatively. No complications
22 White male, P.H.	6	Sub-valvular pulmonary stenosis	16 min.	Recovery. At operation the patient was found to have bacterial endocarditis of the pulmonary valve. The pulmonary valve was therefore excised with the sub-valvular pulmonary stenotic area. The patient was treated postoperatively for bacterial endocarditis. No complications

Case 7

This patient was a Coloured male of 33 years who had undergone a transventricular valvotomy for mitral stenosis 2 months earlier, when the mitral valve, which was severely calcified, tore posterolaterally. Gross mitral incompetence was followed by severe cardiac failure. The mitral valve was approached through an incision in the right atrium and in the atrial septum. At operation evidence of gross aortic incompetence was also found, and it was necessary to clamp the aorta during the open-heart procedure. The tear in the posterolateral leaflet was closed with a teflon patch and mattress sutures. The patient appeared to be improved postoperatively, but he remained in cardiac failure and died 4 months after operation.

Case 19

This was a Coloured female of 39 years, in whom a preoperative diagnosis of mitral stenosis with slight mitral incompetence had been made. Fluoroscopy showed calcification of the mitral valve. It was decided to do a transventricular mitral valvotomy and, if at operation significant mitral incompetence was present, an open operation on the mitral valve would be done. A left thoracotomy was made with the patient lying on her right side. A finger exploration of the mitral valve revealed severe calcification with serious mitral stenosis and slight incompetence. A transventricular valvotomy was done. The commissures opened well, but severe incompetence was present after the valvotomy. The leaflets did not tear, but were markedly deficient posteriorly. The patient was then connected to the heart-lung apparatus and the left atrium was opened with an incision running parallel to the atrio-ventricular sulcus. A series of silk mattress sutures tied over teflon were used to plicate the annulus of the mitral valve as described by Kay, Egerton and Zubiate.[2] After closure of the left atrium, a finger exploration revealed slight mitral incompetence and stenosis. The patient did well postoperatively with minimal clinical signs of incompetence of the mitral valve.

Case 21

This was a White female of 28 years in whom the clinical diagnosis of an ostium secundum septal defect was made. At operation, on inserting the venous catheters through the right atrial wall, the superior vena cava catheter slipped easily into its vein, but great difficulty was experienced in inserting the inferior vena cava catheter since it was being obstructed inside the atrium. Eventually something inside was felt to tear. The catheter then slipped easily into the inferior vena cava. After the patient was on total perfusion and the right atrium opened, the cause of the obstruction to the inferior vena cava catheter was evident: a perforated membrane ran upwards from the Eustachian valve, appearing to form part of the lower margin of the septal defect and covering the inferior vena cava opening. The inferior vena cava catheter had pierced this membrane, which was afterwards excised to free the catheter.

A fenestrated membrane as found in this patient was first described by Chiari in 1897[3] and is therefore called a Chiari network. These intra-atrial fibrous networks represent unabsorbed vestiges of the right sino-atrial valve, and are found at the margins of the Eustachian and Thebesian valves and also along strands which connect these structures to the crista terminalis. Such strands are also occasionally found on the left side of the heart. They are comparatively rare[4] and are reported to be clinically and haemodynamically harmless.[5] It has been said that these Chiari networks might act as filters for emboli from the leg veins,[4] but patients with Chiari networks have been reported to die from pulmonary emboli. This appears to be the first reported case where a Chiari network obstructed the insertion of a venous catheter in an open-heart operation.

Case 17

This was a White female of 19 years who presented with a history of a heart murmur since childhood and palpitations and attacks of lightheadedness for a few weeks. There were no symptoms of cardiac failure. On examination a systolic thrill and murmur were present over the whole praecordium, maximally at the base of the heart. A long diastolic murmur was heard to the left of the sternum. Fluoroscopy showed an enlarged heart, and the electrocardiogram indicated right ventricular hypertrophy. Catheterization of the right heart showed a gradual increase in oxygen content, from 62% in the venae cavae to 69% in the main pulmonary artery. This increase was gradual and not high enough to indicate the presence of a septal defect. It was, however, suggestive of a small left-to-right shunt. Pressure readings indicated an infundibular pulmonary stenosis with a pressure of 87/0 mm. low in the right ventricle and 25/0 mm. higher up. A diagnosis of infundibular pulmonary stenosis with the suspicion of a small left-to-right shunt was made. The clinical examination suggested that this shunt was probably a patent ductus arteriosus, although an aorta-pulmonary window or small ventricular septal defect was not excluded.

At operation a patent ductus was not found. When the right ventricle was opened the patient was seen to have severe infundibular pulmonary stenosis with an infundibular chamber. A continuous flow of red blood entered this chamber. It did not appear to be coming from the left ventricle and stopped immediately when a clamp was put on the aorta. It was then possible to see a fistula, one centimeter in diameter, between the right anterior aortic sinus of Valsava and the infundibular chamber. This defect was closed with interrupted sutures of silk and during this period anoxic arrest of the heart occurred. This lasted, however, only a few minutes as the clamp was taken off the aorta immediately after the fistula was closed. Thereafter the infundibular stenotic area was excised.

A number of reports of sinus of Valsava defects with aorta-right ventricular fistulae have appeared in the literature. The association of a sinus of Valsava fistula with the right ventricle and infundibular pulmonary stenosis is rare, and this is only the fourth case reported in the world literature. The third one has been reported recently by Gerbode, Osborn, Johnston and Kerth.[6] The presence of infundibular pulmonary stenosis makes the pre-operative diagnosis of a sinus of Valsava fistula with the right ventricle difficult, and this interesting case will be reported more fully in a separate paper.

This patient was the only one in this series who developed a serious chest complication postoperatively. She bled from a coronary artery in the immediate postoperative period, and had to be re-explored. After ligation of the bleeding artery repeated aspirations of a haemothorax led to an empyema which was drained with complete expansion of the lung. In addition, this patient was, unknown to herself or to her medical attendants, 3 months pregnant. The open-heart procedure did not interrupt her pregnancy which proceeded normally afterwards.

DISCUSSION OF DEATHS

Four patients died in the postoperative period in this series of 22 patients. They were all in severe cardiac failure pre-operatively. In 2 of them it was not possible to correct the defect responsible for cardiac failure at operation. In the other two the defect was corrected, but the ventricular muscle failed postoperatively. If the heart defect cannot be corrected at operation in a patient in severe cardiac failure, survival of the open-heart procedure is unlikely. Severe cardiac failure in the immediate pre-operative period is a bad prognostic sign. The 4 deaths in this series will be reported in more detail.

Case 9

This was a White female of 43 years who complained of shortness of breath on slight exertion, oedema of the ankles, and attacks of bronchitis for 18 months. Examination revealed a patient with complete situs inversus, in right-sided cardiac failure. A systolic murmur heard maximally over the right third and fourth intercostal spaces, and a short mid-diastolic murmur were present. The second sound at the base of the heart was widely split and fixed. The electrocardiogram indicated dextrocardia with right ventricular hypertrophy. The vector cardiogram showed clockwise rotation above the horizontal. Fluoroscopy showed an enlarged dextro-positioned heart with a large pulmonary conus and a right-sided aorta. Pulmonary plethora was present. Right-heart catheterization

showed a large atrial septal defect. The pre-operative diagnosis was that of a large atrial septal defect in a patient with complete situs inversus. The operation on this patient was a mirror image of the usual procedure for closure of an atrial septal defect. A left thoracotomy with the patient tilted 30° towards the right side was made through the fifth interspace. Because of the reported frequent congenital anomalies associated with dextrocardia, gross anatomical abnormalities were suspected. However, at operation a complete mirror image of the normal anatomy was found. There were left superior and inferior venae cavae which opened into the left atrium. The pulmonary artery arose from the left ventricle. The pulmonary veins returned to the right atrium and the aorta arose from the right ventricle. The superior and inferior vena cava catheters were inserted through the left atrium, and the arterial inflow catheter was inserted into the left femoral artery. When the patient was on total bypass the left atrium was opened. A large ostium primum defect, measuring 8 cm. in diameter, was found. The medial leaflet of the right-sided atrio-ventricular valve was split. This valve, however, appeared to be a tricuspid one and fully competent. On the left side between the atrium and ventricle there was also a competent tricuspid valve. The left ventricle was of enormous size. A patch of teflon was sewn into the defect with interrupted stitches. No difficulty during operation was experienced, and the patient appeared to do well immediately afterwards. However, she soon went into severe congestive cardiac failure and died of pulmonary oedema 12 hours after operation. It was interesting that this patient had an extremely small right ventricle, and it is possible that this small ventricle was not able to handle the increased amounts of blood returned to it after closure of the defect.

The incidence of complete situs inversus is 1 in 10,000. The incidence of congenital cardiac anomalies in these patients is 8%.[7] The heart anomalies that occur in these patients are usually complex, so that multiple defects should always be suspected. The interpretation of these complex defects at operation is extremely difficult.

Case 14

This was a White female, aged 33 years, who gave a history of a 'leaking heart' since childhood. Eighteen months ago she developed symptoms of left-sided heart failure. These symptoms have become more prominent during the past 6 months. Examination showed left ventricular hypertrophy and a harsh systolic murmur heard maximally over the aortic area, which radiated into the neck. Fluoroscopy showed a markedly enlarged left ventricle with a dilated ascending aorta. On the electrocardiogram evidence of left ventricular hypertrophy and myocardial ischaemia was present. A diagnosis of severe congenital aortic stenosis was made. Because of the poor prognosis without relief of the aortic obstruction, an operation was decided on although the patient was in severe left ventricular failure. The aortic valve was approached through an incision in the dilated ascending aorta after the heart had been arrested by circulating cold blood through the coronary arteries. The aortic valve leaflets were normal, but the aortic ring was much dilated. Two centimeters below the aortic valve a fibrous subvalvular stenosis of a diameter of 7 mm. was present. This fibrous ring was incised and dilated to 2·5 cm. After the heart and aorta were filled with saline, the incision in the aorta was closed and the clamp on the aorta released. The warm blood heated the heart quickly, and normal rhythm was established after a single defibrillating shock. The arrest of the cooled heart lasted only 12 minutes. The patient appeared to do well immediately after the operation, but after the second day she went into severe left ventricular failure, of which she died on the fourth postoperative day.

Case 13

This was a White female, aged 43 years, who had undergone an exploration for mitral stenosis 2½ years earlier. At that operation predominant mitral incompetence with minimal stenosis was found. The valve was 2·5 cm. in diameter. The slight stenosis was relieved, but severe incompetence, from a defect at the postero-medial commissure, remained. She remained in congestive cardiac failure afterwards, and two and a half years later it was decided to attempt correction of the incompetence by an open-heart operation. The mitral valve was approached through the right atrium and atrial septum. A good exposure of the valve was obtained and the defective mitral leaflet could be demonstrated. An attempt to replace part of the defective leaflet with a teflon patch was unsuccessful in correcting the mitral incompetence, since the left atrial pressure remained the same, i.e. 30 mm.Hg. The patient developed pulmonary oedema and died 6 hours after operation.

Case 18

This was a Coloured male child of 6 years who was well till 2 days before admission to hospital. He then suffered a febrile attack and developed severe congestive cardiac failure. When admitted to hospital he had a septic sore on the left foot. A harsh systolic murmur was heard over the whole praecordium with a short mid-diastolic murmur at the mitral area. Fluoroscopy showed an enlarged heart and the electrocardiogram showed predominantly right ventricular hypertrophy with a P-pulmonale. The patient was catheterized and a large atrial septal defect was demonstrated. The vector cardiogram showed anticlockwise rotation above the horizontal. The pre-operative diagnosis of an ostium primum defect with congenital mitral incompetence was made. The patient did not respond well to conservative management of his cardiac failure, and he was operated on three and a half months after admission to hospital, still in severe cardiac failure. At operation an ostium secundum defect was found. In addition there was evidence of severe mitral incompetence, from rupture of a large number of chordae tendiniae attached to the middle part of the antero-medial leaflet. This part of the leaflet was plicated according to the technique described by McGoon.[8] The ostium secundum defect was closed. The left atrial pressure was markedly reduced after operation, and the patient did fairly well during the first 7 days. On the eighth day, however, severe cardiac failure again developed, and the patient died of pulmonary oedema a day later. An autopsy was not obtained, but it was felt that the plication stitches in the leaflet tore out on the eighth day.

A number of patients with ruptured chordae tendiniae, who were operated on with the aid of a heart-lung apparatus, have been reported. The main causes of rupture of the chordae tendiniae are acute bacterial endocarditis, rheumatic fever, trauma, and myocardial infarction. In the myocardial infarction a papillary muscle is usually torn.[9] Serious mitral incompetence only develops if more than 2 chordae are ruptured. Osmundson, Callahan, and Edwards reported on 20 patients.[9] In 2 patients only 2 chordae tendiniae were torn and in them minimal cardiac failure was present. It is especially bacterial endocarditis of the aortic valve which leads to rupture of the chordae attached to the middle of the antero-medial leaflet of the mitral valve. This was exactly the situation found in the patient reported here, in whom the illness started with a pyrexia and a septic lesion on the left foot, from which a *Staphylococcus aureus* was cultured. This patient most likely had an acute bacterial endocarditis which was responsible for rupture of the chordae tendiniae, and the atrial septal defect was an accidental anomaly. It is interesting to note that here the rare association of bacterial endocarditis and an atrial septal defect was found. McGoon[8] has described 2 patients in whom plication of the involved leaflet has resulted in marked improvement of mitral incompetence. However, in this patient such a large part of the medial leaflet was free of chordae tendiniae that the strain on the plication sutures must have been excessive.

SUMMARY OF OPERATIVE DEATHS

As has already been stated, all 4 patients were in severe cardiac failure pre-operatively. In 2 patients it was not

possible to correct the anatomical defect at operation, and they died soon after operation. The other 2 patients in whom the congenital defects were corrected, were 33 and 43 years of age. These 4 deaths strongly suggest that heart defects should be corrected before severe cardiac failure develops. The presence of severe cardiac failure is a serious and unfavourable prognostic sign.

DISCUSSION OF COMPLICATIONS

From Table I it will be noticed that the average age of the 22 patients was over 21 years, and 7 were over 30 years of age. The low incidence of complications and the successful operations on these relatively old patients indicate that age as such does not influence adversely the outcome of an open-heart operation. The severity of cardiac failure appears to be the most important single factor, and the type of defect, in addition to the surgeon's ability to correct it at operation, the second most important factor in deciding the outcome of the operation.

Bleeding. Postoperative bleeding was minimal irrespective of the length of the perfusion, and it did not exceed 700 ml. for the first 48 hours except in 2 patients. In 1 patient in whom the postoperative blood loss was 2·2 litres, a re-exploration was done (Case 17). A bleeding coronary artery from the incision in the right ventricle was found and, after ligation of this vessel, the further loss was only 100 ml.

The other patient lost 1·6 l. during the first 24 hours postoperatively (Case 19). It was not necessary to reopen her, and the bleeding stopped on its own 24 hours after the operation. The use of the heart-lung apparatus did not induce a bleeding tendency in any of the patients reported here.

Complications often described as occurring with the use of the heart-lung apparatus, such as metabolic acidosis, electrolyte imbalance, unexplained high postoperative fever, cerebral damage, and pulmonary vascular complications were not seen in this series.

Infection. Superficial wound infection from extensive cauterization of subcutaneous bleeding vessels occurred in 3 patients. The infection was superficial and cleared up quickly. One patient (Case 17) developed an empyema postoperatively, following on repeated aspiration of a haemothorax. This was the patient who was reopened because of a bleeding coronary artery. The empyema was drained later with complete re-expansion of the lung.

Endocarditis. Pre- and postoperative endocarditis occurred in 4 patients. In 1 who underwent a pulmonary valvotomy (Case 15), a positive diagnosis of bacterial endocarditis in the postoperative period could be made. This patient developed attacks of pyrexia with cold shivers, pleuritic chest pain, and splenomegaly. He appeared to suffer from septic emboli from the pulmonary valve to the lungs. He responded to therapy with kanamycin and erythromycin. He was in good health 15 months after the operation. A second patient (Case 17) developed an empyema and, in association with this, pyrexia and multiple petechial haemorrhages. She also had an enlarged spleen. Repeated blood cultures were negative, but she was treated for bacterial endocarditis. She responded well to drainage of the empyema and antibiotic therapy. The third patient was a White boy of 12 years (Case 3) who had definite symptoms and signs of bacterial endocarditis before he underwent an open-heart operation for closure of a ventricular septal defect. At operation no vegetations were found in the vicinity of the septal defect. He did well postoperatively. The fourth patient (Case 22) was found to have vegetations on his pulmonary valve when an infundibular pulmonary stenosis was resected. The affected pulmonary valve leaflets were excised. The patient received 4 week's therapy with 'chloromycetin' and penicillin postoperatively and made a good recovery.

Bacterial endocarditis occurring as a complication of open-heart surgery is extremely serious. Heins and Linde[10] reported an incidence of 3·5% in 144 patients operated on with a heart-lung apparatus. In these 5 patients there were 2 deaths. They point out that the usual symptoms and physical signs of bacterial endocarditis are not present postoperatively. The most important point is fever occurring soon after surgery. Cooper, Morrow, Roberts and Hermann[11] reported a case of candida endocarditis. They point out that the relative rarity of the complication of bacterial endocarditis after open-heart surgery is surprising in view of the damage to the endocardium at operation and the foreign bodies used as sutures and patches inside the heart. To this can be added the lowered resistance of the patient arising from the large amount of foreign blood in the circulation in the postoperative period and the great risk of bacterial contamination of the blood in the heart-lung apparatus.

The place of routine postoperative antibiotic therapy in patients undergoing open-heart surgery is debatable. Kittle and Reed[12] have reported on 2 groups of patients who underwent open-heart operations. The one group received prophylactic antibiotic therapy and the other group not. The incidence of wound and other infections were the same in both groups. However, these writers do not refer to bacterial endocarditis. Cooper *et al.*[11] suggest that antibiotics should be administered as a routine after operation, although they state that the value of antibiotics given prophylactically is doubtful.

It is interesting that in this series the one patient who clearly developed postoperative bacterial endocarditis (Case 15) did not receive any antibiotics in the postoperative period. After this experience we decided to administer chloromycetin and penicillin as a routine to all patients undergoing open-heart surgery from the day before operation to the tenth postoperative day.

CONCLUSION

The results in this series of 22 patients indicate the safety of the Pemco Automatic Heart-Lung Apparatus in open-cardiac surgery. In none of the 22 patients was there a complication that could be attributed to the use of the heart-lung apparatus.

Of the modifications to the Pemco Heart-Lung Apparatus of the Karl Bremer Hospital, the automatic control is of great help to the technician who controls the apparatus; it enables him to attend more fully to other details of the machine. The coronary sinus reservoir works well and can handle large flows of coronary-sinus blood. This is the only part of the apparatus where anti-foam is used. It is applied as a thin film on the inside of the reservoir.

In the absence of severe cardiac failure, open-heart surgery can have a low mortality. In this series the 4 patients who died in the postoperative period were in severe cardiac failure before the operation. There is something to be said for early operation in patients who are in any case going to require it at some future date.

SUMMARY

The Pemco Heart-Lung Apparatus in use at the Karl Bremer Hospital has a few special features: (*i*) An electronic control unit keeps the level of blood in the oxygenator constant, thereby eliminating any loss of blood from the patient into the machine and also preventing the danger of air embolism during perfusion. (*ii*) A precision rotameter flow meter is used in the circuit to control the arterial flow. (*iii*) The coronary sinus reservoir has been designed to handle a large volume of blood with minimal foaming. (*iv*) The arterial filter-bubble trap unit is regarded as an essential part of the apparatus.

The connection of the heart-lung apparatus to the patient is described and an open approach to the mitral valve through a left antero-lateral thoracotomy is recommended.

The first 22 patients operated on at the Karl Bremer Hospital with the aid of the Pemco Heart-Lung Apparatus are reported. Interesting cases amongst these are: a patient in whom a Chiari network in the right atrium obstructed the insertion of the inferior vena cava catheter at operation. This appears to be the first case described in the literature where such a membrane caused difficulty at operation. Another patient with infundibular pulmonary stenosis had a fistula of the sinus of Valsava with the infundibular chamber. This is the fourth case of this nature described in the literature.

Four of the 22 patients died in the immediate postoperative period, and there was one death 4 months after operation. All 4 patients who died soon after operation were in severe cardiac failure pre-operatively, and in 2 it was not possible at operation to correct the cardiac defect. These 4 patients are reported in detail. The presence of pre-operative cardiac failure appears to be the most important single factor in determining the survival of the patient. The other factor is the surgeon's ability to correct the heart defect at operation.

The postoperative complications in this series of 22 patients are discussed. There were no complications that could be attributed to the heart-lung apparatus itself.

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