

# The Charles Reed Memorial Lecture Savannah 2016

## Extracorporeal Circulation and Cardiac Surgery Some Moments in History

Colin G. Green - Copenhagen, Denmark

It is a privilege and pleasure to be here today and I want to thank the Academy for the invitation. This lecture series is to honor the memory of Charles C. Reed. Charlie was a very important moment in perfusion history, for perfusion education, the perfusionist and perfusion generally. His life and achievements have been presented in detail in previous years, last year by Earl Lawrence, Jr and in 2008 by Aaron Hill. Their memories of Charlie can be read on the Academy's website.

I met Charlie from time to time in the 70's and 80's although I never got to know him properly. Something I regret very much. We did work on a project together modifying the Polystan Venotherm bubble oxygenator. This resulted in the TMP Venotherm



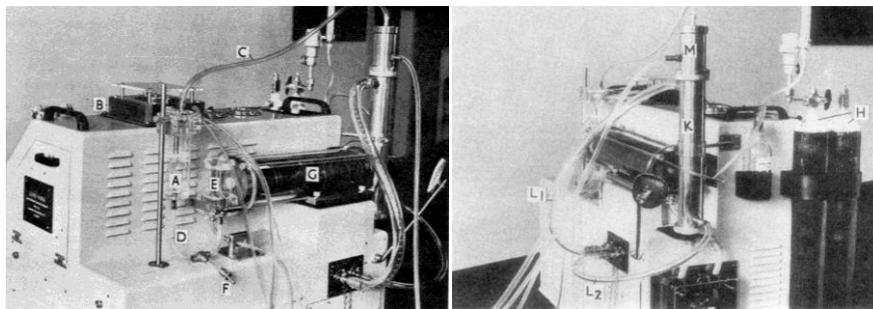
Charlie wanted to put it into use at the Texas Heart Institute as he felt that it would be a safer oxygenator for students to use due to the full collapsibility of the arterial reservoir thus the inability to pump gross air from an empty reservoir.

It is 90 years since the first report of a successful heart valve procedure. If I were to include two significant moments or events for each year up to now, I would be giving you one moment every 15 seconds for the 45 minutes I have been allocated. This would make both of us breathless. I have therefore chosen to cover the 59 years from 1923 to 1982. Maybe the Academy will invite me back next year to do the remaining 31 years. As is always the case in a presentation like this, choices have to be made on what to include and exclude. Always a dilemma. I have chosen what I believe to be significant moments or events – many of which are “firsts”. The choices are mine and mine alone.

I'd like to start by sharing with you my first perfusion moments. In 1961 I was working as an instrument nurse at St. Georges Hospital in London, England. The operating room I worked in was used for cardiac surgery once weekly with cardiac surgeon Mr. Charles Drew. He used deep hypothermic circulatory arrest and autogenous lung oxygenation. This involved initial surface cooling of the patient in a water bath to 33°C followed by left and right heart bypass and cooling to 15°C allowing Mr. Drew up to 60 minutes of circulatory arrest. His technician used a custom-built machine, the Westminister-Drew Hypothermia Machine, for the extracorporeal circulation. This was a two-pump machine with two glass/stainless reservoirs, a large stainless heat exchanger and a temperature recording disc.



This was fascinating stuff for me and from the very first time I witnessed a procedure I knew I had to be part of it. I befriended the technician, a Singaporean named Sabapathy, and my supervisor allowed me to assist him on surgery days. Initially I was only allowed to chart temperatures and not touch anything. With time I was allowed to clean the machine. It was during this period that I made a conscious decision to take up and follow a career in perfusion, and in 1962 I applied for and got the job as a number 2, assistant pump technician at Guys Hospital in London, England. It was here in 1962 that I did my first case using the Guy-Ross Heart Lung Machine.



A = Cardiotomy Reservoir, B = Sucker Pump, C = Recirculation Line, D = Cardiotomy to Venous Reservoir Connecting Line, E = Venous Reservoir, F = Bleed-Off Port, G = Disc Oxygenator, H = Oxygen Supply, K = Heat Exchanger, L = Water Lines, M = Arterial Filter

This was a two pump (sucker and arterial) machine with a disc oxygenator, venous and cardiotomy reservoirs and stainless heat exchanger + filter. The machine incorporated a heater-cooler unit. All blood contact components, except circuit tubing, were re-usable and required lengthy dis-assembly, cleaning, re-assembly and sterilization.

So let's start this journey in time.

In the early 1900's, how to treat and manage children with congenital heart disease was a very relevant discussion. In **1913** Sir James Mackenzie, a cardiologist at The London Hospital, London, England, summarized the situation as follows:

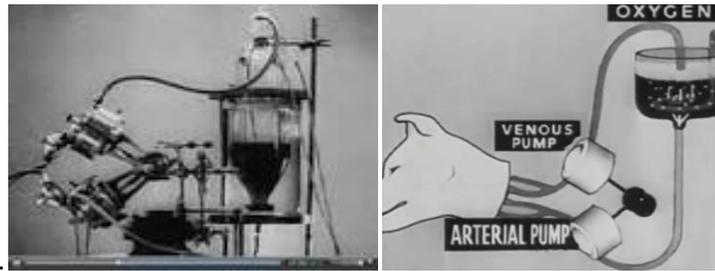
"If the heart maintains the circulation well, no treatment is required. In more serious cases, beyond attending to the child's comfort and nutrition, special treatment of the heart is of little benefit"

In **1923** Dr. Elliott Cutler at Harvard performed the first successful heart valve surgery relieving a mitral valve stenosis on a 12 year-old girl. He used a tenotomy knife and did seven more similar operations using the same technique and knife, or Cardiovalvulotome as he named it.



The instrument was inserted in the left ventricular apex and the stenosed cusps were gently split open.

In **1929** Dr. Sergei Brukhonenko in Russia maintained temporary function of dogs heads initially using donor lungs for gas exchange and a bellows pump for circulation. He later developed probably the first functional pump/oxygenator, his Autojector system, and used it to maintain the function of a severed dogs head.

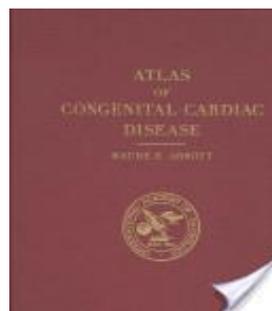


A short film on Dr. Brukhonenko's work and showing his Autojector in use, can be found on YouTube. It's a slightly controversial film, but very interesting.

In **1934** Dr. DeBakey developed a dual roller pump. This basic design has been, and still is the most used type of blood pump for extracorporeal circulation applications including dialysis.



In **1936** The Atlas of Congenital Heart Disease by Dr. Maude Abbott was published. Dr. Abbott was appointed curator of the McGill Pathological Museum in Montreal, Canada in 1901. In the following years she described and recorded the findings from over 1000 clinical and post mortem specimens.



This resulted in a new disease classification system. The Atlas was a major contribution to the understanding of congenital heart defects and provided an important stimulus for the rapid advancement in the diagnostic, physiological and surgical aspects of congenital heart disease.

In **1938** Dr. Robert Gross at Boston Children's Hospital, ligated a 7/8mm patent ductus on 7 year-old Lorraine Sweeney using a braided silk tie. She made an uneventful recovery. This was the first report of a successful PDA closure. In the following years PDA's were divided rather than just tied, because in some cases the tie eventually "cut through" the vessel with fatal bleeding consequences. Dr. Gross did more than 1500 such procedures.

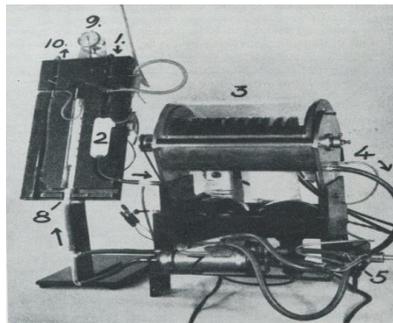
In **1944**, on September 19th, Dr. Clarence Craaford in Stockholm performed the first successful resection of an aortic coarctation on a 12 year-old boy using hypothermia. The coarctation was excised and the open ends of the aorta were sutured together. The post-operative course was uneventful and the boy made a full recovery.

Also in **1944**, on November 24th, Dr. Alfred Blalock at John Hopkins performed the first Blalock-Taussig procedure on a 15 month-old girl who weighed only 4 kg at the time of surgery. The left subclavian artery was anastomosed end-to-end to the left pulmonary artery. Following a difficult post-operative course she was discharged home after 2 months. The surgical technique and the special instruments needed were developed by Mr. Vivien Thomas, Dr. Blalock's laboratory technician. Mr. Thomas did the procedure over 100 times in the animal lab. After many years without the appropriate recognition for his work, Mr. Thomas was given an honorary degree in 1976, but not in medicine. It was a law degree. The surgical procedure is now named Blalock-Thomas-Taussig.

In **1946** Sir Thomas Holm Sellars at Harefield Hospital and Sir Russel Brock at Guys Hospital, both in London, England, do trans-ventricular dilation of stenosed pulmonary valves in patients with Tetralogy of Fallot using a specially designed dilator. This remained a standard procedure until 1955 when cardiopulmonary bypass became available to allow open valvotomies to be performed,

On a personal note Sir Russel , who later was elevated to the House of Lords with the title Lord Brock of Wimbledon, was head of the Thoracic Unit at Guys Hospital in the 1960's and as such was my immediate boss. He was a giant of a man, both in size and temperament. I ran the pump for him on many occasions and was the object of his temperament several times. However he always popped into our pump room after each case and thanked us.

In **1948** Dr. Viking Bjoerk in Stockholm, Sweden extended the limit of circulatory arrest in animals by perfusing the brain with blood oxygenated in his small rotating disc oxygenator.

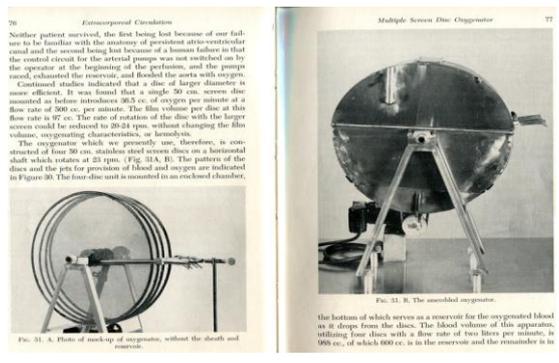


The oxygenator consisted of 40 rhodium plated stainless discs each with a diameter of 13 cm. They were in groups of 4 on a stainless rotatable shaft. With a rotational speed of 120 RPM and discs dipping into a 15 cm blood level, the oxygenator could handle blood flows of up to about 650 ml/min. A larger oxygenator was subsequently developed with 50 discs and could handle blood flows up to about 800 ml/min. This oxygenator was the forerunner to the Kay-Cross disc oxygenator which was used clinically for total CPB in the 1960's. Below is a photo of Mr. William Kotels, the founder of Pemco Inc. in Cleveland, who manufactured the Kay-Cross oxygenator, heart-lung machines and other related components.



In **1950** Dr. William Bigelow at Toronto General Hospital in Canada showed that surface cooling of dogs to below 25°C allowed the heart to be safely arrested for up to 15 minutes and to fully recover. In the same year, and for the first time, silicone compounds are described and used as antifoam agents

In **1951** on April 5th, Dr. Clarence Dennis at the University of Minnesota performs the first clinically recorded cardiopulmonary bypass using his vertical rotating disc oxygenator. The patient was a 6-year-old girl with an ASD. She unfortunately died during the procedure due to the failure to be familiar with the anatomy of a persistent atrio-ventricular canal. A second patient also died during surgery due to a human error allowing the reservoir to empty with a resulting major oxygen embolus.



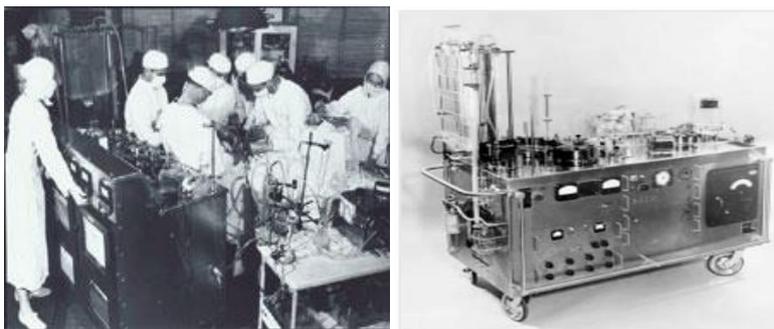
The original stainless wire screen discs were 38 cm in diameter and made from 18 x 18 stainless steel with a wire size of 0.009 inches. Venous blood entered the centre of each of the 4 discs and filmed out to the periphery. The discs were rotated at a speed of 55 RPM in an atmosphere of oxygen that was introduced adjacent to the blood inlets in a closed stainless reservoir. A 50 cm disc was developed that, with 4 discs and a rotational speed of 20 to 24 RPM, allowed blood flows of up to 2000 ml/min.

In **1952** On October 21st, Dr. Forest Dodrill at Harper Hospital in Detroit performed the first right heart bypass on a 16 year-old boy and did a direct vision pulmonary valvuloplasty.

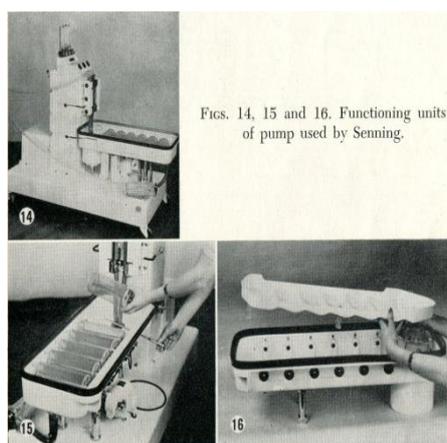


He used a blood pump he developed together with General Motors. The pump cylinders were activated by air pressure and vacuum. Dr. Dodrill did 13 procedures with this pump between July 1952 and December 1954.

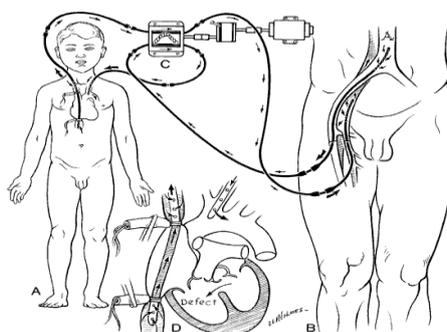
In **1953** on May 6th at Jefferson University Medical Center, Dr. John Gibbon closed an ASD in 18 year-old Cecelia Bavolek using his heart-lung machine with a vertical screen oxygenator. This was the first successful clinical use of cardiopulmonary bypass. Cecelia was discharged home on the 13th postoperative day.



Dr. Gibbon operated on 3 additional patients with his HLM. They all died during surgery and Dr. Gibbon put a moratorium on the use of his machine. Dr. John Kirklin at the Mayo Clinic further developed and commercialized it which was now called the Mayo-Gibbon machine. The person standing behind the machine in the left hand photo is Mary Gibbon, Dr. Gibbons wife. History has named her as the first clinical perfusionist. Prior to this in **1951**, Drs. Craaford and Senning in Stockholm perform the first reported open heart procedures in Eurpe using their rotating roller oxygenator. The cylinders made of perforated plastic foil and were disposable. The roller basin for smaller patients had a volume of 1600 ml. Two basins with 12 rollers was used for larger patients and these had a volume of 2100 ml. When the rollers rotated they picked up a film of blood which was exposed to an atmosphere of oxygen.



In **1955** on March 26th Dr. C. Walton Lillehei in Minnesota used controlled cross circulation for the first time on a 12 month-old boy to close a VSD. Dr. Lillehei used this technique on 45 patients repairing a variety of defects. There were 17 hospital and six late deaths. The remaining 22 were long-term survivors.



Many of Dr. Lillehei's colleagues were highly critical of this technique as, in their opinion and in principal quite rightly so, it was the only surgical procedure that carried a potential 200% mortality.

For several years, Dr. Lillehei attended the yearly Scandinavian thoracic surgical meetings and I met and talked with him on these occasions. He was a very interesting personality and a great innovator.

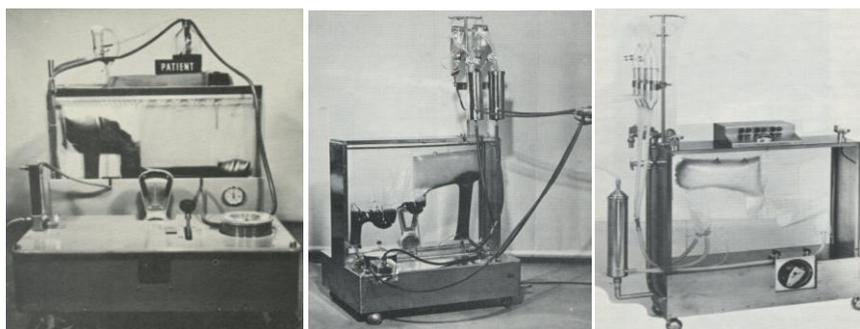
The Sigmamotor pump used in the cross circulation circuit was used with the Lillehei-DeWall oxygenator and machine which was the impetus for the start of routine cardiopulmonary bypass world-wide and the development and availability of pre-sterilized, disposable bubble oxygenators.



The original Lillehei-DeWall oxygenator and machine is in the left hand photo. The bubble oxygenator consisted of disposable tubing that was used for the vertical bubble column, the angled defoaming section and the helix arterial reservoir that was in a water bath. Venous drainage was by gravity into a separate venous reservoir from which a Sigmamotor pump transferred the blood to the bubble column. Suction was vacuum assisted using a separate reservoir positioned close to the floor. A second Sigmamotor transferred the suction blood to the bubble column. A third Sigmamotor pump was used to return the oxygenated blood from the helix reservoir to the patient.

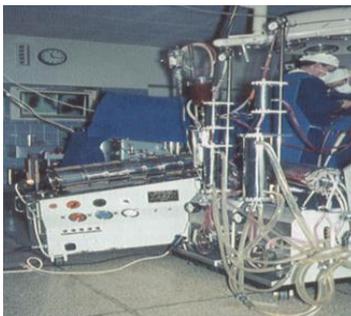
Drs. DeWall and Gott together with Travenol Laboratories developed the oxygenator into a plastic sheet pre-sterilized device which became commercially available in 1957. Between 1960 and 1980 an estimated 30 commercial pre-sterilized disposable bubble oxygenators were made available from several manufacturers.

In **1957** Rygg- Kyvsgaard bubble oxygenator and heart-lung machine, developed and manufactured by Polystan in Denmark, became available with the first clinical procedure done in Copenhagen on the 22nd of February the same year.



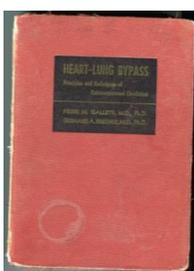
The left hand photo is the original machine with a horizontal single 360 degree arterial single roller pump on the right hand side, a vertical heat exchanger on the left hand side and a butcher's scale in the middle. The weight of the oxygenator was displayed continuously and was very helpful in going on and coming off bypass – oxygenator volume changes could be seen and measured directly. The middle photo shows the next version with the pump repositioned to the left hand side and the heat exchanger pole mounted on the right hand side. The scales are still in use and vacuum suction has been incorporated with 3 vacuum chambers supplied with vacuum from a vacuum pump in the machine base. The right hand photo shows the machine configuration in 1966. The pump is now mounted vertically, the oxygenator is now weighed from its suspension bar and the weight is displayed on the top panel. A Brown-Harrison stainless heat exchanger is now mounted on the left hand side. The machine was positioned at right angles to the table so that all table lines were as short as possible. This machine and the disposable oxygenator were used to start many open heart programmes in Europe.

In **1958** Dr. Dennis Melrose at the Hammersmith Hospital in London, England describes, for the first time, the use of potassium citrate to safely arrest the heart during surgery. He also designed and developed his heart lung machine using a slanting disc oxygenator. Manufactured in England, this machine was used in several countries worldwide. For example the first open heart procedures were done in New Zealand with this machine.



In **1960**, Dr. Albert Starr at the University of Oregon implanted the first commercial artificial valve prosthesis – the Starr Edwards caged ball valve.

In **1962** Grune & Stratton publish the textbook “Heart Lung Bypass: Principles and Techniques of Extracorporeal Circulation” by Pierre Galletti and Gerhard Brecher.



In the 1960's there was no formal education for pump techs in England. It was on the job training or learning by doing. This textbook was a godsend for us. The contents are still very relevant today – 53 years later!

In **1963**, Drs. Kolobow and Zapol develop a silicone coil membrane oxygenator. It was commercialized first by Scimed, then AVECOR and finally Medtronic. It is no longer in production due primarily to the current availability of oxygenators with polymethylpentene fibers. The basic design remained unchanged for over 40 years although at various stages heat exchanger solutions were incorporated. It is estimated that well over 30,000 ECMO procedures have been done with this oxygenator over the years.



Also in **1963**, Dr. Hariuchi at Kyoto University in Japan, introduced the Kyoto cooling technique using surface cooling and cardiopulmonary bypass for re-warming.

In May of **1967** Dr. Rene Favoloro at the Cleveland Clinic did the first CABG using the saphenous vein.

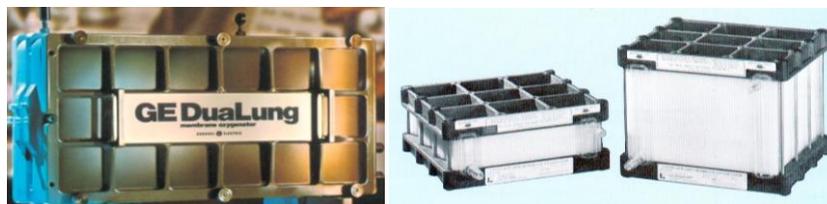
In September of **1967** Mr. Donald Ross at Guys Hospital in London, England did the first Ross procedure replacing the patient's aortic valve with his own pulmonary valve and inserting a homograft valve into the pulmonary position. I recall this 150 min perfusion well as I ran the pump. The homograft valve bank at Guys was located in our pump room. We pump techs managed the bank, doing the collection of autopsy hearts, dissecting out the aortic valves and processing them. I very much enjoyed this part of our job as it was a break from the routine O.R. work.

Again in September of **1967**, Dr. Christian Barnard at Groote Schuur Hospital in Cape Town did the first human heart transplant. I visited Groote Schuur on several occasions but never formally met Dr. Barnard however I met and worked with his brother Marius, also a cardiac surgeon, several times. Dr. Marius Barnard did surgical missions, operating on children, to Romania in the 1980's and I travelled with the team as a supply and logistics coordinator. I also helped out in the O.R. and did run the pump on a couple of occasions.

In **1968** Bentley Laboratories introduced the Temptrol bubble oxygenator. This was the first pre-sterilized disposable hardshell bubble oxygenator with an incorporated heat exchanger. Prior to this there had only been two commercial pre-sterilized, disposable bubble oxygenators used in Europe – the Rygg-Kyvsgaard (Polystan) and Travenol.

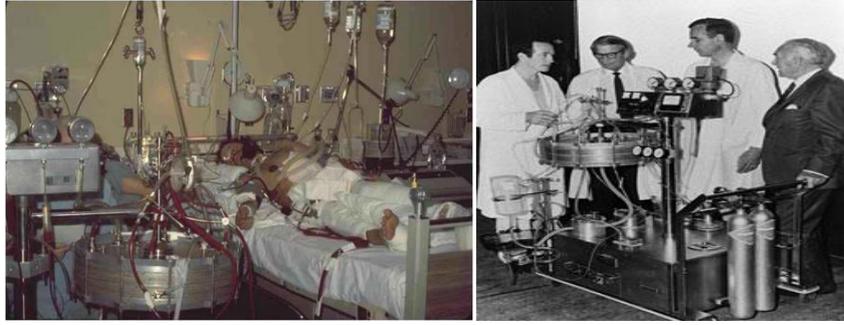


In **1970**, General Electric and Edwards Laboratories introduced their membrane oxygenators – the GE Pierce with silicone/polycarbonate co-polymer envelopes and an incorporated heat exchanger, and the Lande Edwards using a folded silicone sheet (no heat exchanger). The GE Pierce was technically and from a construction point of view, very advanced but had a relatively short market life. I seem to recall that at that time the price for the disposable membrane was around USD 600. The Lande Edwards had a longer market life. I can't recall pricing but I do remember the need to flush the units before priming as the silicone sheets were powdered to stop them sticking together.



Also in **1970**, Sir Brian Barratt-Boyes at Greenlane Hospital in Auckland, New Zealand modified the Japanese Kyoto cooling protocol by using initial surface cooling then cardiopulmonary bypass to induce profound hypothermia and subsequent re-warming.

In **1971**, Dr. Donald Hill in Santa Barbara, California initiates and supervises the first successful adult ECMO using a Bramson membrane oxygenator and machine. The patient had post-traumatic respiratory failure and was supported for 3 days.



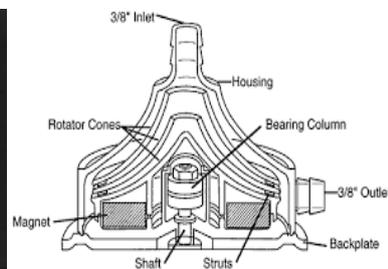
The man in the dark suit on the right hand side photo is Mr. Mogens Bramson. He was both a pilot and aeronautical engineer. In the early 1900's he was a member of a U.K. based sky writing team that flew advertising missions throughout Europe. Later, as a consulting engineer, he wrote the reports that enabled funding for the development of the Whittle jet engine. This was the first jet engine to be mounted and used in airplanes. He held several patents for aeronautical devices as well as for his membrane oxygenator. I met him in London, England in the mid-1960's. Great Ormond Street Hospital took delivery of a Bramson machine and I had several very interesting talks with him over a pint..

In **1975**, Dr. Robert Bartlett and his team at Orange County Medical Center in California supported a new born baby with meconium aspiration for 3 days. She completely recovered. This was the first successful neonatal ECMO.



The baby girl, who was abandoned by her Mexican mother at birth, was named Esperanza by the intensive care nurses. Esperanza means hope. I believe she is alive and well today with two daughters of her own.

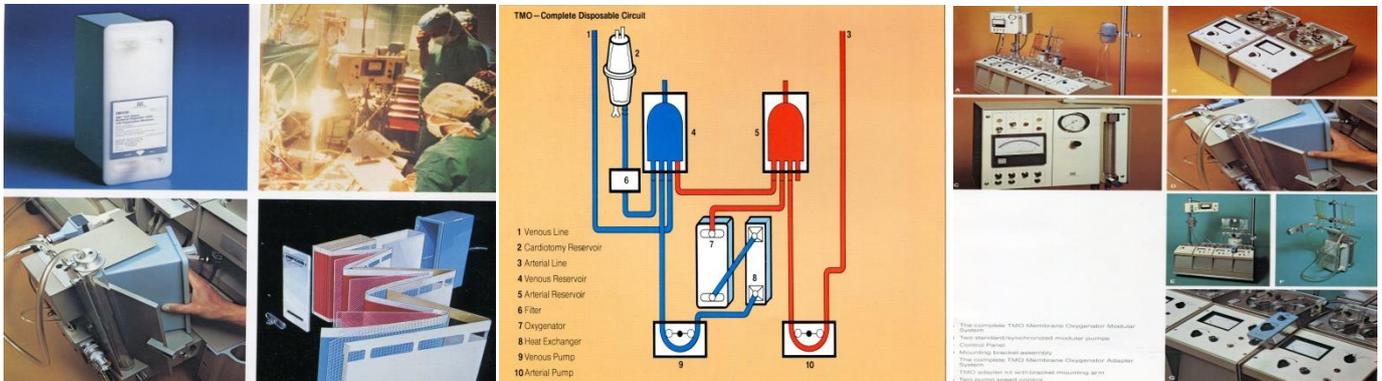
**1975** saw the first successful use of the Biomedicus (now Medtronic) Biopump using it as a left heart assist device. This was the first commercial disposable centrifugal (constrained force vortex) pump. It was developed by Kletschka and Rafferty as part of an artificial heart project.



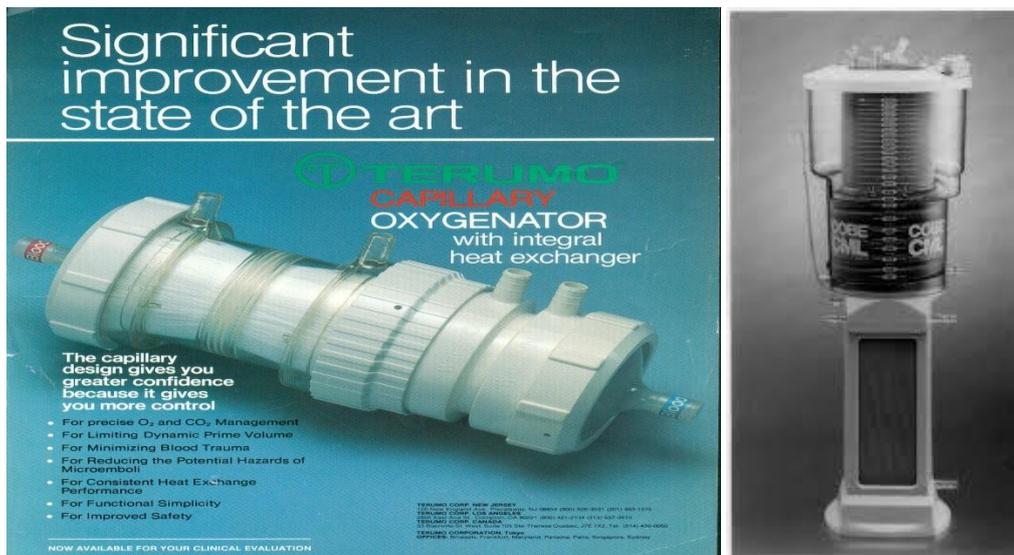
**1975** also saw the first successful arterial switch procedure performed by Dr. Adib Jatene at the University of SaoPaulo in Brazil, switching the pulmonary vein and aorta and re-positioning the coronary arteries. Prior to this procedure baffles were used for TGA's. Dr. William Mustard in Toronto used autologous pericardium for the first time in 1964 and Dr Aake Senning in Stockholm used the atrial septum for the first time in 1959. The smallest baby

known to have survived an arterial switch was Jerrick de Leon who weighed 680 grams at the time of surgery which was done by Dr. Mohan Reddy at Stanford on the 6th February 2005.

In **1976** Travenol Laboratories introduced their TMO (Travenol Membrane Oxygenator System). Travenol invested considerable resources in not only the development of a complete system but also in user education and support. A classic product launch and support activity which today I still remember and regard as a “gold standard” activity and a perfect example of how to do it correctly and responsibly.



In **1982** Terumo introduced the first hollow fiber oxygenator for clinical use, and in the same year Cobe introduced the first clinical sheet membrane, the CML, with integrated venous/cardiotomy reservoir and heat exchanger. These were the “kick-offs” to the membrane oxygenator revolution. 1985 was a cross-over year in the U.S.A. with 50% use of bubble oxygenators and 50% use of membranes.



I would like to end this talk by thanking you all for watching and listening, something for you youngsters to contemplate and perhaps to bring back some memories for the older members of the audience. I want to leave you all with a quote by Benjamin Disraeli, a great British Prime Minister who lived from 1804 to 1881:

**“The more extensive a man’s knowledge of what has been done, the greater will be his power of knowing what to do.”**