

Development of cardiopulmonary bypass – A historical review

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SUMMARY

The idea of isolated organ perfusion, a precursor of cardiopulmonary bypass, came by Legalois in 1812. First isolated organ perfusion was described by Loebell in 1849. The first closed system for oxygenation and returning the blood through arteries was created by Frey and Gruber in 1885. Gibbon Jr. is considered the father of extracorporeal circulation. In spring of 1934 he began constructing a machine for extracorporeal circulation in Boston. He published the first description of this system in 1937. Gibbon won the grant of the International Business Machines Corporation for developing the machine in 1947. Together they developed Model I in 1949 and Model II in 1951. After a few unsuccessful attempts in 1952, the first successful surgical intervention on the heart (closure of atrial septal defect) using cardiopulmonary bypass was performed on May 6, 1953. In 1945, Kirklin and his working group reported on a series of eight successfully treated patients in a row who underwent surgery with extracorporeal circulation. First successful valve surgery under the direct vision was performed by Dodrill in 1952, using his "Michigan Heart" machine as a right heart bypass. Using cardiopulmonary bypass, cardiac surgeons can deal with the complex cardiac pathology and save millions of lives.

Keywords: invention; history; cardiopulmonary bypass; extracorporeal circulation; Gibbon

INTRODUCTION

Cardiac surgery, a radical-reconstructive surgical discipline like it is today, could not have been developed without the interaction between medicine and engineering. For most reconstructive surgical procedures on the heart it is necessary to stop and empty the heart to acquire clear operative field, especially for the surgery of cardiac chambers. The only possible way to achieve this is to use cardiopulmonary bypass in cardiac arrest induced by cardioplegic solution. Discovery of heparin in 1917 by William H. Howell and Jay McLean led to the idea of developing extracorporeal circulation [1]. Our objective is a historical review of the cardiopulmonary bypass development.

HEART SURGERY BEFORE THE DEVELOPMENT OF EXTRACORPOREAL CIRCULATION

Before the invention of cardiopulmonary bypass, cardiac surgery had a high rate of perioperative complications, often resulting in fatality. The surgery of a 24-year-old patient, performed by Daniel Williams Halle in Chicago on July 10, 1899, is considered to be the first successful operation of a stab wound on the heart, although the patient had only suffered pericardial trauma with no heart involvement [2]. The first attempts of pulmonary artery thromboembolotomy were described by Trendelenburg in 1908 and 1909. Both of them were unsuccessful [3]. The first

successful pulmonary artery thromboembolotomy was performed in 1924 by Kirschner [4]. Poor outcomes of patients with attempted pulmonary thromboembolotomy were noted by Gibbon in 1937, inspiring him to develop a machine for extracorporeal circulation. Specifically, at that time, only nine out of 142 patients worldwide in whom pulmonary embolotomy was attempted survived this procedure [4]. At that time, heart valve surgery and congenital heart disease surgery were mainly at palliative level.

ISOLATED ORGAN PERFUSION AS A PRECURSOR OF CARDIOPULMONARY BYPASS

The idea of the isolated organ perfusion came from the reports of Julien Jean César Legalois in his monography *Expériences sur le principe de la vie* in 1812. He argued that if it were possible to make an artificial device that could use injectors to deliver arterial blood to the device, then it could be possible, using this device, to keep life of any part of the body, as well as throughout the body, indefinitely, thus ensuring resurrection.

The first isolated organ perfusion (artificial blood supply to a dog's kidney) was described by Karl Eduard Loebell in his dissertation in Marburg in 1849. Alexander Ludwig and Carl Schmit presented a method for continuous artificial blood supply to a dog's kidney with venous blood under the effect of hydrostatic pressure in 1867.

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At the Institute of Pharmacology in Strasbourg, Walde-
mar von Schroeder developed a device that could oxygen-
ate the blood during perfusion (a primitive bubble oxy-
genator) in 1882. [5].

The real precursor of extracorporeal circulation was con-
structed at the Institute of Physiology in Leipzig in 1885 by
Max von Frey and Max Gruber. The system consisted of the
venous blood supply, oxygenation cylinder that used film
oxygenation principle and pumps that pumped the blood
in continuing fashion under the influence of hydrostatic
pressure. Their system consisted of devices that affected the
blood temperature, a thermometer, and pressure gauges. It
was the first machine that could perform blood oxygenation
without any interruption of the blood flow [6]. This device
seemed too complicated for Carl Jacoby, from the Institute in
Strasbourg, and in 1890 he developed his perfusion system
that he called "Hematizator." He used a pump with pulsa-
tile blood flow, and, unlike before, he developed systems
that had pumps with continuous blood flow [7]. The pump
with pulsatile flow dynamics was developed by Hamel at
the Institute of Physiology of the University of Bern [5].
Oxygenation of the blood was performed in the tank, by
direct air contact (bubble oxygenation). Since air embolism
was a concern, Jacoby abandoned this technique in 1985. He
developed a machine that he named "Double Hematizator."
The machine consisted of two pumps. Isolated lungs of an
experimental animal were inserted between the pumps per-
forming blood oxygenation [8].

At the beginning of the twentieth century, Zeller in
Berlin created a link between the earlier experiments of
artificial perfusion of organs and eventual use in clinical
practice. In 1908 he declared that the use of artificial
perfusion should be considered in the surgery of heart
wounds, pulmonary thromboembolism, as well as in
bleeding to death [5].

JOHN HEYSHAM GIBBON JR. – THE FATHER OF EXTRACORPOREAL CIRCULATION

Gibbon Jr. was born on September 29, 1903 in Philadelphia.
He attended Princeton University in New Jersey from 1919
to 1924. In 1927 he completed his studies at the Jefferson
Medical College in Hillsboro, Missouri. He was the fifth
generation of physicians in his family, and the third gen-
eration of surgeons. His father was a professor of surgery at
the Jefferson Medical College and a nationally recognized
surgeon [9]. After graduation, he spent two years on intern-
ship at a hospital in Pennsylvania [10]. After that he went to
Harvard and carried a one-year research fellowship under
the guidance of surgeon Edward Dunderg Churchill [11].
During that time, Gibbon got an idea that changed his life
and profoundly influenced the history of cardiac surgery.

Gibbon's wife, Mary Hopkinson, who was Gibbon's tech-
nical assistant in the research, said that October 3, 1930 was
a day that changed the history of cardiac surgery. On that
day, in the afternoon, Dr. Churchill and his colleague James
White were called by a patient, who was recovering from
a gallbladder surgery, and complained about the problems

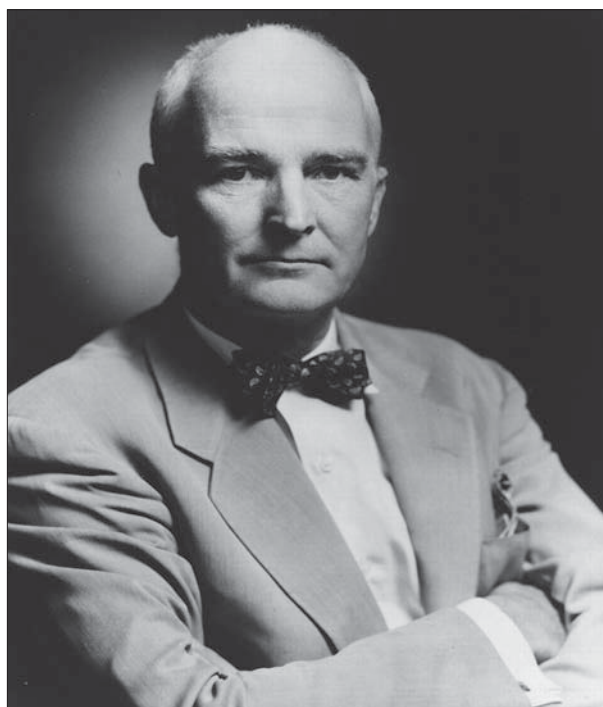


Figure 1. Dr. John Heysham Gibbon Jr.

regarding shortness of breath. Based on the clinical symp-
toms and signs, they quickly diagnosed acute pulmonary
thromboembolism [12]. It was obvious that the patient
needed surgical intervention. However, since pulmonary
thromboembolism was successfully performed only in
Europe, Churchill decided to postpone surgical interven-
tion, and said that the intervention could be performed
only if the patient's condition became so bad that there was
no other solution. A day later, the patient's condition dete-
riorated, and Churchill performed the surgery. The patient
did not survive [12, 13]. Gibbon, who was responsible for
monitoring the patient's condition prior to the surgery, in
order not to miss the moment when the operation was nec-
essary, got an idea. Several years later, Gibbon recounted
his thoughts, "... during the 17 hours by this patient's side,
the thought constantly recurred that the patient's hazardous
condition could be improved if some of the blue blood in
the patient's distended veins could be continuously with-
drawn into an apparatus where the blood could pick up
oxygen and discharge carbon dioxide, and then pump this
blood back into the patient's arteries. Such a procedure
would also lend support to the patient's circulation while
the embolectomy was being performed" [14].

At that time, Gibbon was interested in the study of
pulmonary thromboembolism. On October 15, 1930, he
began experimenting on cats, examining the correlation
between the degree of artificially created stenosis of pul-
monary artery and drop of blood pressure [15]. In March
1931, Mary Hopkins and John Gibbon were married, and
shortly thereafter they returned to Philadelphia. Gibbon
talked about his idea for the next three years, but it was
generally thought impossible to implement this idea in
practice. Meanwhile, Gibbon worked with Eugene M.
Landis on other experiments, but it was Landis that en-
couraged his intent to make invention [16]. In the spring

of 1934, Gibbon returned to Churchill in Boston, and convinced him to provide a laboratory for his research. Churchill accepted it, but without much enthusiasm [13].

Gibbon thought that the biggest problem was to provide adequate oxygenation of the blood, although at that time several methods for blood oxygenation had already been discovered. He published the first description of this system in 1937. His perfusion system was able to provide the blood oxygenation for the flow of 500 ml per minute. Oxygenation was conducted in a rotating vertical cylinder under the principles of film oxygenation. The system consisted of two pumps that were securing a continuous flow under the influence of hydrostatic pressure, one that pumped the blood from the venous cannula to the oxygenator, and the other that pumped the blood from the oxygenator to the arterial circulation [17]. Shortly afterwards, Dale and Schuster proposed a modification, according to which the pump worked in pulsatile fashion [18].

Gibbon had been using cats as experimental animals since 1934. He wanted to prove that it was possible to maintain life without the blood flow in the lungs. After another year spent in Boston, he returned to Philadelphia. After solving various technical problems of the pump, on May 10, 1935, he was able to open and close the pulmonary artery of a cat. During that time (39 minutes), the function of cardiopulmonary system was replaced by extracorporeal circulation, and the cat survived. He continued his research, with an interruption from 1941 to 1944 due to World War II [17].

After World War II, Gibbon recognized that there was a problem in the capacity of blood oxygenation. Such a low capacity was insufficient for larger animals. He became aware that he was unable to improve the machine by himself, and decided to seek help from engineers. Dean of the University of Philadelphia advised Gibbon to meet with heads of IBM (International Business Machines Corporation) in 1946, and they referred him to the director of IBM, Thomas J. Watson, with whom he met in 1947 [11]. After listening to Gibbon, Watson promised him financial and technical support for the development of the extracorporeal circulation over the next seven years [12].

THE RESULT OF COMMON WORK

IBM and Gibbon produced Model I extracorporeal circulation in 1949. This model had improved the capacity of oxygenation of the blood, while the pulsatile pump was used instead of the double-roller pump. Michael DeBakey modified the pump with the pulsatile flow [19]. However, during the experimental use, a flaw was spotted – the capacity of blood oxygenation was still insufficient for the animals larger than cats. In addition, there was a problem with hemolysis and repeated air embolisms. They decided to stop experiments on animals until they found a solution to these problems [20].

The result of further common research was Model II, which was significantly different from the previous model. Instead of the cylindrical oxygenator based on the prin-

ciple of film oxygenation, Model II used a system of grids placed in an oxygen atmosphere. This system combined the principles of film oxygenation and turbulent blood flow through the grid. The grid had openings of different diameters, depending on the required capacity of blood oxygenation. It still had the double-roller pump, whereby the venous pump had to provide recirculation of blood in the oxygenator, and to maintain constant thin film of the blood on the grid [21]. The machine was capable of measuring blood pH, blood oxygen saturation, blood flow rate, and temperature, and possessed a mechanism for regulating the temperature and the pH level [20]. This model was much more effective than the previous ones. In April 1951, at the Jefferson Institute in Missouri, a dog weighing 10 kg survived a 96-minute-long total cardiopulmonary bypass. After the development of Model II, the mortality of experimental animals reduced considerably, compared to the period before 1949 [22]. Despite a significant reduction in mortality, there was still a problem of gas embolism after opening the heart cavities. Attempts to solve this problem were made in different ways, and the optimal solution was found by Bernard J. Miller in 1952. He described the need for an artificial tube, which would be introduced into the heart chambers to draw out the air. Miller's advice was that this kind of tubes, called vents, could be introduced through the heart apex into the left ventricle [23]. After that, Albritten reported the introduction of the vent through the left atrium [24].

FIRST ATTEMPTS AT CLINICAL USE OF EXTRACORPOREAL CIRCULATION

After the encouraging results of experimental studies on animals, the conditions for the clinical use of extracorporeal circulation were met. The first clinical use of the Model II machine took place in February 1952 by Gibbon. It was a 15-month-old baby girl with the suspected presence of atrial septal defect (ASD). After placing the patient on cardiopulmonary bypass and opening the right atrium, there was no sign of ASD. The patient died on the table, and a large patent ductus arteriosus was found on autopsy.

In an adult patient, Model II was first used on March 7, 1952. It was a 41-year-old patient with heart failure, with suspicion of myxoma or thrombus in the right atrium. Frank Albritten performed the surgery, using the machine as a right heart bypass. Cardiopulmonary bypass was overseen by Miller. After opening the right atrium, neither a tumor nor a thrombus was found. After terminating cardiopulmonary bypass, cardiac contraction began to fail and finally stopped. Resuscitation methods briefly restored the heart function, and they were able to close the chest, but during immediate postoperative course, the patient developed pulmonary edema and died. The autopsy report verified that the preoperative diagnosis was misplaced. The patient was suffering from dilated cardiomyopathy due to interstitial myocarditis [25].

On April 17, 1952 Gibbon used his machine to support the circulation in an older anuric patient with central



Figure 2. Heart–lung machine dating from 1958 (design first appeared in 1955), used in London's Middlesex Hospital

cyanosis and edema. For angioaccess, he used the right internal jugular vein and the right radial artery. He set the flow rate at 300 ml/min. for a period of 45 minutes. During the circulatory support, the patient's face turned pink. The patient died three hours after the termination of assisted circulation [17].

FIRST SUCCESSFUL SURGICAL INTERVENTION USING CARDIOPULMONARY BYPASS

Cecilia Bavolek, an 18-year-old girl, had symptoms of the right heart failure. Donald Burns Lewis initially thought that she had mitral stenosis, and introduced Gibbon to the case under that diagnosis [25]. After the cardiac catheterization, Gibbon and co-workers found that she most likely had ASD, and decided to perform the exploratory surgical intervention.

On May 6, 1953 Gibbon and associates started with the surgery, for which he had prepared the Model II machine, filled with heparinized blood of adequate blood group. Through the bilateral thoracotomy in the fourth intercostal space, they accessed the mediastinum and identified the dilated right ventricle and the pulmonary artery. After opening the pericardium, they saw that the right atrium was also dilated. By palpation, Gibbon found that the patient had ASD. It was decided that the patient should be placed on total cardiopulmonary bypass, during which they would cannulate the left subclavian artery and both venae cavae. After the onset of cardiopulmonary bypass, they spotted a blood clot in the oxygenator, due to the insufficient dose of heparin applied, but they continued with the operation. Opening the right atrium, Gibbon verified a small ASD. At the initiative of his assistant Frank Albrichten, the defect was closed by the direct suture instead of

the pericardial patch, as was done in experimental animals. After 26 minutes of total cardiopulmonary bypass, they removed the ligature from both venae cavae, proceeded as a partial cardiopulmonary bypass, removed the vent from the left ventricle, and after 45 minutes stopped extracorporeal circulation. An hour after the surgery the patient woke up without any neurological deficit. After the surgery, Gibbon personally informed Alfred Blalock and Clarence Crawford by telephone that the operation was successful [25].

Subsequently, in July 1953, Gibbon operated on two more patients with congenital heart diseases, but none of them survived [26]. In 1954, Gibbon closed the ventricular septal defect in a 38-year-old patient with four interrupted sutures. The patient survived the operation, but died a few hours later [27]. Gibbon was so disappointed that he announced that he would not operate on heart for one year and would deal with liver surgery [26].

IBM discarded Model II, and presented Model III, which was submitted to Jefferson College in July of 1954. IBM presented its plans to produce it for about ten institutions around the world [28].

From March 22, 1954, modified Model II, called Mayo Gibbon Pump Oxygenator, was used in Rochester by a working group led by John Webster Kirklin. They first published a report on a series of eight consecutive patients successfully treated with the use of extracorporeal circulation (Figure 2).

OTHER WORKING GROUPS

While Gibbon was developing his machine, there were attempts from other working groups as well. Clarence Denice started to develop his machine for extracorporeal circulation in Minneapolis in 1947, on the principles of Gibbon's experiments. In April and May of 1952, they already clinically tested their pumps in two patients. The first patient, who instead of his preoperative diagnosis of ASD actually had atrioventricular canal defect, died in the operating room, while the other patient, despite successfully closed ASD, died of a massive gas embolism [29, 30].

Forest Dewey Dodrill and General Motors developed their machine, which initially had no oxygenator and did not exclude lung function. The machine changed the function of one or both chambers separately. They started the trials in 1951. The first use of their machine called "Michigan Heart" was on July 3, 1952. The machine was used as the left heart bypass (cannulation of the left subclavian artery and the left superior pulmonary vein, after which the cannula was moved in the left atrium) in a 41-year-old patient with mitral stenosis. Initially, it was planned to perform the operation of the mitral valve under the direct vision; however, Dodrill failed to execute the operation due to excessive bleeding, and performed closed commissurotomy with finger. The patient survived after a 50-minute-long left heart bypass [31]. Dodrill performed the first operation of the pulmonary valve under the direct vision on October 21, 1952. It is considered the first

successful operation of valves with the application of extracorporeal circulation. The operation was performed on 16-year-old Charles Moses, with the diagnosis of congenital pulmonary stenosis. The operation was carried out using the right heart bypass (cannulation sites were the right atria and the pulmonary artery) with the “Michigan Heart” machine, with blood flow rate of 5.4 L/min., and by total clamping of the pulmonary artery. They performed valvuloplasty of pulmonary valve, and the clamp was taken off after 25 minutes. The patient was discharged after one month [32]. After the successful use of different types of oxygenators by Gibbon and Kirklin, Dodrill changed his mind about the uselessness of the oxygenator. In 1955, he developed a machine with an integrated oxygenator, and

in 1956 reported the successful closure of VSD in six patients and a successful operation of tetralogy of Fallot [33]. However, Dodrill's machine was replaced by the modified Mayo–Gibbon machine shortly thereafter, because Dodrill's machine required complicated cannulation.

CONCLUSION

The machine for extracorporeal circulation, and John Gibbon as its inventor, radically changed cardiac surgery and the prognosis of patients with cardiac diseases. With this invention, cardiac surgeons can deal with complex cardiac pathology and save millions of lives.

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Проналазак кардиопулмоналног бајпаса – историјски преглед

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КРАТАК САДРЖАЈ

Идеја о изолованој перфузији органа, која је претеча кардиопулмоналног бајпаса, долази од Легалое 1812. године. Прва изолована перфузија органа је описана од стране Лебела 1849. године. Први затворен систем за оксигенацију и враћање крви кроз артерије је конструисан од стране Фреја и Грубера 1885. године. Гибон млађи се сматра оцем екстракорпоралне циркулације. Он је почео да конструише машину за екстракорпоралну циркулацију на пролеће 1934. године. Први опис овог система даје 1937. године, а 1947. године добија подршку за развој машине од *International Business Machines Corporation*. Они развијају Модел I 1949. и Модел II 1951. године. После неколико неуспешних покушаја

1952. године, 6. маја 1953. године је први пут успела операција на срцу (затварање атријалног септалног дефекта) уз помоћ кардиопулмоналног бајпаса. Године 1945. Кирклин и његова радна група публикују прву серију од осам успешно третираних пацијената уз помоћ екстракорпоралне циркулације. Додрил је извео прву успешну операцију залистака под контролом ока 1952. године, коришћењем машине *Michigan heart* као бајпаса десног срца. Уз помоћ машине за екстракорпоралну циркулацију кардиохирурги су у могућности да решавају комплексне срчане болести и да спасу милионе живота.

Кључне речи: проналазак; историја; кардиопулмонални бајпас; екстракорпорална циркулација; Гибон

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