Historical Perspectives

John H. Gibbon

The First 20 Years of the Heart-Lung Machine

Adora Ann Fou

The thought of operating on the heart probably never quite left the minds of surgeons in the 19th and early 20th centuries. The early 17th century had yielded a report that the heart could heal from a cut. In *Alphabeton Anatomikon* (Geneva, 1604), Barthelemy Cabrol had described postmortem examinations that showed scars of significant sizes on the heart. Those wounds were clearly not the cause of death, since Cabrol knew firsthand that his subjects had been hanged as criminals and had enjoyed apparent good health before that. In America, by 1909, there existed a collection of cases in which it was shown that wounds of the heart could heal.[1] This stimulated interest in the tantalizing and novel idea that taking a scalpel to the heart could be curative, but the terrible odds against success discouraged avid pursuit. At first, heart surgery progressed very slowly, for procedures that could work in theory had very low success rates in application. For example, in the 1930s, reports in the European literature indicated that only 9 patients out of 140 survived the Trendelenburg operation, named after the German surgeon who 1st described pulmonary embolectomy. There had, at that time, been no successful attempts in the United States.

Robert Richardson, MD, remarked in his writings that when someone thinks of a new idea, there are at least a few other people in the world thinking of the same thing. Extracorporeal circulation was a possible answer to intracardiac operations, but in what form could it work? What else besides lungs could oxygenate blood? How could one "short-circuit" the heart? The often repeated remark that chance favors the prepared mind seems to have been at work. Here we look briefly at 1 of the men who were contemplating extracorporeal circulation in the early 1930s. John Heysham Gibbon, Jr., known also as JHG, was at Harvard completing a 1-year fellowship under Edward D. Churchill.

At 2:45 on the afternoon of 3 October 1930, Dr. Churchill and Dr. James White were called to the bedside of a middle-aged, rather obese woman, who had pale, clammy skin and was breathing with difficulty. Only minutes before, this patient had been well, apparently recovering uneventfully from gallbladder surgery 2 weeks before. She complained of a "lump" in her chest that had turned into a sharp pain. Meanwhile, she was becoming paler, apprehensive, and nauseated. The diagnosis was massive pulmonary embolism. They prepared for an emergency Trendelenburg embolectomy as a last resort, if the patient became moribund. Gibbon was assigned to monitor her vital signs, every 15 minutes. At 8:00 a.m. the next morning, the patient became unconscious, had no palpable pulse, and stopped breathing. Dr. Churchill immediately opened her chest and in 6 and a half minutes removed the embolus and closed the opening in the pulmonary artery.[2] The patient never regained consciousness. Gibbon wrote about that night's vigil: ". . . helplessly watching the patient struggle for life as her blood became darker and her veins more distended, the idea naturally occurred to me that if it were possible to remove continuously some of the blue blood from the patient's swollen veins, put oxygen into that blood and allow carbon dioxide to escape from it, and then to inject continuously the now-red blood back into the patient's arteries, we might have saved her life. . . . we would have bypassed the obstructing embolus and performed part of the work of the patient's heart and lungs outside the body."[3]

This was the critical event that shaped Gibbon's thoughts for the next 2 decades. If only a machine could be made to take over the function of the heart and lungs, for only a short, critical period of time, long enough for effective surgery to be done. Gibbon approached Dr. Churchill with the idea to construct an extracorporeal blood circuit that could be life-saving in the event of pulmonary artery

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obstruction. Although not enthusiastic about the project, Churchill accepted Gibbon for another fellowship year and even hired Gibbon's wife, Mary Hopkinson Gibbon, who had been Churchill's own surgical research technician. Gibbon recalled that a friend at Massachusetts General Hospital had been even less encouraging and that only 1 of his medical friends, Dr. Eugene Landis, had not discouraged him from undertaking his project.[4] Gibbon the researcher, determined and armed with an analytical mind, undertook the making of the heart-lung machine and started what colleagues and friends were later to call the "Gibbon era."

History of Artificial Circulation

The 1st ideas of extracorporeal circulation were born when the relationship between the heart and oxygenation was discovered. It was 1st recorded in 1812 by LeGallois, who remarked that, "If one could substitute for the heart a kind of injection of arterial blood, either naturally or artificially made, one would succeed in maintaining alive indefinitely any part of the body whatsoever."[5,6] After that, many scientists experimented with individual organs, trying to sustain them with perfusion of oxygenated blood.

In the middle of the 17th century, Lower performed the 1st recorded successful direct blood transfusion. However, progress was hampered by problems with clotting. Late in the 18th century, Lavoisier discovered the theory of gas exchange in the lungs and, accordingly, the vital role of oxygen in sustaining life. The integration of these 2 ideas allowed Brown-Séquard, by the middle of the 19th century, to understand the need to oxygenate blood used as a perfusate. He used his own circulation to perfuse the limbs of guillotined criminals, thereby showing that muscles in rigor mortis could be revitalized and kept responsive while the unperfused part degenerated.[7] Ludwig and Schmidt, in 1868, described an apparatus that enabled artificial blood to be infused under constant pressure from a reservoir into an isolated mammalian organ. In 1885, von Frey and Gruber used, in their own oxygenator, von Schroder's method of aerating blood, which was to froth it by bubbling oxygen into venous blood from the bottom of a receptacle.[8,9] However, they had to discontinue this method of aeration once the fatal effects of air emboli in the heart and lungs were observed.

The 20th century brought McLean's discovery, in 1916, of heparin as an anticoagulant. It was one of the essential elements in the early success of Gibbon's heart-lung machine because of the absolute need for recirculating fluid blood with no clots in it. (Hirudin, discovered in 1855, was purified from the saliva of leeches and used as an anticoagulant until it was largely supplanted by heparin.)

A pump oxygenator, it was hoped, would enable the performance of physiologic observations unattainable by other means, in addition to enabling intracardiac operations under direct vision in the dry and motionless field so needed for delicate cardiac surgery.

Components of an Extracorporeal Apparatus

Gibbon was aware of the 4 basic components that any heart-lung machine would require: a venous reservoir, an oxygenator, a temperature regulator for the extracorporeal blood, and an arterial pump. The oxygenator was probably the most difficult part to conceive and execute. In this, Gibbon was aided by an engineer on the Harvard faculty. The physiologic properties of blood are such that the greater the surface area exposed to oxygen, the better the gas exchange will be. Therefore, the venous blood was introduced tangentially into a rotating metal cylinder that both spread the blood thinly, by centrifugal force, and kept it in motion to maximize perfusion. Gibbon's initial goal was to attain 95% oxygenation. The narrowness of the outflow and the nearness of the receiving cup were both planned to minimize trauma to the red corpuscles, such as would occur during abrupt changes in flow rate and direction. This concern about traumatic hemolysis was to underlie all future plans for constructing the pump oxygenator. Keeping the cylinder reasonably small also required ingenuity, for the engineer at 1st estimated that the cylinder would have to be about 2 stories high in order to adequately perfuse a human adult. The venous reservoir had to collect the venous blood via gravity-induced flow, and had to allow for the escape of newly accumulated bubbles. The 1st arterial pump that Gibbon settled on was the Dale/Schuster pump, which yielded sufficient output without undue stress on the cellular components. That and all future pumps had to be calibrated frequently to regulate the flow rate in accordance with the immediate situation. The actual pump that Gibbon used in his 1st apparatus was de Burgh Daly's modification of the Dale/Schuster model.[10,11] By 1938, he was using the valveless roller pump[12] (Fig. 1). The final element was a device to control the temperature of the blood. That was accomplished by putting the reservoir into a sleeve through which water (or other solution with suitable heat capacity) could flow. The water could be heated or cooled to the desired systemic temperature.

In order that the machine could be used for human surgery, each part had to function flawlessly, so Gibbon tested every component both in the mechanical laboratory and during surgery on animal models. The surgery was done 1st on cats, and then, as the capacity of the machines increased, on dogs.

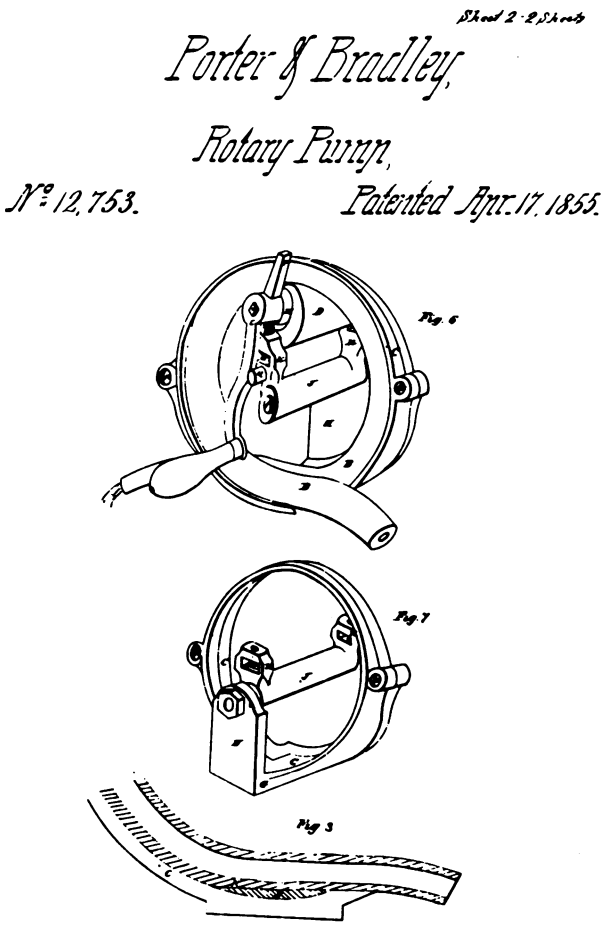

Fig. 1 *Patent drawing of the Porter and Bradley rotary pump (1855). This is the earliest patented version of a constant-injection valveless roller pump, upon which slight modifications have been made by numerous inventors until the present day. Gibbon's was motor driven.*

Many different factors had to be considered in testing and designing. In the early 1930s, Gibbon had very little choice of materials: there was gum rubber for tubing, and either glass or metal for cannulas and connections (Fig. 2). He had to decide upon the material for inflow and outflow valves, and for the surface upon which gas exchange would occur. Allergic reactions, damage to the blood cells, clotting, and the need to adjust the flow rate intraoperatively were all problems that had to be solved. To accommodate the requirement for sterility in the surgical setting, Gibbon decided that the machine's parts should be removable for efficient cleaning. Moreover, the danger of air embolism dictated that the pump and tubing be filled with blood from the exit point of the body to its re-entry point. For this reason, the smaller and more efficient the pump structure, the smaller would be the percentage of total blood volume out of the body at any given time. Gibbon needed a means of measuring the temperature of both the perfusate and the patient, in addition to gauges for the continuous monitoring of blood gases and pump pressure.

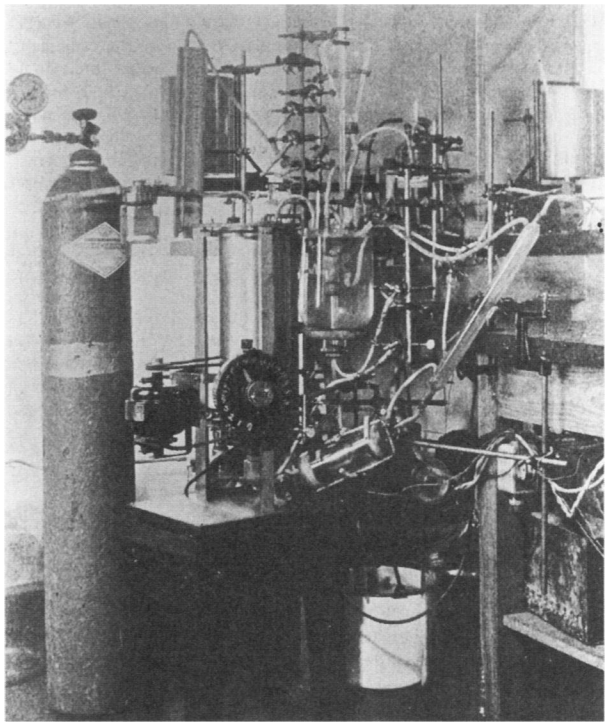

Fig. 2 *Equipment used by Gibbon in early laboratory experiments in extracorporeal circulation.*

Experiments of 1934-1935

Between 1934 and 1935, the 1st apparatus (Fig. 3) was put through countless hours of testing. Gibbon used a mixture of 95% oxygen to 5% carbon dioxide, a higher oxygen content than that delivered by any oxygenator previously described. The principal

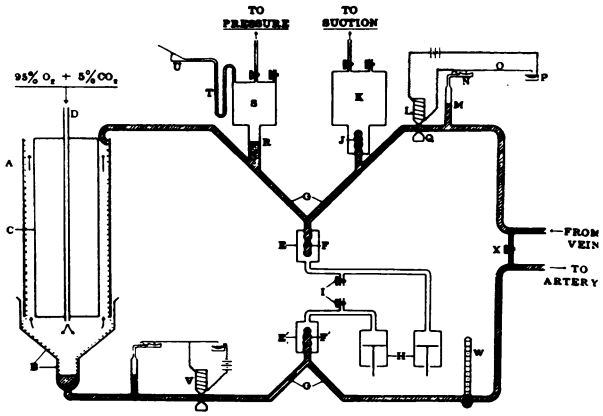

Fig. 3 *Diagram of the 1st apparatus. Oxygenation occurs within the large rotating cylinder at left, from which blood is withdrawn and pumped back into the arterial system.*

(From Gibbon JH, Jr.[13] Used by permission. Copyright 1937, American Medical Association.)

feature of each pump was an electrically powered air piston that controlled a rubber finger-cot between 2 unidirectional valves. The upstroke of the piston would draw blood through the inlet valve and close the outlet valve, and the downward stroke would close the inlet valve and push blood through the outlet valve. A needle valve controlled the degree of compression and expansion of the finger-cot and hence the volume of flow through the pump.[13] A flow of 500 cc or more per minute was achieved by the ¼-horsepower motor, which could pump 150 up-and-down strokes per minute.

Gibbon and his wife ran all the early experiments. Mary (Maly) Gibbon had her own impressive record of research work, and she and Gibbon worked closely together. The 1st experiments were done on cats, which were easier to obtain than dogs, were more suitable in size for the capacity of the apparatus, and had vessels and organs that could be manipulated relatively easily. Gibbon and Maly simulated a pulmonary embolism by compressing the pulmonary artery. The venous blood was then siphoned off into the apparatus with the aid of gravity; gas exchange occurred in the cylinder, and the oxygenated blood was pumped back into a peripheral artery. Recently, in Canada, heparin had been purified sufficiently for human use, so Gibbon and Maly used heparin as the anticoagulant. Before the experimentation was over, they would have tried many different ratios of heparin to blood in the hope of finding the optimal ratio that would prevent clotting, yet not be a hazard to the patient. Sodium barbiturate was chosen as the anesthetic. In order to observe the effects of their procedures on respiration, they simulated an intact pleural cavity by using the Drinker preparation, which exposed the heart while closing the thorax to enable the animal to breathe naturally.[14] They finally settled on a routine method of using the external jugular from which to withdraw blood and the femoral artery into which to inject the arterialized blood.

One of the earliest problems encountered was that of obtaining a sufficiently rapid flow of blood through the cannula in the external jugular. The thin walls of the vein were in constant danger of being sucked into the cannula, occluding it, and bringing on the rapid death of the animal. Two methods were devised to circumvent this problem. The 1st was to change the flow from intermittent pumping to continuous flow, which could double the flow without increasing the suction or could obtain the same volume of flow at half the velocity, either of which was useful. The 2nd method of guarding against accidental occlusion of the cannula was the use of a closed-circuit "switch" that, if activated, would stop the pump and thereby stop suction on the vein.[15]

Yet another problem was that the volume to be returned to the arterial circulation was too large to re-enter the arterial cannula if none but intermittent flow was used. Intermittent flow had been chosen in the belief that it was the closest emulation of the natural circulation induced by the action of the heart. The solution was to widen the tubing between the outlet of the arterial pump and the cannula inserted in the artery. Subsequently, the change from completely intermittent flow to continuous flow to counter the problem of cannula occlusion proved also to solve the dilemma of too much volume. The roller pump actually provided a slightly pulsatile continuous flow that was very satisfactory.

In order to ensure that the blood volume did not become too low while the animal was connected to the apparatus, Gibbon would inject a 6% acacia (a blood substitute) solution in physiologic saline, while the 1st volume of blood was being withdrawn from the jugular.[16]

Temperature was monitored carefully and was controlled by altering the temperature of the water bath circulating around parts of the apparatus.

On 10 May 1935, it was 1st shown that extracorporeal circulation could be carried out on a living animal for a period of time while the heart was stopped, and that the animal could recover and survive for several days after the surgery.[17] Theretofore, the longest survival time after restarting the heart had been 2 hours and 15 minutes. At this point, there were still 2 major obstacles that Gibbon could not overcome. One was severe acute anemia that could not be reversed. The other was hemolysis caused by the blood's passage through the apparatus. Ahead of him were some of the most difficult struggles with planning, technique, and construction.

The 1938 Experiments

With funding from the Josiah Macy, Jr. Foundation of New York and the National Institutes of Health, Gibbon worked another year in an effort to present new data by 1939. One of the main objectives was to prevent the severe anemia caused by the acacia or saline solution's dilution of the blood. Gibbon, in his 1938 experiments, made it standard practice to use donor cat blood to make up the volume. The donors were given heparin before the blood was drawn and were given a compensatory amount of saline during the drawing, to make up for lost volume.

It was determined that the flow rate necessary to maintain adequate blood pressure was 99 cc per minute, per kilogram of body weight. The other important observation made during these experiments was that there was need for about 75% more blood-filming surface to maintain sufficient oxygenation.

After extracorporeal circulation was established, the pulmonary artery of the animal was gradually occluded by a clamp to simulate an embolism. Com-

plete occlusion was maintained for 10 to 25 minutes. The clamp was then gradually removed and the animal's natural circulation was allowed to take over. Postoperative recovery was always aided by 100 cc of 5% glucose in saline solution to boost caloric and fluid intake. In these experiments, the survival rate was 13 out of 39. The major cause of death was anoxemia: hence Gibbon's conclusion that oxygenation techniques must be improved. Factors contributing to the deaths were hypotension, shock, and hypothermia. The cause of death in 2 cats was pericarditis, severe jaundice in 1, and hepatic necrosis in 1. Four cats survived in healthy condition, 1 proceeding to deliver a healthy litter of kittens. Gibbon had succeeded in showing that whole body perfusion was possible for up to 25 minutes in animals the size of cats, with a 30% survival rate, a never before accomplished task.

In the 1930s, John H. Gibbon was the chief architect and proponent of the heart-lung machine. Although many great scientists soon would race to help perfect this wonderful apparatus, Gibbon had conquered most of the problems associated with extracorporeal circulation and stood alone at his level of knowledge. Future years would see the refinement of Gibbon's apparatus and its adaptation for use on the human body, as parts of it were perfected 1 at a time.

The 1940s

In 1942, just before he went into the army, Gibbon built a slightly larger model. He returned, in 1945, to his position as assistant professor of surgery at the University of Pennsylvania. In January of 1946, he accepted a position, offered by Dr. Thomas Shallow, as Professor of Surgery and Director of Surgical Research at Jefferson Medical College. Once at Jefferson, Gibbon returned to his work on the heart-lung apparatus with his surgical residents. He decided that it was time to test its new oxygenating capacity. With funding from the National Institutes of Health, he began a series of experiments on dogs.

Among the people with whom Gibbon worked in the late 1940s was a medical student named E.J. Clark, a former Air Force pilot. Clark's future father-in-law, the president of Lafayette College, was a good friend of Thomas J. Watson, the Chairman of the Board at IBM. Clark saw a distinct possibility of a partnership between IBM, with its many excellent engineers and machine experts, and Gibbon, who was still trying to make a heart-lung machine with greater oxygenating capacity. Needless to say, the idea appealed to both Watson and Gibbon. Noah V.A. (Alf) Malmros was placed in charge of the group that was to deliver Model I in 1949 (Fig. 4).

Gibbon and his surgical residents worked closely with the IBM people. The basic principles behind the working parts of his apparatus remained the same, and improvement came in the form of IBM's advanced technology and vastly greater access to materials.

Before each perfusion experiment, the entire apparatus was cleaned. The joints between glass and rubber, where fibrin was most likely to collect, were carefully scrubbed with an alkaline detergent and rinsed with large amounts of water. (Indeed, in manufacturing, the inner surfaces of the glass and rubber parts had been coated with silicone to decrease the amount of fibrin that could be deposited.) For an hour before the experiment, sterile water, followed by sterile saline solution, was circulated through the device. Once again, the apparatus was filled with donor blood, in order to prevent the depletion of blood volume in the animal. Canine blood is much more delicate than human blood and the use of autogenous blood for priming the apparatus minimized the difficulties associated with that. Thiopental sodium at 25 mg/kg was used for anesthesia. Heparin was administered at 5 mg/kg. A mixture of 96% oxygen and 4% carbon dioxide was blown over the blood film in the rotating cylinder. When the perfusion started, that was changed to 100% oxygen.

The 1st series of experiments, designed to observe the effects upon dogs of passing part of their circulation through the apparatus, resulted in no survival past 12 hours. The only cause of death that could be discerned upon autopsy was the presence of many small emboli throughout the viscera.[18] This led Gibbon and his associates to believe that a filter was needed to extract the emboli. At 1st, they used the lungs of the animal as a filter, before returning the blood to the femoral artery. However, none of the animals survived those experiments, either. An artificial filter was used: a non-metal 300- × 300-micron mesh. The next 6 consecutive trials were successful,

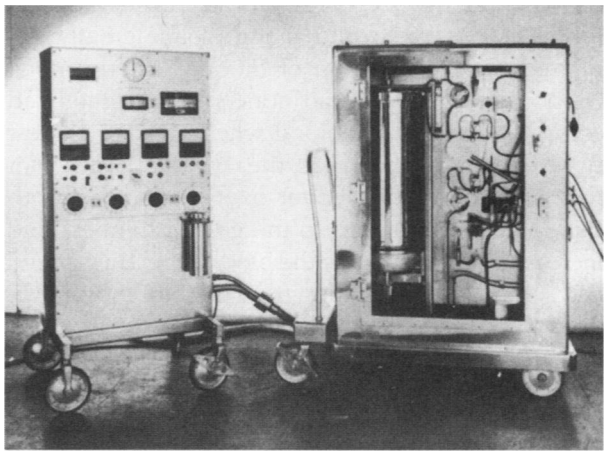

Fig. 4 *Model I, the 1st oxygenator built by IBM (1949). (From Romaine-Davis A.[11])*

with no significant hemolysis caused by the mesh. The filters collected grey gelatinous masses that microscopically were shown to contain fibrin and nonintact cellular components.

The next set of experiments was designed to observe the effects of diverting total body circulation through the extracorporeal apparatus. The entire vena caval output was diverted to the apparatus, so the only blood that reached the right heart was from the coronary veins. Of a total of 39 dogs operated upon, the 3 that had their venae cavae clamped for 60 to 113 minutes did not survive.

From a 2nd set that had their venae cavae clamped for 33 to 47 minutes, the results looked more promising. Four of the 8 in this group died within 5 to 25 days, 1 from injuries sustained in falling off a tall lab table. Two died of pericardial effusion. Pericardiocentesis was performed on 1 of the 2 animals, and the dog appeared to be on its way to recovery when the pericardium became densely adherent to the heart and effusion re-accumulated. This dog, the vena cava of which had been completely occluded for 46 minutes, died 23 days after perfusion, and was believed to have survived the longest period during which cardiorespiratory functions were completely maintained by an extracorporeal circuit.[19] The remaining 4 of the 33-to-47-minute group lived from 245 to 306 and more days.

A large proportion of the deaths occurred early in the investigations. Several deaths due to hemorrhage were caused by heparin. The acid-base balance could be maintained adequately only after the proper use of carbon dioxide in the aerating mixture was discovered. The most frequent cause of death was anoxia, due both to the difficulty of drawing enough blood to match normal cardiac output and to the difficulty of sufficiently oxygenating the blood that had been drawn. The effort to resolve the problem of insufficient oxygenation passed a major hurdle when, in the late 1940s, Drs. T. Lane Stokes and John Flick, Jr. realized that turbulence greatly improved the oxygenation of blood.[20] Interestingly, Gibbon and his wife had noticed the brighter red color assumed by the blood when, in their earliest experiments, they rotated the cylinder faster. But instead of attributing better oxygenation to turbulence, they attributed it to the greater thinness and increased surface area of the blood film. This indeed had signified the transition from the blood-film oxygenation process to the use of screens or mesh—anything that would introduce a dramatically greater surface area over which the blood could spread and, at the same time, increase turbulence. By 1950, with the engineering help of Stokes and Flick, wire mesh was routinely used in the oxygenating part of the apparatus.[21] First, wire mesh was used to line the rotating cylinders. Soon it was discovered that the most efficient method of oxygenation completely did away with the cylinder and consisted instead of passing the blood over 6 vertical stainless steel screens of wire mesh[22] (Fig. 5). Gibbon and his team then experimentally determined the rate of flow over the screens that was needed to saturate the venous blood up to 95%.

The results of their work in the 1940s had produced a list of at least 5 requirements that the heart-lung machine had to meet in order to sustain partial cardiorespiratory functions. The blood returning from the apparatus had to be saturated with oxygen. The pH of the returning blood, governed by carbon dioxide tension, had to remain within physiologic limits. Hemolysis had to be minimal. Blood had to be free of clotting during the procedure and able to regain its coagulability during recovery. Last, the blood had to be filtered if it passed through an extracorporeal circulation unit. In order to sustain complete cardiorespiratory function, there were 2 further requirements. For at least 46 minutes (the longest occlusion time for a surviving dog in their series), the normal cardiac output of the animal had to be matched as closely as possible by the apparatus, although pulsatile blood flow was not necessary for adequate organ perfusion. Further, all the blood from the venae cavae had to be diverted into the apparatus.[24]

After the First 20 Years

Model I had performed as well as anyone had expected. Gibbon was ready to move on. The use of screens was one of the many changes that IBM's Model II introduced in 1951 (Fig. 6). The ongoing

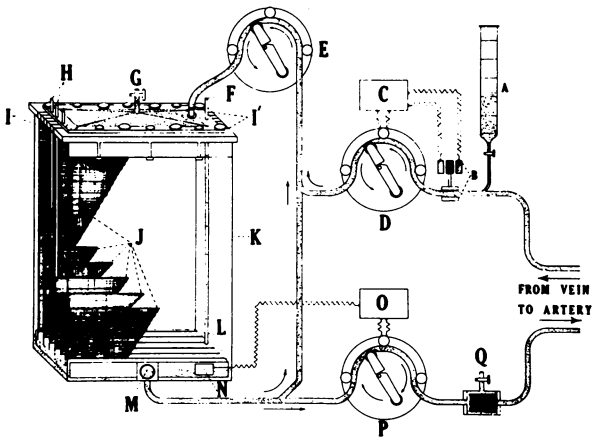

Fig. 5 *Diagram of the 1st screen oxygenator, a modified version of Model II (1951). The vertical screens (J) introduced turbulence at the point of gas exchange, greatly improving oxygenation.*

(From Miller BJ.[23] Used by permission of Surgery, Gynecology and Obstetrics, *now known as the* Journal of the American College of Surgeons.*)*

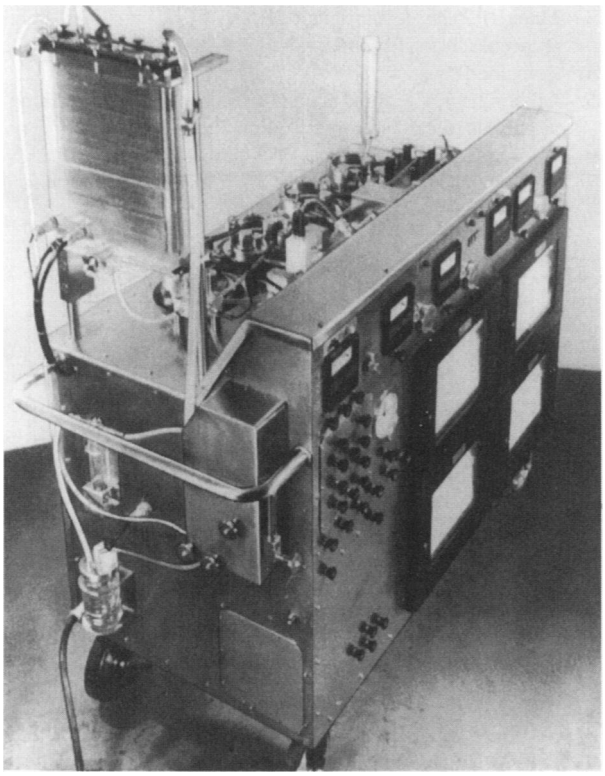

Fig. 6 *Model II, just before shipment to Gibbon (1951). (From Romaine-Davis.[11])*

cooperation of Gibbon and his Jefferson team with the IBM engineers resulted in continued successes. Mortality rates associated with the experiments of this period (1949-1952) dropped from 80% to about 10%. It was especially significant that, during this same period, Gibbon and his colleagues were able to steadily lengthen perfusion time.

The major problems that were overcome in the 1949-52 experiments were those of blood clotting, low oxygen levels, and the difficulty in adjusting intraoperative flow rates. A recurring problem was that of air emboli: the air trapped beneath the leaflets of the mitral valve when the left atrium was open would embolize to the coronary arteries, resulting in immediate death. Dr. Frank F. Allbritten suggested venting the cardiac apex with a tube through which the air could escape, a solution that came after many unsuccessful alternative attempts by Gibbon and his surgical residents, and one that would be used routinely in human open-heart surgery.

The 1st coronary artery bypass procedure on a human being was performed in February 1952, on an 11-pound 15-month-old girl. Diagnosed with a large atrial septal defect, she could not undergo cardiac catheterization because of her small size and edematous limbs. Gibbon and his colleagues decided to go ahead without catheterization. The baby's condition had been precarious from the start. When they opened the right atrium, no defect was found. Before they had time to explore further, the baby died. Autopsy revealed that she actually had a huge patent ductus arteriosus. This operation emphasized the importance of catheterization, as well as the necessity of improving the heart-lung machine to support total body perfusion long enough to enable cardiac exploration.[25]

The next bypass patient was an 18-year-old girl who had a large interatrial septal defect. She was quickly succumbing to heart failure, and after Gibbon's careful counseling and detailed explanations, her family decided upon the operation. On 16 May 1953, the atrial septal defect was repaired while the girl was kept on the heart-lung machine for 26 minutes. Her recovery was uneventful and catheterization 2 months later showed that the defect was completely closed, with no leakage. The patient is recorded to have been healthy well into the late 1980s. In Gibbon's own words, his idea ". . . was born and developed into a reality and finally was employed successfully in an operation on the heart of a human patient twenty-two years later, an event that I hardly dreamed of in 1931."[26]

Conclusion

Even before the 1st successful bypass surgery in 1953, Model III was in the works. Besides improvements on the standard components, Model III acquired a pH electrode. By now, Gibbon's was not the only team working on artificial cardiorespiratory bypass. The 2nd successful bypass surgery occurred in 1955 when Dr. Clarence Dennis and his team at King's County Hospital, Brooklyn, used his own disk oxygenator.

In the 1950s, the Mayo Clinic decided it would pursue the development of intracardiac procedures. The Clinic approached Gibbon, since Gibbon's machine was the most appealing. At first, Gibbon was reluctant to hand over his blueprints, fearing that the Mayo Clinic's capabilities and resources would enable it to perform the 1st bypass surgery before he could. Nevertheless, Gibbon shared his knowledge. The Mayo Clinic called its model the Gibbon-type oxygenator and, in 1955, reported a 50% success rate in procedures undertaken in 8 patients. In 3 of the 4 deaths, the failure was due not to a defect in the perfusion apparatus, but to the underlying cardiac problems. In the following years, the Mayo Clinic performed hundreds of operations on patients of all ages, thus becoming a major contributor to the acceptance of the new field of intracardiac surgery. By the 1960s, Galletti and Salisbury could duplicate Gibbon's results. William Gemeinhardt and William Jamison devised a pump of their own that was more suited to bypassing 1 or the other side of the heart,

which proved useful in cases of cardiac asystole and ventricular fibrillation. Other names emerging in the field of thoracic surgery included those of Alfred Blalock and Helen Taussig at Johns Hopkins, Robert E. Gross in Boston, Cooley and DeBakey in Houston, Björk in Denmark, Clarence Crafoord in Sweden, Andreasen and Watson in Britain, and Brukhonenko and his colleagues in Russia.[27] All of these surgeons were in touch with each other. Ada Romaine-Davis, in her book on John H. Gibbon's life and work,[28] said, "Evidently, time must pass in order for the inventor and others to realize the true worth of any discovery or invention." More than 2 decades had passed since Gibbon's initial conception of artificial circulation. What he had originally planned as a mechanism to enable the surgical removal of pulmonary embolisms opened a new field of thoracic surgery, far beyond his imaginings.

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Editorial Comment

The dream of aspiring cardiac surgeons before the pioneering research by John Gibbon (and by many others not included in this essay) was to operate on a quiet, bloodless heart in a deliberate and precise manner. Prior to Gibbon's 1st successful operation on a patient with an atrial septal defect, most procedures done on the beating heart were hurried, hectic, and often incomplete. The goal in those early days was to develop a reliable and practical means of visualizing intracardiac anomalies and lesions that could be repaired with precision. While induced total body hypothermia permitted 5 to 10 minutes of so-called "open" repair, the restrictions on repair limited its success, and the effect on patients was not infrequently disastrous. Lillehei's early use of a standard experimental laboratory technique known as cross circulation revealed the feasibility of operating inside the heart in children. The mother usually became the temporary "donor lung" or oxygenator. Despite the success of this approach, a simpler, more reproducible method was needed, and that could be achieved only with a totally mechanical device or circuit.

John Gibbon deserves much credit for the years of laboratory research that encouraged him to try his elaborate device clinically, with success in 1 of his first 2 attempts. One can only marvel at his ability to attempt such a clinical experiment supported by what now would be considered marginal and unacceptable results in the experimental laboratory. That event stimulated investigators to move ahead at an almost frantic pace. Today, open heart procedures are accomplished regularly with low risk, and extracorporeal circulation is used not only for cardiac conditions but for diverse other conditions.

This essay provides some insight into the fundamental scientific developments of other investigators, which preceded Gibbon's operation and were essential to its final accomplishment. John Gibbon's determination and courage are certainly laudable.

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