
How Open Heart Surgery Came to Hawaii

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The evolution of open heart surgery had its beginnings in 1938 with the closing of a patent ductus arteriosus. In 1954 Hawaii began to perform right heart catheterizations and a bubble oxygenator was made locally out of plastic food tubing and a Sigmamotor double head pump. The first open heart surgery was successfully performed at Queen's Hospital in December 1959 on a woman from Hilo with a large interatrial septal defect (IASD).

The evolution of open heart surgery had its beginnings in 1938 with Robert Gross in Boston closing a patent ductus arteriosus. Dwight Harken in World War II was removing intracardiac foreign bodies, Alfred Blalock and Helen Taussig in Baltimore developed the *Blue baby* operation in 1944, and Gross and Hufnagel corrected coarctation of the aorta in 1945. By 1948 Bailey, Harken, and Brock were correcting mitral stenosis with closed finger-fracture procedures. In Philadelphia John Gibbon and his wife Maly brought their laboratory experiments to successful conclusion in 1953 by closing two interatrial septal defects using a heart-lung machine. However, after losing the next two patients they called it quits. In 1954 C. Walton Lillehei, at the University of Minnesota, corrected cardiac defects in children employing cross-donor circulation utilizing one of the parents as an oxygenator. He was criticized about the ethics of subjecting a normal parent to surgical risks; therefore, the following year he began using a bubble oxygenator constructed of plastic food tubing designed by Richard DeWall.

In Hawaii the Bureau of Crippled Children (BCC) was supervising the care of an increasing number of children with cardiac disease. Regular cardiac clinics were being held at Kauaikeolani Children's Hospital (KCH) as well as cardiac conferences regarding their treatment. There were no cardiac diagnostic procedures available to these children other than the usual EKG, chest x-rays, and physical exam. In 1956, with financial assistance from the Hawaii Heart Association (HHA), a two channel Sanborn recorder was purchased to provide intracardiac pressures through a catheter and EKG monitoring. Right heart catheterizations became a reality.

These cardiac procedures were performed in a regular, darkened fluoroscopy x-ray room with the operator wearing red goggles equipped with a sterile plastic *horn* used to manipulate the goggles when the room lights were turned on in order to draw blood or check the patient. There was no type of monitor visible to the operator so the technician would give a continual verbal report of the catheter tip location by observing the pressure curves and reporting any type of arrhythmia on the EKG. Serial blood samples were drawn through the catheter from various intracardiac locations to establish the level of shunts. It would take the technician all day to run oxygen levels on samples by the Van Slyke method. KCH was selected as the hospital to start cardiac catheterization because most of the patients were children and the x-ray department was open to scheduling most of the time. The technician came from the University of Oregon, and her salary was partially supported by the HHA.

Shortly after the start of cardiac catheterizations the need for angiocardiology as a supplement became evident. There were no commercial pressure injectors available for dye injection through small lumen catheters. It was possible to purchase a 50 cc-thick-wall glass syringe, with a luer-lock tip to use with hand injections. A pressure injector that looked like a bottle capper was fabricated by Kat's General Repairs of Honolulu utilizing a car axle as a center post and a steel cylinder in which to set the syringe so that if it broke the shards of glass would be retained. This worked well until an air pressure injector with a steel syringe became available. The angiograms were recorded on a long strip of x-ray film utilizing a Fairchild head unit with a picture speed once every 30 seconds. Lacking a full-time radiologist at KCH, the procedure was not completed until the film had been sent via taxi to the Honolulu Medical Group for George Henry to inspect and pronounce them to be adequate. The cardiac catheterization results and angiograms were reviewed at a monthly cardiac conference. If a child was in trouble, the Bureau of Crippled Children would forward the materials to Dr Lillehei in Minnesota to see if the child was a surgical candidate. Some of these children with extracardiac lesions not requiring cardiopulmonary bypass such as patent ductus arteriosus, coarctation of the aorta and cyanotic lesions that would benefit from systemic pulmonary shunting, were operated on in Hawaii, usually at KCH.

In 1956 we began cardiopulmonary bypass runs on dogs using a Sigmamotor double head pump and a DeWall bubble oxygenator made out of plastic food tubing. These half hour runs were done at Queen's Hospital in the old obstetrics delivery rooms. Any of the available surgical house staff were commandeered for assistance, and it was obvious that any successful effort toward open heart surgery would have to better organize personnel and physical accommodations. Dr Sumner Price, Queen's Hospital administrator, was approached about space for experimental animal surgery. He allocated the old World War II orderly barracks and common kitchen at the *mauka* end of the Kamehameha wing for this purpose. A portion of the barracks was fitted with fencing for dog kennels and the old kitchen was set up for dog surgery.

Even though a large number of animals were destroyed weekly, the Hawaii Humane Society was very reluctant to become involved with any type of surgical program because of antivivisection leanings of their financial donors and board members. This made it difficult to obtain a supply of animals for surgery and blood to prime the oxygenator. Dr Morton Berk, president of the HHA, mailed reprints of a *Time* magazine article, which detailed the development and progress in OHS, to different companies, the Humane Society board, and HHA donors, saying OHS could be available in Hawaii but would need dog surgery to develop a team. This put the squeeze on the Humane Society to the extent that they allowed us to anesthetize the dogs they were going to terminate and use a trochar to obtain intracardiac blood to prime the oxygenator. The Humane

Society would not agree to sell or give us animals for surgery, so we would line up a member of the house staff or a friend each week to go to the Humane Society in Kapahulu to purchase the largest dog available. The \$10 fee included a dog license and a veterinarian's examination which was supposed to exclude heart worms, but we still encountered a 60% to 70% rate of heart worms—a squirming mass in the right ventricle.

We received numerous dogs through private donations. If we weren't going to use them right away they had to be anesthetized and their vocal cords excised so they wouldn't disturb the hospital patients. These debarked dogs had wonderful regenerative powers and would be hoarse for two or three weeks and gradually regain their bark. We would receive an early morning call from the nursing supervisor to come stop the racket that was disturbing the patients.

A basic surgical team of Drs Albert Chun, Carl Mason, Paul Gebauer, Unogi Goto, John Hanley, and I would do OHS on a dog every Wednesday morning. This consisted of putting the animal on the pump oxygenator after anesthetizing and heparinizing it and then opening the right ventricle for a minimum of half an hour. We then repaired the heart and watched the dog for survival. Carl Mason would arrive early at the Humane Society and get two or three pints of blood, while Paul Gebauer and Mary Connor, the pump technician, would be assembling the pump oxygenator. After anesthetizing the dog, Al Chun and I would prepare the dog, open the chest and expose the femoral vessels for cannulation. We were quite fortunate that Medicare, computers, and cost accounting had not arrived—the departments at Queen's were quite liberal in giving us supplies. We could always obtain fresh pentothal from the patient mix in surgery and intravenous equipment. The central supply department would regularly phone to see if we could use outdated solutions and equipment. We calculated the cost for this disposable equipment to be about \$125 per dog. We were using a considerable amount of electrical equipment which threw a heavy load on the old wiring. It wasn't unusual to blow a fuse and have to replace it during the operation. Something electrical would then have to be replaced by hand power during the pump run.

We continued to use a bubble oxygenator with the Sigmamotor pump until the arrival of the horseshoe circumferential pumps. We changed to these and a small Plexiglas screen oxygenator since it was much more gentle with red blood cells. This oxygenator would have to be cold sterilized, since Queen's did not have a gas sterilizer and had other short-comings, so we decided to switch to a disk oxygenator. As a prototype we had Hawaii Restaurant Supply fabricate a concave stainless steel trough approximately 18 inches long and 6 inches deep. Bearings were mounted at either end of the trough to support a small diameter steel axle running lengthwise on which we mounted dictaphone disks separated by 1/4 inch washers. These were enclosed with a Plexiglas cover with a connection for oxygen. By the time the blood traveled from the venous end to the outflow end, it had turned to a bright red and was obviously oxygenated; this little unit worked very well.

In late 1959 the volume of cardiac catheterizations had increased considerably due to the arrival of younger pediatric cardiologists. Demand increased further as diagnostic procedures on teenagers and adults were undertaken. The pediatric residents at KCH voiced their opposition to adult patients being admitted for cardiac catheterization so we approached the executive committee and board about the possibility of making the necessary investment to upgrade the catheterization equipment with the goal of starting an open heart surgery program later. They rejected it. Since selected angiography procedures were already being done at Queen's and with an increase in the number of adults needing diagnostic procedures, it was decided to move the majority of cardiac catheterization

procedures to Queen's, and Mary Connor, the technician, became a full-time employee of Queen's Hospital.

There continued to be a lot of sick children referred through the BCC to Lillehei at the University of Minnesota for open heart surgery. Pulmonary hypertension developing from intracardiac shunts was recognized soon after the establishment of OHS so that in addition to diagnostic cardiac catheterization and angiocardiology the cardiologists working with Lillehei were requesting lung biopsies. These patients were subjected to a minithoracotomy and biopsy, usually of the lingula, and their slides, with the paraffin block, were sent for review before the patients were accepted for surgery. After heart surgery some of these children would have a rough postoperative course with complications at the sternal closure or complete heart block. The wire sternal sutures were usually bolstered with Ivalon sponges on both sternal surfaces and if they became infected had to be removed. The patients with complete heart block needed to have a cardiac pacemaker implanted since complete heart block would be lethal eventually. This required a left thoracotomy to suture the myocardial leads onto the heart. Only fixed rate pacemakers were available. They measured about 2 1/2 inches in diameter and 3/4 inches thick with two nipples protruding from the edge into which a Keith needle could be inserted percutaneously to turn controls for voltage and rate. The entire unit was covered with a thick layer of self-sealing silicone for protection if the Keith needle adjustments were used. These pacemakers were huge in contrast to the small recipient they were to be implanted in and there were many complications of skin breakdown particularly over the two control nipples. The subcutaneous pocket would have to be revised or possibly the entire pacemaker unit replaced.

Our success with the locally fabricated disc oxygenator led us to purchase a Kay Cross disc oxygenator manufactured by Pemco of Cleveland, Ohio, which could be totally heat sterilized. The oxygenator consisted of a Pyrex glass cylinder onto which stainless steel ends were fitted to support a long steel axle on which stainless steel discs were mounted separated with washers. There were ports at the proximal end for venous blood and oxygen, with oxygenated blood and gas outflow at the opposite end. The entire unit had to be boiled in Xylene and resiliconized between cases, reassembled and sterilized, a service of about 12 hours. While we were waiting for the arrival of this oxygenator, Paul Gebauer fabricated a steel table with the pump heads and controls mounted. He could raise or lower the entire table assembly to control siphonage of venous blood from the patient.

In November of 1959 we had completed 100 animal open heart procedures and felt qualified to move into the human theater. Unogi Goto had a patient from Hilo who had a large IASD and was a little cyanotic. After we explained the surgery and informed her that she would be our first open heart case, she readily agreed. In anticipation of this, Bill Kekoa, the Queen's Hospital electrician, had run additional circuits into the selected operating room (OR). We moved all our equipment to the OR, which included John Hanley's anesthesia machine from Children's Hospital, so we could use halothane. The monitoring equipment consisted of an aneroid pressure manometer with a three-way stopcock for continuous arterial pressures, a water manometer for venous pressures, and a single lead Electronics for Medicine sealed EKG monitor on John Hanley's anesthesia machine. Two operations on dogs were done at night (with Charles Price, the assistant hospital administrator, guarding the door) so that the equipment spacing, patient draping and electrical connections could be worked out. This culminated in successful closure of Harumi Yoshimoto's IASD in December 1959. The recovery room was utilized as an OHS intensive care unit.

We were grateful to have the recovery room nurses providing around the clock shifts with Harumi and the other patients. There was no medical or surgical intensive care unit (ICU) then so after 48 hours, when Harumi appeared stable, she was transferred to a private room until discharge. Today Harumi works as a seamstress for Hilo Hattie's in Hilo.

Gladys Tsugawa RN organized this recovery room unit and it became axiomatic that no matter when she called and tactfully announced that the "chest tubes felt warm," the bleeding source needed to be checked out. The postoperative cardiac monitoring was done with an Electrodyne unit which was a combination EKG monitor and pacemaker. The EKG screen was smaller than a playing card and had no rate meter, but alarms could be set for high and low rates and the pacemaker was supposed to cut in at the lower rate. This monitor was set in a tubular aluminum stand and raised above the height where explosion was a danger. All four legs, spread-eagled, were on wheels. The small screen forced virtually everybody to put their noses on the screen to read it and invariably they tripped over or kicked those monitor legs. Blood gases were not available then but we did run pHs with a Sanborn machine. We relied heavily on venous pressure monitoring for fluid administration because there were no quick-acting diuretics. If the patient had a low blood pressure, low urinary output, and low venous pressure, we gave more volume either blood or fluids but kept the patient on the dry side. The patients were all extubated as soon as possible in contrast to present protocol of longer respiratory assistance. The postoperative pain was controlled with small, frequent doses of narcotics intravenously. Actually the most frequent post operative complaint proved to be thirst.

We had a dry spell until our next case and then had quite a few cases, mostly pediatric, from Guam, Samoa and Hawaii. Many of the children from Samoa couldn't speak English. When possible, a family member would come with them, but before any diagnostic or surgical procedure could be carried out it had to be explained to the High Talking Chief who would talk to the family and then give his consent to proceed. All of these children were wonderful patients and were sent back to the pediatric ward from the recovery room. As soon as we removed the chest tubes and monitoring lines they would be out of bed and scooting down the hall to play with the other children in the TV playroom.

We did well until we lost case 13 due to mechanical problems and then continued on into the 20s without incident. The Hawaii Medical Association (HMA) held its annual meeting at the Princess Kaiulani Hotel about 1961 and Paul Gebauer took all the oxygenator equipment and table to the meeting as a display. One of the women newspaper reporters who always attended the HMA annual meetings walked up and started chatting with him about the number of cases we had done and how many had we lost. He told her we had lost case 13. She thought this was a most newsworthy item and on the front page of the second section of the *Star Bulletin* that day appeared huge headlines in red ink: QUEEN'S BARES OPEN HEART DEATH. Needless to say I received a letter from an attorney in the next morning's mail requesting specific details!

The Hawaii Blood Bank did a terrific job with the added load of these open heart cases since fresh heparinized blood was required to prime the oxygenator and for transfusion during the case, and fresh regular blood was needed for transfusion postoperatively. This required the bank to cross-match about 20 donors for each case and then have these donors show up early the morning of surgery to draw the blood. The blood bank operation of course made it really hard to delay or cancel surgery for unexpected fevers, colds, etc.

The BCC wanted accreditation of our team by a team already approved by the government so in the early 1960s they invited Dr

C.W. Lillehei, cardiac surgeon, and Dr Paul Adams, pediatric cardiologist, of the University of Minnesota, to evaluate the diagnostic and surgical facilities at KCH and Queen's as well as our team. We scheduled three surgical cases in two days with a "double header" in which two cases had the same blood type. The oxygenator with the blood in it was kept intact and utilized for the second case. Both physicians observed the surgery. Dr Adams participated in cardiac clinic and conferences, watched some cardiac catheterizations, and monitored our postoperative care. They also had a follow-up clinic with cases from Hawaii they had operated on in Minnesota. It was a good learning experience for all of us and we received our accreditation.

In the early 1960s the need for an expanded cardiac catheterization department became apparent and a full time technician, Annette Wills, was employed by Queen's. Cardiac catheterizations were still being done in surgery in the room used for carotid angiography. This room had a small fluoroscopy unit and a Fairchild angio camera which would take serial radiographs similar to the one at KCH. Several younger cardiologists had started practice and the volume of catheterization cases rapidly increased. A five channel Electronics for Medicine Monitor was acquired and the procedures were moved into x-ray. In 1965 an image intensifier with a cine camera was purchased and installed by the Queen's Hospital Auxiliary allowing rapid movie filming of angiocardiograms. The image intensifier made the procedure much easier since the catheterization could be done in a lighted room. About this time hydrogen gas recirculation curves were instituted and were much more accurate in identifying intracardiac shunts. The hydrogen tank had to be kept down the hall away from electrical equipment, making it necessary for someone to leave the room and walk down to the tank with an anesthesia bladder attached to a mask, fill it with hydrogen and then walk back to the room. The patient would inhale from the mask with a timed recording to determine how rapidly the gas circulated to show if there was a defect into the right heart where the electrode on the catheter tip was located.

In the early 60s the cardiac lab purchased an oximeter which allowed blood oxygen saturation determinations to be done almost instantaneously as the samples were drawn during a cardiac catheterization. This oximeter also allowed us to determine pulmonary artery saturations postoperatively. Sometime later the cardiac lab purchased a blood gas analyzer which permitted much more precise acid-base balance during longer pump runs and postoperative care.

In 1965 Paul Gebauer fabricated a heat exchanger out of hydraulic airplane tubing that fit right into the oxygenator under the rotating disks and would allow the temperature change to be accomplished at the time of oxygenation with less blood trauma. This heat exchanger was copied and manufactured by Pemco to be sold with their oxygenator. This equipment was used with dextran hemodilution to close a septal defect in an adult patient who was a Jehovah's Witness. He did very well. We used hypothermia quite often and even used deep hypothermia down to approximately 22° C at which point the oxygenator was stopped and the blood drained from the patient into the oxygenator. After the procedure was done under complete cardiac arrest, the blood was returned and the patient rewarmed using the oxygenator.

Deep hypothermia without the oxygenator was used in two infants with total pulmonary anomalous venous return. The infants were anesthetized and then packed in ice until their temperature fell to about 20° C. This produced cold cardiac arrest and then incisions were made in the back wall of the left atrium and the anterior surface of the pulmonary veins. Anastomoses were carried out from inside the atrium. The first child's temperature was returned to normoth-

ermic spontaneously with external rewarming and the second one with the pump utilizing a heat exchanger.

The availability of hypothermia led to participation by other specialties. The neurosurgeons wanted to use brain cooling and arterial occlusion to ligate or clip cerebral aneurysms. They would do a craniotomy while we dissected out and cannulated the common carotid arteries and one femoral artery. Also both vertebral arteries were encircled with occluding tapes. With the patient on a warming blanket to maintain body temperature, cooled femoral artery blood was pumped into both carotids to achieve rapid brain cooling. Then with all four cerebral vessels occluded, the neurosurgeon would deal with the aneurysm after which the patient's own circulation was restored to rewarm the brain. Several extremity malignancies were treated using a heat exchanger in conjunction with a small bubble oxygenator to perfuse and arterially isolate a leg. Extremity hyperthermia was used in conjunction with an anticancer drug being introduced into the system for a specified time. This caused a rapid regression of the malignant lesion and reduction in pain for a time.

In 1961 the Starr ball-valve prosthesis was introduced for replacement of the mitral valve. This was followed shortly by aortic valve replacement. As is usually the case with new procedures the sickest patients were selected first. They had had the full medical course, were usually in negative protein balance and chronically ill. These patients didn't do well with surgery unless their heart failure was relieved. This was the period when mercurial diuretics, digitalis and low salt intake were the mainstays of treatment for cardiac failure. To reduce the energy requirements of respiration on the heart, a tracheotomy was done. Utilizing low pressure tracheotomy tubes, breathing was taken over completely with an Engstrom respirator. The Engstrom respirator came from Sweden and was well engineered to deliver specific ventilatory requirements. These patients would usually improve in 48 hours and then the internists would want to wait another 24 hours before surgery. The patient would often lose some of their improvement and then we would have to deal with another 24 hour postponement or proceed with surgery. The Engstrom respirator had a built in anesthesia unit so it could be utilized during surgery. We began by using the Starr ball valve for mitral valve replacement. Then during the 60s there was a flood of new valve prostheses designed with a low profile in which the ball was replaced by a flat disk because the ball in the Starr valve took up too much space in the ventricle causing a low cardiac output syndrome postoperatively.

Dr Frank Spenser at the New York University School of Medicine pioneered the technique of placing a small diameter polyethylene catheter through the chest wall, into the right ventricle and on into the pulmonary artery to use for pressure monitoring and blood sampling postoperatively. Pulmonary blood oxygen saturation gave a very useful indication of cardiac output. Faced with a low saturation, even though the patient appeared to be doing well, you knew that the patient would never leave the hospital unless you could improve cardiac output.

The aortic valve results were better when replacement was done with a homograft. So we collected and measured aortic valves from autopsies and then freeze-dried them to be reconstituted at the time of surgery. They were a lot more difficult technically to suture into what was frequently a calcified aortic root without twisting or deforming the graft. Nevertheless, aortic homografts were a lot better from a physiologic and an embolic standpoint. A supply of homograft aortic valves was hard to come by and ultimately we started using commercially prepared porcine mitral and aortic valves sutured onto stents.

The early 1960s saw a large increase in patient volume at

Queen's, both medical and surgical, bringing about a demand for an ICU. One was constructed at the Ewa end of Nalani II and was supposed to accommodate both medical and surgical patients. Electronics for Medicine wall-mounted bedside monitors with a central console were installed and for the OHS patients a portable three channel Electronics for Medicine unit was used which put the EKG and venous and arterial pressures on the screen. This ICU was poorly situated for surgical patients because of the distance from surgery and the elevator ride necessary to reach it plus the poor patient monitoring during the trip from surgery. Demand for these ICU beds far exceeded the few beds available and there was a constant battle between the internists and surgeons for them. Ultimately in the early 1970s additional surgical ICU space was built on the Diamond Head end of Kinau IV and a medical ICU on Kinau II.

The 1960s were dynamic and innovative for OHS. There were many mechanical and perfusion problems experienced by all teams and attending bull sessions at the thoracic surgical meetings was quite rewarding in solving these problems. Some of the problems discussed were: sucker design to avoid hemolysis, type of blood filters to use, postoperative headache and occasional confusion suspected of being due to silicone particles, optimum perfusion rates and temperatures. Also, there were two separate camps: one in favor of coronary perfusion, the other cardiac arrest. The *Thoracic Surgery Journal* changed its name to the *Journal of Thoracic and Cardiovascular Surgery* to reflect these changing interests and the articles covered many approaches to exposure, instruments and ideas for improving OHS, as well as pitfalls. It is interesting that during this decade there developed two main divisions of thoracic surgeons: the older group with a primary interest in lung diseases and cancer and the younger group just coming out of residencies more interested in open heart surgery. This finally resulted in the establishment of the Society of Thoracic Surgeons by the younger group with their own journal, *The Annals of Thoracic Surgery*. [Dr Brainard was a founding member of the society.—AM]

There were many foundations and individuals who made it possible for us to perform the first open heart surgery in Hawaii on Harumi in 1959. Financial assistance by the McNerny Foundation, Mary Castle Foundation, Hawaiian Electric Co, Hawaiian Telephone Co, Honolulu Gas, Hawaii Heart Association and the Medical Group Research Foundation as well as the Queen's Auxiliary and Queen's Hospital Board were ongoing and always generous. There were many individual contributors who gave their time and knowledge. To name a few: Lucy Douglas, Fran Batura, Gladys Tsugawa and the recovery room nurses, Thelma Jones, Bess Owens, Yoki Higa, blood bank personnel, Will Henderson, Katsuki Nakamoto, Kenneth Bermudes and many others to whom we are indebted and grateful.



Reminder

Please complete and return the readership surveys that were in the October issue of the Journal. Extended deadline is November 30.