

Chapter 3



THE DIAGNOSIS OF PEDIATRIC HEART DEFECTS AND THEIR SURGICAL TREATMENT

SPECIAL ISSUES IN PEDIATRIC MEDICINE

Pediatrics involves the treatment of children and has long been recognized as a separate medical specialty because of the differences in the medical issues that children and adults face. The care and treatment of children, in fact, can involve medical conditions that simply are not seen in adults. Some conditions are so unique to children that, if treated successfully in childhood, they will never manifest themselves again.

GENERAL ISSUES

The first major difference between adult and pediatric patients arises from the disparity in their sizes. While this disparity becomes less of an issue with older and teenaged children, where younger children and neonates (at the HSC, those less than six weeks of age) are concerned, the size of bodies and organs is a significant factor. The common statement that ‘your heart is approximately the size of your fist’ takes on enormous significance when one considers the size of a newborn’s fist. The size of a baby’s heart, in fact, has been compared to the size of a peach pit.

A second major difference is that a child is less able (and sometimes less likely) than an adult to articulate his or her medical problems and concerns to a doctor. Infants, and other children who are unable to speak, present a particularly difficult issue. While a doctor can be guided by a description of symptoms from an adult in assessing a particular medical problem and in determining the best course of treatment, that guidance remains elusive where children are concerned. Thus the determination of a child’s health problems relies more heavily on observation and examination than is the case with adults. Of necessity, great reliance is placed on second-hand information about issues, such as how the child is eating or behaving. This information is usually gathered from people who are not medically trained (such as those adults involved in the care of the child).

It is true that adult patients are sometimes unable to articulate their problems (because of physical or intellectual limitations and even for psychological reasons), but this is invariably the case with infants. Thus the person diagnosing the child's medical problems must not only exercise care and attention to detail, but also must pay great attention to what might be considered extraneous information.

These factors also place the parent or guardian of the child in a position of considerable dependency (and therefore of trust) on the medical practitioner or nurse, when it comes to assessing the child's condition and recommending a particular course of action.

Besides size and lack of ability to speak, infants present other differences too. These include anatomical (the structure of the body), physiological (how the body works) and pharmacological (how the body responds to drugs) differences.

AN ISSUE SPECIFIC TO CARDIAC CASES

A major difference between adults and children arises in the area of cardiology and cardiac surgery. Children with cardiac problems tend to have congenital heart defects while adults tend not to have such defects. Additionally, no two children with the same type of cardiac lesion will present in exactly the same way, whereas adults with heart problems tend to have similar presentations. The anatomy of each congenital heart defect can differ significantly from one to the next, whereas adult hearts tend to appear the same, with medical problems that do not show anatomical differences.

The process of assessment and treatment of pediatric patients attempts to determine the anatomic anomalies unique to each child. Doctors treating children with heart problems have come to expect that, while in every case a child's cardiac defect can be categorized, what may be seen when a surgeon opens the child's chest can differ substantially from child to child. This may be so even when the children have the same category of defect.

PEDIATRIC SUBSPECIALTIES

All medical practitioners undergo training initially at medical school to become medical doctors. They then undergo a period of training in one or more teaching hospitals as a 'resident', during which they are assigned to work on various wards of the hospital. After that period of residency they can apply for a licence as a general medical practitioner or can continue training in a specific area of specialty, such as pediatrics.

Being licensed as a doctor and being recognized as a specialist are separate issues altogether. While training is generally the field of the academic community (universities and teaching hospitals), licensing is left to the various licensing authorities in each province. Recognition as a specialist in this country is the purview of the Royal College of Physicians and Surgeons of Canada.

As the specialty of pediatrics has expanded, so have the number and types of subspecialties, or more specialized areas of medical work. These include pediatric cardiology, pediatric cardiac surgery and pediatric anaesthesia.

PEDIATRIC CARDIOLOGY

Cardiology is the science of evaluating the condition of a patient's heart, identifying problems associated with it and recommending treatment for the conditions identified.

The cardiologist's most important function is the identification and diagnosis of heart defects and heart disease. These doctors stand at the front line in society's fight against heart problems, for it is their ability to identify a patient's heart condition quickly that will give rise to early intervention and successful treatment. While some heart conditions can be successfully treated without surgical intervention, it is the cardiologist who is usually the first to identify a condition that may require a heart operation. Invariably, the decision to proceed with cardiac surgery is a decision made between the patient, the family, the cardiologist and the cardiac surgeon.

If it is thought that surgery may be required, the cardiologist is expected to be able to provide a clear picture to the surgeon as to the exact state of affairs within the heart itself. For example, the functioning of valves and the location of defects, such as a hole in the wall separating the chambers of the heart, must be accurately described. This permits the surgeon to determine if surgery is, in fact, the best option and what the potential surgical issues are likely to be.

Often, in order to make a diagnosis, the pediatric cardiologist must do more than merely observe external signs, since these can sometimes indicate only that there is a problem and not what the problem is. More direct exploratory methods may have to be undertaken. Since children are usually unable to explain or describe their condition, a pediatric cardiologist's diagnostic skills emphasize the use of technology and accurate measuring devices to allow the cardiologist to form opinions and conclusions as to the cause of a child's apparent heart problem. Cardiologists now perform their tasks with the aid of modern technology unavailable to their colleagues of previous eras.

Some of the technologies available to today's cardiologist are:

- electrocardiography (the production of electrocardiograms or ECGs/EKGs, which are graphs showing the electrical impulses produced by the heart);
- echocardiography (the production of echocardiograms or ECHOs) through ultra-sound imaging; and
- cardiac catheterization, which involves inserting a long, fine tube into the femoral artery in the groin, through connecting arteries and then up and into the heart. The tubing is connected to a device that allows the cardiologist to measure the various pressures within the heart and the blood vessels surrounding it. The cardiologist may also take samples of blood for testing or inject special X-ray contrast material or dye through the tubing to obtain real-time pictures of how the heart works.

Intra-operative echocardiograms can be done in more than one way. One technique uses an external probe placed on the chest. However, it cannot be used throughout the entire operation. The other technique uses a transesophageal echocardiography probe (referred to as TEE) inserted into the esophagus. TEE provides superior images of structures in the heart without interference from the chest wall. For example, by imaging from directly behind the left atrium, TEE can produce minute detail of the mitral valve and the atrial septum. Since the probe is in the esophagus, it can produce ECHO images throughout the operation without interrupting the surgical procedure. Usually the probe is inserted by the anaesthetist and manipu-

lated by either the anaesthetist or a cardiologist. Many cardiac anaesthetists now possess the skills to interpret the TEE.

While the HSC gained access to TEE equipment during 1994, none of the anaesthetists or cardiologists had experience with TEE.

In addition, a new field of invasive cardiology has developed in recent years. Cardiologists who have specialized in this field use technology to carry out procedures within the heart without having to cut open the patient's chest. For example, an 'invasive cardiologist' might perform a balloon atrial septostomy (as described in Chapter Two).

PEDIATRIC CARDIAC SURGERY

Surgery is a course of treatment that involves operating on the body of the patient, and cardiac surgery involves surgery on, within and around the heart. Cardiac procedures can involve operating on blood vessels attached to the heart or on the surface of the heart, or can involve operating on the heart itself, where the walls of the heart are actually opened up. Cardiac surgical procedures are referred to as either closed or open-heart surgery.

Closed-heart surgery is that surgery in and around the heart which does not involve having to either bypass blood from the heart or stop the flow of blood to the heart. Open-heart surgery is that surgery which often, but not always, involves actually opening the walls of the heart. Open procedures are those that require that blood-flow through the heart be diverted through the heart-lung machine, because the heart itself or its major blood vessels must be opened.

Adult cardiac surgery is an area of specialty that has enjoyed wide acceptance and recognition as a medical specialty for many decades. By contrast, pediatric cardiac surgery is a relatively new area of specialization. Indeed, it has only been since the latter part of the 1950s that science and medicine have begun to address the special issues that infants and young children with cardiac anomalies presented.

Initially, persons trained as adult cardiac surgeons performed cardiac surgery on children. However, the training that an adult cardiac surgeon receives is now considered insufficient for the complex procedures performed in pediatric cardiac surgery. Specialty training programs for pediatric cardiac surgeons are now found at a number of hospitals in North America, including McGill University in Montreal, the Toronto Hospital for Sick Children and Harvard Medical School in Boston.

If a doctor wishes to specialize as a surgeon, a further period of residency in a surgical training program is required, with additional periods of training in other specific fields. For a pediatric cardiac surgeon, that would involve training initially as a general surgeon, then as a cardiothoracic surgeon, then as a cardiac surgeon, then as a pediatric cardiac surgeon. Training in this specialty can exceed ten years.

ANAESTHETISTS

Anaesthesia is the field of medicine involving the administration of drugs that produce a loss of consciousness or sensation. Most often, anaesthetics are given for a surgical procedure but sometimes, especially in the case of children, anaesthesia may also be needed for a diagnostic procedure, such as a special X-ray examination.

Anaesthetists are doctors who have completed their medical degree and have then completed an additional residency in the study of anaesthesia and anaesthetics. This residency usually lasts a minimum of five years. In Canada, the term ‘anesthesiologist’ is gaining wider acceptance as the term applied to such doctors. However, as the witnesses in this Inquest used the term ‘anaesthetist,’ that term will be used throughout this report.

Anaesthetists have extensive knowledge of the drugs used to enable patients to undergo surgery without pain and suffering. Anaesthetists are also very knowledgeable about how the body works and the various techniques and treatments needed to maintain patients in a state whereby the necessary surgical procedures can be carried out in a safe manner. Another of the anaesthetist’s responsibilities is to determine if a patient is in a condition to be safely anaesthetized and undergo an operation.

While pediatric cardiac surgery and pediatric cardiology are viewed as distinct specialties with a distinct training regimen, such is not the case with pediatric cardiac anaesthesia. There is, in fact, no separate training program for pediatric cardiac anaesthetists recognized by the Royal College of Physicians and Surgeons of Canada. Anaesthetists who specialize in pediatric cardiac anaesthesia generally have been trained in adult cardiac anaesthesia. Some may have undertaken an additional six to twelve months of training in a fellowship program in pediatric cardiac anaesthesia. Others will have developed their expertise in pediatric cardiac cases through experience, as opposed to any special training regimen. In addition, pediatric cardiac anaesthetists in Canada have developed their own ongoing medical education programs to improve their knowledge and skills.

NURSING

Nurses care for the sick and disabled, and promote, restore and maintain health. These services are usually co-ordinated with doctors and other health-care providers. By virtue of their education, experience and 24 hour-a-day presence with patients, registered nurses (RNs) play a unique and critical role in hospital care. Some of this care is in specialized areas, such as the operating room and intensive care unit, and nurses working in these areas are expected to develop the knowledge, skills and judgment essential for the management of complex patient problems. RNs are often the first to identify changes in a patient’s condition, as well as trends in a patient’s response to care. Nurses often act as a guide and interpreter for patients and their families trying to negotiate the complex and highly specialized environment of hospitals. RNs also provide the co-ordination of care and day-to-day management for both individual patients and patient care programs, ensuring that the right resources are in the right place at the right time to meet patient needs.

Scholars of the history of nursing in Canada stress the need to examine the role that gender stereotyping and discrimination has played in the history of nursing. Women dominate the profession of nursing. Approximately 98 per cent of nurses in Canada are female. Furthermore nurses, like most women who

entered the Canadian labour market, were historically poorly paid and were expected to be completely obedient to male authority. In fact, the motto of Canada's first successful school of nursing, the General and Marine Hospital established in 1874 in St. Catharines, Ontario, was "I see and am silent." (Judy Coburn, "I See and Am Silent," in *Women and Work, 1850–1930*, Toronto: Women's Press, 1974, page 140)

For most of this century, Canadian nurses received their training in hospitals, where they served essentially as free labour to the hospitals as they apprenticed to their craft. Students were often required to live at their training hospital, where they regularly worked 12-hour days, 7 days a week. According to Katheryn MacPherson, author of a recent history of nursing in Canada:

Deferring to one's superiors was learned early on the job. Probationers entered the hospital at the bottom of the nursing hierarchy, subordinate to juniors, who in turn looked up to intermediates, who deferred to senior students. Seniors were expected to comply with the directives of supervisory graduate nurses, who themselves answered to the superintendent of nursing. Deference extended well beyond merely following orders to include physical demonstrations of differential rank. Nurses were instructed that, when in the presence of more senior nursing staff or any medical practitioners, they were to stand up 'at attention', surrender their place on elevators, and allow superiors to walk ahead. (Katheryn MacPherson, *Bedside Matters: The Transformation of Canadian Nursing, 1900–1990*, Don Mills, Oxford University Press, 1996, page 32)

While it has been possible to receive a Bachelor of Science in Nursing (B.Sc.N.) in Canada since 1919, the number of university training programs and the number of university-trained nurses in Canada remained low for most of the century.

Historically, nurses trained in hospitals for three years. During this period they constituted the main nursing labour force, while most graduate nurses provided supervision, not bedside care. When they graduated, nurses sought work in private care, public health or hospitals. While today approximately three out of every four nurses work in a hospital, for the first half of this century a very large percentage of nurses sought and found work in private practice. Graduating nurses took examinations that permitted them to be registered with local nursing registries, hence the designation Registered Nurse. These registries served as referral services and provided a variety of services to the nurses who were registered with them, including sick benefits and pension funds.

The focus of the diploma programs was to prepare nurses to provide care in hospitals and personal care homes, with the curricula focused on the nursing response to people suffering illness and disease. The baccalaureate curriculum still provides this focus, as well as requiring a broader foundation in the arts and sciences. Courses include anatomy, physiology, psychology, sociology, and both theory and clinical practice in nursing. In addition, there is an expectation that students learn scientific reasoning and how to apply current research to practice. The degree provides students with an in-depth knowledge of the determinants of health, which enables graduates to be effective in helping individuals, groups and populations prevent illness and lead healthier lives, as well as provide nursing care for those who are ill.

The last twenty years have also seen a dramatic expansion in nursing specialization—close to one-third of nurses are enrolled in post-RN training. Despite this expansion in training, formal recognition for specialized training has been slow in coming.

More recently, governments have closed hospitals and beds. Hospitals have moved toward reducing the length of time that patients spend in hospital, whether it be after having an operation, a baby or heart attack.

This has resulted in an increase in the percentage of very ill patients in hospital, and markedly influenced the workload of the nurses who care for these patients.

During the last decade, hospitals across Canada have experienced difficulties attracting and retaining nurses. This is the result of several factors. Within Canada's health-care system, nurses occupy a unique and yet controversial position. Nurses have many of the responsibilities and obligations of professionals, and indeed, they are trained as professionals. However, they lack the control over working conditions that usually accompanies professional status. This, in combination with the increase in the workload and what is perceived as low pay for the care that nurses provide, has caused many to leave the profession. In addition, hospitals involved in cost-cutting efforts have looked for ways to reduce further their nursing costs—making greater use of part-time staff and having more tasks performed by non-nurses. Unintentionally, this has sent the message to current and potential nurses that the profession has a cloudy future. The Winnipeg HSC was participating in such an exercise in rationalization in 1993 and 1994.

The events in the pediatric cardiac surgery program in 1994 involved nurses who specialized in the nursing diagnosis and therapy of patients with cardiac problems, in cardiac surgery and in the intensive care treatment of young children in critical condition. All the nurses involved had a variety of educational backgrounds and different personal responses to the events of 1994. Those responses were shaped by their profession, its history and the place that it occupied in the broader health-care system.

HOW A PEDIATRIC CARDIAC SURGERY CASE PROCEEDED

The rest of this chapter sketches out in a general fashion the manner in which pediatric cardiac surgery was undertaken in Manitoba in 1994. Just as each patient is unique, each case was also unique, with the actual sequence of care differing in some respects from the procedure described below.

EVENTS LEADING UP TO THE DAY OF SURGERY

Diagnosis

A cardiac case began with the diagnosis. A child's heart problem might be noted at any point before or after the child was born, by the mother's doctor during a prenatal examination, by the doctor attending at the birth, by the child's pediatrician or by the family doctor during a routine checkup.

Once a heart problem was discovered, in Manitoba during 1994, the child was usually referred to the Variety Children's Heart Centre at the Winnipeg Health Sciences Centre to be seen by a pediatric cardiologist.

Variety Children's Heart Centre clinics

A child who was referred to the Variety Children's Heart Centre (VCHC) by a pediatrician or family doctor would be seen at one of the centre's regular clinics. These clinics were conducted by the cardiologist, the nurse clinicians and the technicians who were assigned to the VCHC. The necessary diagnostic tests would

be performed at the clinic, and parents would normally be provided with test results before they left. The nurse clinicians would both assist with the tests and provide support to the families once the test results were provided. The nurse clinicians usually reinforced the information the parents had heard from the cardiologist. If a complex problem was detected, a cardiac catheterization might then be required. Catheterization procedures are usually performed to examine, in intricate detail, the anatomy and circulation of a patient's heart. Such information is essential in advance of surgery (and other treatment).

Surgical consultation

If the cardiologist believed the patient required surgery, he would consult with the pediatric cardiac surgeon. The surgeon would usually examine the patient and determine if the heart defect required surgical intervention. The surgeon's obligation was to assess the information available about the child and determine if, in his opinion, the child's problem could be best addressed surgically and where the operation could best be done. The surgeon could refer the patient to another heart centre, if he thought that the problem was beyond the team's ability or if the specific operation could best be done elsewhere.

The surgeon was expected to consider the particular lesion, the child's condition, his own skills and the skills of the operating team, and any special needs that the operation might require in terms of equipment, environment and organization. The surgeon would advise the cardiologist of the outcome of his meeting with the parents. He would also be expected to discuss his conclusions with the parents.

The nurse clinician would attend the meeting between the surgeon and parents. Part of the nurse clinician's role was to reinforce the information the surgeon told the parents. The nurse clinician also acted as ongoing support for the parents throughout the hospitalization and would continue the relationship during follow-up at the VCHC clinic.

Cardiovascular thoracic conferences

In all cases where surgery was indicated or considered possible, the matter was referred to a weekly meeting usually held every Wednesday morning at 0700 hours and known as the Cardiovascular Thoracic Conference, or CVT conference. At the CVT conference, the cardiologist, the Variety Children's Heart Centre nurses and the surgeon discussed the case. If any interns or residents were working on the cardiology service, they too would be present. Technicians who conducted the diagnostic tests at the VCHC with the cardiologists might also attend, if their reports were being considered. The purpose of the discussion was to decide if and how to proceed with the case and consider other issues, such as whether or not the case should be scheduled (or slated) for surgery in Winnipeg. Other hospital staff, such as operating room nurses, anaesthetists and intensive care staff were not usually included in the CVT conference.

The surgeon or the cardiologist advised the referring doctor of the diagnostic findings and the decisions made in the CVT conference by letter and/or charted the information in the Patient Progress Notes portion of the hospital record (in the case of emergency operations).

Consent

Before the operation took place, the child's legal guardians needed to give their consent in writing. This would occur after a discussion that should have included a full explanation of the need for surgery and a full explanation of the risks, including complete answers to all questions asked. At the Health Sciences Centre, the responsibility to explain a surgical procedure and obtain the appropriate consent from the parents fell to the surgeon. The practice at the HSC was to have the consent form signed just before the day of surgery, although the meeting explaining the procedure might have taken place several weeks before.

Scheduling of the operation

A child scheduled for surgery might be considered as an emergency case, an urgent case or an elective case. The difference among these three descriptions would be determined by how soon the operation had to take place. Emergency cases needed to be operated on as quickly as possible, while urgent cases could endure a longer time delay. In emergency cases, often the CVT conference and the actual pre-operative assessment were combined to expedite surgery. Elective cases were planned for in advance, with a considerably longer time frame, even though they were ultimately necessary for the life of the child.

If a child was assessed with a heart defect shortly after birth, an operation might be scheduled while the newborn was still in hospital. If the operation could wait, the child would be discharged home, with follow-up in the VCHC. Infants with heart defects who were born in other hospitals would be transferred to the Children's Hospital or referred to the VCHC for assessment.

Admission to hospital

In elective cases, the family would receive a letter from the VCHC, stating the date the child was booked for surgery, when to come for admission to the hospital and other details. Along with the letter, the family would receive a pamphlet describing the surgical ward (CH₃) that the child would be in and other general information.

The child would usually be admitted to the Children's Hospital at least one day before surgery. The VCHC would forward to the hospital the results of any tests done on the child on an outpatient basis as part of the pre-operative preparation. There was also a patient education record that was filled out by different nurses, starting with the VCHC nurse clinician. This record documented the steps taken to educate the parents and patient (where appropriate) about the particular heart problems and prepare the child for surgery. The nurses would explain the hospital experience to the family. They would discuss such matters as pain control and the fact that the patient would be looked after by a number of different people doing different tasks. One of the important responsibilities of the VCHC nurse was to ensure that parents understood that they could ask any questions and that they did not have to sign a consent for surgery until they felt prepared to do so.

Pre-operative conference

The pre-operative conference for each case was held on Tuesday mornings in the week before the date of surgery. The cardiologist, the surgeon, the VCHC nurse clinicians, operating room nurses, anaesthetists, intensive care doctors and nurses, perfusionists and respiratory therapists attended this meeting. Since the HSC was a teaching hospital, interns, residents, and fellows might also be present.

While the intent was that the staff who were going to be involved in the operative procedure or follow-up care of the patient attended this meeting, often, due to other commitments, someone else would attend in their place. However, it was expected that if this happened, the person attending the meeting would brief the person actually participating in the case.

The meeting involved a presentation of the cases scheduled for surgery the following week, with the diagnostic part of the presentation being made by the cardiologist and the surgeon providing information and answering questions about the operation. Any of the people in attendance asked whatever questions they needed to ask. The child's complete medical history and current status, as well as the results of medical tests, were outlined. Echocardiograms and videotapes of the cardiac catheterization that illustrated the patient's condition might be shown. The VCHC nursing staff would also present information on the child's social circumstances.

Pre-operative anaesthetic evaluation

Following the pre-operative conference, the anaesthetist would examine the patient and the patient's chart. In this examination, the anaesthetist would confirm the information provided at the conference and would examine the patient to discover if there were issues specific to the anaesthetic, such as whether or not the patient had a normal airway. Since the material presented at the conference could be several days old by that time, the anaesthetist would check to see if the child's condition had changed or if there were more up-to-date test results. If chest X-rays were not available at the pre-operative conference, the anaesthetist would attempt to view the X-rays and/or the X-ray reports.

The parents were often present during this evaluation, giving the anaesthetist an opportunity to discuss the child's medical history, the family's medical history and family issues relating to anaesthetics. The anaesthetist would explain the risks and problems of anaesthesia, what the anaesthetist would do and the drugs that might be used. At this point parents gave verbal consent. (In Canada there is generally not a separate written consent for anaesthesia, the need for an anaesthetic being covered by surgical consent.)

Following this meeting, the anaesthetist recorded any concerns and requested any additional necessary tests. An order would be placed with the pharmacy for any drugs that the anaesthetist needed to have made up ahead of time. The anaesthetist might also approach other specialists who might be dealing with the child to discuss issues that were not in the area of anaesthetic expertise.

The anaesthetist would also assign a status evaluation to the patient, which was based on the physical health of the patient. This evaluation used a classification system adopted by the American Society of Anesthesiologists (ASA), called the ASA Class. There are five classes, and adding the postscript 'E' indicates that the patient is to undergo an emergency operation. The classes range from ASA I, representing a very

healthy patient, to ASA V, representing a patient who is not expected to survive 24 hours with or without surgery.

Most of the children who were the subject of this Inquest were assigned a Class III or IV. A Class III patient is one who has health problems that limit the ability to function normally. A Class IV patient has health problems that represent a constant threat to life.

Contact with the child and the family

Depending on the heart condition, the child might be living at home before surgery or might be in the hospital. Contact between the child and the child's parents and the hospital was maintained by the nurse clinicians working for the VCHC. It was their responsibility to prepare the family for both the operation and the post-operative period. Children who were not in the hospital were usually brought into hospital the day before the operation.

The nurse clinicians would also maintain contact with any child who was already in the hospital. In most cases, neonates would have been in the neonatal intensive care unit from the time of their diagnosis until the operation. Such a patient usually needed an emergency operation because of the severity of the heart condition: the heart defect was so serious that it had to be dealt with quickly or the child would die.

Preparation of the patient

It was the joint responsibility of the cardiologist, surgeon, anaesthetist and intensivist (where applicable) to ensure that a child was in optimum condition for surgery. Any one of these doctors might raise objections to proceeding with surgery if he or she thought that the child was not in optimal condition.

THE DAY OF SURGERY

Preparation of the operating theatre

Open-heart operations took place in Theatre 2, the largest of the Children's Hospital operating rooms, because of the need to have the cardiopulmonary bypass (CPB) machine in the room. If the operation was a closed procedure, Theatre 1 would often be used.

Theatre 2 was renovated before 1993, specifically to accommodate the special needs of pediatric cardiac surgery. The theatre was enlarged to contain the anaesthetic and perfusion equipment. Special wiring prevented power surges from affecting the heart-lung machine. At the same time, a new ventilation system was installed.

The term Operating Room, or OR, is used to describe both the suite of operating rooms in a hospital and the actual room in which surgery takes place. This room contains an operating table, an anaesthetic machine, monitoring equipment, an anaesthetic drug cart, equipment tables, intravenous poles and sterile drapes.

Operating theatre personnel

Besides the surgeon, assistant surgeon and anaesthetist, the personnel in the operating room consisted of:

- scrub nurses
- circulating nurses
- anaesthetic nurse
- perfusionists
- residents (on occasion)
- cardiologist (on occasion).

Scrub nurses

Most people who have seen an operation are familiar with scrub nurses. They are the nurses seen standing, usually at the elbow of the surgeon, overlooking the operative site and handing equipment to the surgeon as needed. The term comes from the fact that the scrub nurse has ‘scrubbed in’—that is, has washed hands and forearms carefully and donned sterilized clothing. To maintain the sterility of the operative field, a scrub nurse does not leave the side of the operating table until the procedure is completed or another nurse has scrubbed in.

Although an operation could be performed with only one scrub nurse, there were usually two scrub nurses for the operations involving the 12 children under discussion in 1994.

Circulating nurses

Circulating nurses ‘circulate’ around the operating room and between the operating room and the outside, seeing to any equipment and other needs of the operating team, including those that might require outside contact.

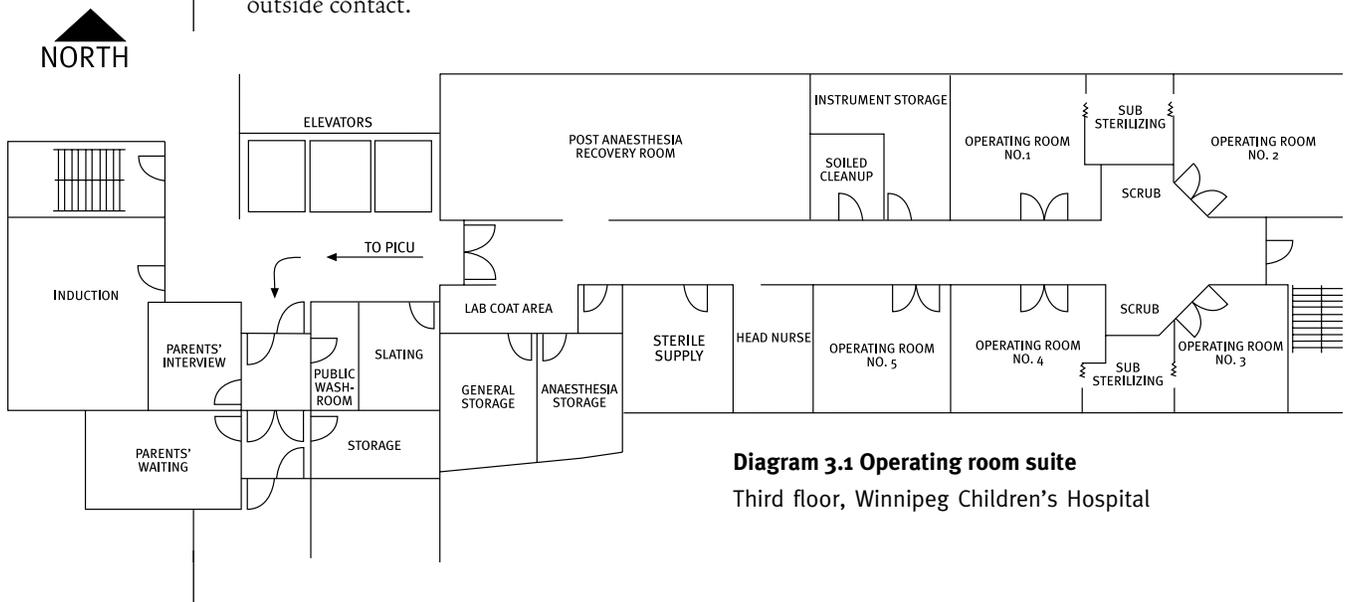


Diagram 3.1 Operating room suite
Third floor, Winnipeg Children's Hospital

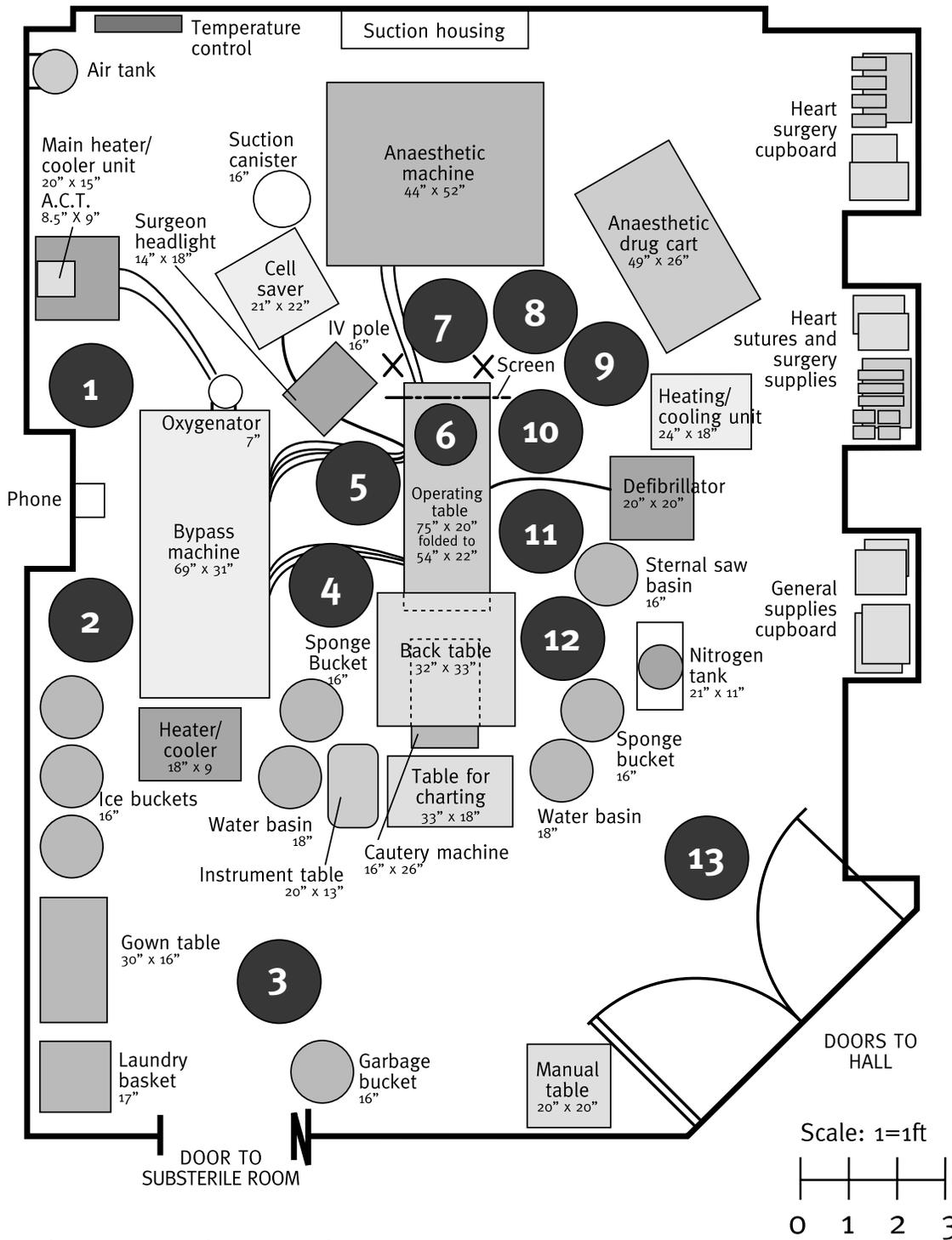


Diagram 3.2 Operating room number 2

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| 1 Primary perfusionist | 6 Patient | 11 Second surgical assistant |
| 2 Secondary perfusionist | 7 Anaesthetist | 12 Second scrub nurse |
| 3 Circulating nurse | 8 Anaesthetic resident | 13 Circulating nurse |
| 4 First scrub nurse | 9 High risk anaesthetic nurse | |
| 5 Surgeon | 10 First surgical assistant | |

In the case of the Pediatric Cardiac Surgery Program, the circulating nurse was usually in the OR, often observing the progress of the operation and assisting the scrub nurse as needed. Sometimes a circulating nurse would scrub in, to relieve a scrub nurse during surgery.

Anaesthetic nurse

The anaesthetic nurse assisted the anaesthetists during high-risk operations. The nurse set up the lines, such as an arterial line or a central line, prepared the anaesthetic drugs, attached monitors to the patient and took samples of blood for the measurement of blood gases. Once the child was on bypass, the anaesthetic nurse might leave the OR until the patient was ready to come off bypass. On return to the OR, the nurse would co-ordinate bringing blood products into the room, preparing special drugs for administration and assisting with resuscitation as necessary. She would prepare the transfer sheet that accompanied the child from the OR to the Intensive Care Unit, identifying any problems or issues that arose during the course of surgery. She would then help prepare the patient for transfer, accompany the patient to the ICU, help set up the patient in ICU and give a report from the transfer sheet in order to make the transfer smoother.

Perfusionists

The perfusionists operated the cardiopulmonary bypass machine and administered cardioplegia (a treatment that stopped the heart during the actual operation). There were two perfusionists in each operation under discussion during this period.

Residents

Since the HSC was a teaching hospital, at times there would be residents or medical students, who would help either the surgeon or the anaesthetist. Surgical residents might be allowed to perform part of the procedure under the supervision of the surgeon, but most usually helped the surgeon by suctioning blood from the operative field or holding lines or instruments out of the surgeon's way to give him a clearer view. The resident was present primarily to learn. Anaesthetic residents might be permitted to administer drugs or insert tubes or lines, as directed and supervised by the anaesthetist. Usually, they also recorded (or charted) everything that occurred during the procedure.

Cardiologists

On occasion the surgeon would call for the cardiologist to enter the OR to help with identification of heart anatomy and discuss any issues with the case. The cardiologist would not scrub in but would wear OR garb and would then stand with the anaesthetist at the head of the OR table.

The team

These persons constituted the operating room team. Historically, the surgeon was seen as the captain of the surgical ship, particularly since the patient, in medical terms, belonged to the surgeon, although that view has changed over recent years. As a result, the lines of command in the operating room also changed.

The surgeon and the anaesthetist each were expected to have mastered separate medical specialties with distinct skills. Thus, neither the anaesthetist nor the surgeon was solely in charge. The surgeon was not responsible for matters relating to anaesthesia, while the anaesthetists were not responsible for the operation. They had a joint, if independent, responsibility for the patient's health and well-being. Both might discharge their duty by delegating certain aspects of the treatment to assistants who were properly qualified and experienced.

However, it would be a mistake to simply focus on these two doctors. An operating room team depends on the skills, dedication and talents of all of its members. A team is more than a collection of highly skilled individuals, charged with working together. While it is essential for each team member to have the skills needed to accomplish the task at hand, a team needs a leader who is skilled in problem-solving and decision-making. As a whole, the team must be able to communicate effectively and resolve conflicts. This requires effective interpersonal skills. In a strong OR team, leadership is shared, problems are solved through discussion, members are accountable to each other and performance is measured collectively and regularly.

Charts

A medical chart is a record of what was done to a patient in the hospital. It is the record of medical proceedings and is an important—and, in most cases the only—source of information available when a patient dies, for those who then attempt to assess what happened. The office of the Chief Medical Examiner for the Province of Manitoba must by law and by policy be called whenever a child dies during or after a surgical procedure. In determining whether or not to direct that an autopsy be ordered or that an Inquest be called, one of the first steps a medical investigator takes is to look at the medical chart for information about the patient's treatment. If the information on the chart is not accurate or lacks a material fact, the Chief Medical Examiner's office is unable to come to a proper conclusion.

The staff anaesthetist had the ultimate responsibility for charting on the anaesthetic record, but in some cases, a resident might do the charting. The anaesthetist charted the monitors used (such as types of lines), type of anaesthetic used, the drugs given, the dose and times they were given, the vital signs, the timing of bypass, intravenous fluids and blood products given and any problems that may have arisen.

The perfusionists entered their information on the Perfusion Record. They recorded pump times and rates, line pressures, blood chemistry and blood gas values, information on clotting time, the delivery of heparin, cardioplegia doses and any blood products given.

The circulating nurse was responsible for recording on the OR Count Sheet the OR times, the staff involved in surgery, the procedure performed and which specimens were sent for testing. A vital part of the record was the outcome of the needle, sponge and instrument count. To determine this, a count was made by the scrub nurse and the circulating nurse together.

The surgeon did not do any record keeping during surgery. However, at the end of the operation, the surgeon dictated an operative report. A copy was placed in the patient's hospital record.

There did not appear to be any systematic evaluation of surgical outcomes. Although the duration of each case and other factors were noted at the time, there was no process of tracking common indicators. These indicators could include duration of use of the heart-lung machine, duration of total circulatory arrest, vol-

ume of blood loss, number of units of blood transfused and number of blood components transfused: e.g., red blood cells, plasma and platelets.

The three phases of the operation

Every cardiac operation had three phases: pre-surgical, surgical and post-surgical. Sometimes these were quite distinct. At other times, because of the urgency of the operation and the condition of the patient, the first two phases might appear to occur almost simultaneously.

The pre-surgical phase

The pre-surgical phase started with the arrival of the anaesthetist. After suitable preparation, including attaching monitors, the patient would be anaesthetized, then positioned on the table for the operation. Special padding would be placed to protect the child. The area of the operation (also known as the 'surgical field') would be washed (or 'prepped') and then draped with sterile towels, ready for the first incision.

These procedures were undertaken in the operating room. The anaesthetist largely performed the first step, preparing and anaesthetizing the child. The scrub nurse, often assisted by the surgeon, would do the prepping and draping of the patient. While these steps took place roughly in the order described, certain portions of these steps might be undertaken simultaneously or were completed in stages throughout the process of the start of the anaesthetic.

Arrival of the anaesthetist

The anaesthetist arrived in the operating room at least 30 minutes before the patient was scheduled to arrive. In high-risk cases the anaesthetic nurse and a respiratory technologist would assist the anaesthetist. The technologist would check equipment, such as monitors, while the nurse, under the direction of the anaesthetist, helped prepare necessary drugs and intravenous (IV) lines.

The patient and parents

After the arrival of the anaesthetist, the parents and child were brought to the waiting room, which was outside the operating room. The patient might or might not have been given a sedative before going to the operating room. In the case of infants and small children, the parents would carry their child in their arms to the operating room door and deliver the child into the arms of the waiting OR nurse.

Anaesthetic monitoring

Monitoring was an essential part of anaesthesia for pediatric cardiac surgery. Before the induction of anaesthesia, the anaesthetist would usually set up monitoring equipment. This equipment included devices to monitor:

- the heart beat (using an electrocardiogram and also through a stethoscope placed on the child's chest);
- blood pressure (first with a blood pressure cuff and then with a small plastic catheter inserted into an artery of the wrist, the foot or the groin); and

- heart and breath sounds (through the stethoscope placed on the child's chest). This stethoscope, which was placed on the child's chest, was known as a precordial stethoscope. This would be replaced later in the operation by a stethoscope that was inserted into the child's esophagus.

Oxygen saturation was also monitored. Oxygen saturation is a term that describes how much oxygen is in the blood. A normal saturation is 97–100 per cent. When air enters the lungs, oxygen moves from the air, into the lung tissues, through the walls of the very small blood vessels (capillaries) and into the blood. Some of the oxygen stays in the liquid (or plasma) of the blood. Most of the oxygen enters the red blood cells, where it combines with a special chemical, known as hemoglobin. The amount of oxygen that actually binds with the hemoglobin is known as the oxygen content. The amount of oxygen that could bind with the hemoglobin is known as the oxygen capacity. The ratio between the content (actual) and the capacity (possible) is the oxygen saturation.

Oxygen saturation can be easily measured by using a special probe, called a pulse oximeter. The probe is simply clipped onto a finger (or toe or earlobe), just like clipping on a clothes peg. No needles are inserted into the patient. Instead, the probe uses a special light beam to measure the oxygen saturation. The pulse rate is also measured, as the device notes each time a pulse of blood is pumped into the finger (or toe), each time the heart beats.

Most pulse oximeters make a beeping noise every time a pulse is detected. This beeping will increase or decrease in rate with the pulse. The pitch (or musical tone) of the beep will also change as the saturation decreases.

Other monitors were:

- a temperature probe;
- a special 'muscle twitch' monitor to assess the effects of the anaesthetic drugs that temporarily weakened or relaxed the patient's muscles; and
- an end-tidal carbon dioxide monitor, which was a special sensor to detect the amount of carbon dioxide in the patient's breath.

In addition, extra monitoring would be provided by special lines inserted into other blood vessels, such as the jugular vein in the neck, in the form of a central line (see below).

Not all the monitors would be attached or inserted until after the start of the anaesthetic. Some children would be well enough that only a few monitors were needed for induction. Other children might be too agitated to have all monitors attached or inserted until they were either well sedated or actually anaesthetized. In addition, other monitors, such as the urinary catheter (usually referred to as a Foley catheter), generally were not inserted until after the child was anaesthetized. The circulating nurse would insert the catheter to measure and collect urine output.

The placement of lines

There were at least two intravenous lines (or catheters) inserted into veins in either the child's hands or feet. These were referred to as peripheral IV lines because they were inserted into veins in the patient's extremities (or periphery). If the patient was to undergo intravenous induction of anaesthesia, a line would be inserted (or placed) to allow the delivery of the anaesthetic drugs.

Depending on the nature of the case, other lines might be inserted for monitoring purposes. These could include an intra-arterial line for the continuous measurement of blood pressure and the taking of samples of arterial blood during the course of the operation. Common arterial catheter sites included the vessels of the wrist, the foot, the groin and, in newborns, the umbilical vein.

Another line might be used to measure central venous pressure. (Central venous pressure reflects the filling pressure on the right side of the heart and blood volume status). In addition, central venous lines were often inserted to allow the rapid administration of drugs, fluids or blood and permit the insertion of pulmonary artery or pacing catheters. Sites used for placement of central venous catheters included the internal or external jugular veins, the femoral vein (in the groin), a vein in the elbow and the umbilical artery. Central venous catheters might also be placed directly into the right atrium during cardiac surgery (and were often termed 'RA lines').

In most cases, these lines were inserted by putting a needle through the skin and then threading the catheter through the needle. However, the lines could also be inserted by performing a 'cut-down', a procedure in which the skin was cut open and the vein or artery exposed, to make it easier to insert the catheter.

The catheters were then connected to tubing that was connected to transducers to facilitate the reading of pressures. (A transducer is a small device that changes the mechanical energy from the monitored pressure to an electrical signal captured on the monitoring screen.) The anaesthetists generally used two transducers (one arterial and one venous). The surgeon might require three transducers: one for a right atrial line, one for a left atrial line (an LA line) and sometimes one for a pulmonary artery line (a PA line). Depending on the operation, these lines might be put in intra-operatively and/or post-operatively. (Intra-operative is the term that refers to events that occur during the operation.) As long as these lines were in place, the transducers were left attached and were used in the ICU.

Induction and intubation

The induction phase of anaesthesia was the process of rendering a patient unconscious by giving the patient intravenous drugs through an intravenous line or inhaled drugs through a mask attached to a tube from the anaesthetic machine. After the anaesthetic drugs had taken effect, the anaesthetist then inserted a special breathing tube down into the patient's windpipe (in medical terms, the trachea).

The anaesthetist would not start the anaesthetic until receiving confirmation that the surgeon was in the hospital. The process of induction and intubation could then take from twenty minutes to two hours, depending on the condition of the child and any difficulties encountered.

INDUCTION

The anaesthetist would have determined which drugs were to be used to anaesthetize the patient. Initially the anaesthetic would be administered either intravenously or as a gas that the child breathed in. (In medical terms, this special gas is known as an 'inhalational anaesthetic agent' because the drug is inhaled or breathed in.) Once the child had lost consciousness, the anaesthetic would be continued with both intravenous and inhaled drugs. These drugs included sedatives (such as midazolam), narcotics (such as fentanyl, sufentanil, alfentanil and morphine) and an inhalational agent (such as halothane or isoflurane).

In addition, the child might also breathe in some nitrous oxide (known to many people as ‘laughing gas’). The state of anaesthesia was maintained with further intravenous drugs and inhaled gases.

For these cardiac operations, the patients were also given specific anaesthetic drugs to weaken or relax their muscles. This helped the anaesthetist to be able to place the breathing tube into the trachea and then allowed the surgeon to operate on the chest without tearing the normally tight muscles of the chest. These special drugs were known as muscle relaxants. They included pancuronium, vecuronium and atracurium.

INTUBATION

Intubation refers to the placing of one tube inside another. The intubation that was referred to in a pediatric cardiac case was called endotracheal intubation. In this process a tube was inserted into the patient’s trachea or windpipe, through either the nose or the mouth. The tube guaranteed a passage or ‘airway’ through which the patient could be ventilated. The tube also helped to prevent unwanted substances from going into the patient’s lungs. To make intubation easier, the child was given a muscle relaxant.

As a result, the child would not be able to breathe and therefore required artificial ventilation. (This ventilation delivered oxygen to the lungs and removed carbon dioxide, in the same way that normal breathing did, except that the breathing was done for the patient.) First, the anaesthetist would hold a rubber mask over the patient’s face, making an airtight seal. Then the anaesthetist would squeeze a special rubber bag that was attached by a rubber tube or hose to the mask. When this bag was squeezed, oxygen would be pushed from the bag, through the tube and mask, into the patient’s nose and mouth and down into the lungs. Once the muscle relaxant was fully effective, the anaesthetist would insert the breathing tube in through the patient’s nose or mouth and down into the windpipe or trachea. (In medical terms, this procedure is known as ‘performing tracheal intubation’.) Once this tube was positioned and secured (usually with some tape), the anaesthetist would use a machine called a ventilator to breathe for, or artificially ventilate, the patient’s lungs. This ventilation was delivered through the breathing (or endotracheal) tube.

Positioning, padding, prepping and draping the patient

The positioning, padding, prepping and draping of a patient could take half an hour.

POSITIONING

Most operations were carried out with patients lying on their backs. Occasionally, some operations were performed with the patient lying on his or her side. This meant that the patient had to be carefully turned and positioned, after the start of the anaesthetic and the placement of all the lines and monitors.

PADDING

The patient’s head and face and the lines would be padded for protection during surgery. Padding was not a sterile procedure and was done by the circulating nurse, anaesthetic nurse and anaesthetist.

In some cases, the anaesthetist would pack ice around the patient’s head and neck to cool the brain. This was done to protect the brain when there was to be a complete stoppage of both the heart and the heart-lung machine.

PREPPING

For heart surgery, the site of the operation (or 'operative field'), which was the chest, was then washed with a special antiseptic solution. The surgeon, or his assistant or the scrub nurse, would do this.

DRAPING

Because draping was a sterile procedure, it was done by the surgeon (or his assistant) and the scrub nurses. They placed sterile cloths or drapes over all but the operative field. A small, flexible screen would separate the patient's head from the surgical field. This screen would be draped with a sterile cloth to denote the barrier between the sterile surgical field and the patient's head, to which the anaesthetist would usually have access. This sterile drape was hung or draped in a manner to maintain the sterility of the area where the operation would be carried out.

The surgical phase

The surgical phase would start with the first incision and proceed until the completion of the operation. Pediatric cardiac operations were either closed or open procedures.

Closed-heart surgery

Closed-heart surgery was that surgery in and around the heart that did not involve having to stop blood flow to the heart. It therefore did not involve having to bypass blood around the heart or involve having to stop the heart from beating. Generally, closed-heart procedures were less risky than open procedures because the process of bypassing the heart did not need to be undertaken. Nonetheless these procedures did involve their own risks and some were as risky as or riskier than some of the simple open-heart procedures.

Open-heart operations

Open-heart surgery required the use of a cardiopulmonary bypass (CPB) machine. The CPB machine was a pumping device that diverted blood away from the heart, and returned it to the body at a point beyond the heart. Because the heart itself is essentially a pump, when it was stopped or blood was diverted around it, the CPB machine had to take over the pumping function of the heart. The CPB machine also allowed the blood that was pumped to pick up oxygen and be cleansed of carbon dioxide. These two essential functions were made possible through a membrane oxygenator that allowed oxygen to move into the blood and allowed carbon dioxide to move out of the blood.

The use of CPB was an important development in cardiac surgery. It has allowed surgeons to operate on the heart and major blood vessels while the patient's systems were otherwise maintained. However, a patient could not be maintained on CPB indefinitely.

A lengthy bypass would affect many aspects of a patient's system. The lungs would become wetter and the small airways would collapse. The liver and kidneys could be damaged. The heart could accumulate water and become swollen (or in medical terms 'edematous'). As a result, the heart could become less and less compliant and the heart muscle itself could also be damaged, contracting poorly, because of difficulties with techniques intended to protect the heart. (In medical terms, these techniques were known as 'cardiac

preservation'.) The patient's blood could also be damaged. Increased CPB times could also increase the risk of air in the cannula lines, creating an airlock in the patient's blood vessels.

Open procedures could also involve stopping the heart from beating for a while. This was referred to as total circulatory arrest (or TCA). While open procedures were considered the riskiest of the cardiac procedures, those requiring TCA placed the patient at greatest risk. When the beating of the heart was stopped, the CPB machine was also stopped and blood flow through the body was stopped. In a procedure known as deep or profound hypothermia arrest (DHA or PHA) the body was invariably cooled to as low a temperature as possible (usually around 16–20 degrees Celsius) and the head was packed in ice. Despite such measures, however, TCA was a time-limited procedure. Most medical experts agreed that a period of 30 minutes of TCA would not likely impair brain function and that 45–60 minutes was the safest maximum period of TCA allowed. Beyond that time, most experts agreed that the chances of brain damage or neurological impairment increased dramatically.

There were three stages to an open-heart pediatric cardiac operation. These were pre-bypass, on-bypass and post-bypass.

PRE-BYPASS

The pre-bypass stage started when the surgeon made the initial incision and then proceeded to open the patient's chest. Before doing this, the surgeon made it clear that he was ready to start and gained assurances that all other members of the team were ready. The patient's body might react to the initial incision in ways that could not always be predicted. The anaesthetist then needed to respond to these changes by increasing or decreasing the amount of anaesthetic or administering other drugs or fluids, depending on the patient's reaction. For this reason, it was essential that the rest of the team be alerted to and prepared for the surgeon's activities.

There were certain procedures the surgeon needed to perform before going on-bypass. These could be addressing palliative repairs that had been done previously, carrying out repairs that could be done without going on-bypass (thus shortening the length of the bypass) and finally inserting the cannulas into the heart (cannulation) and attaching them to tubing for connection to the CPB machine.

The major elements of the pre-bypass portion of the surgery were:

- repairs;
- heparinization;
- cannulation; and
- cardioplegia.

Repairs In either open or closed-heart surgery, it was at this point in the operation that the surgeon attempted to carry out some of the necessary repairs to the heart. (These repairs were briefly outlined in Chapter 2.) It should be again emphasized that these repairs were extremely difficult to execute, given that the surgeon was working on a very small, very variable structure that might be moving with every heartbeat and every breath if CPB was not being used.

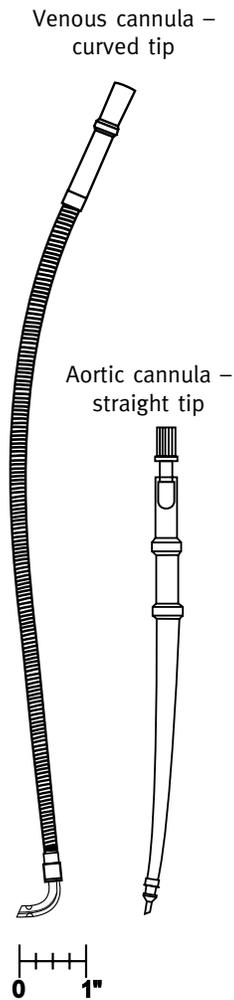


Diagram 3.3
Venous and
aortic cannula

Heparinization In order to go on bypass, the patient’s blood had to be treated with a drug called heparin to prevent it from clotting. If blood was passed through the heart-lung machine without heparinization, it would begin to clot immediately. This would be fatal to the patient. Before administering heparin, the perfusionists measured the child’s activated clotting time (ACT). After the heparin was given, a second ACT measurement was taken to ensure that the patient was fully heparinized. After this, the clotting time was measured at regular intervals during bypass to ensure that it stayed above a set limit. The patient could then be cannulated, cardioplegia could be given and CPB could be established.

Cannulation The pediatric cannulas were tiny catheters used to connect the patient’s heart to lines (or tubes) that were connected to the cardiopulmonary bypass machine (CPB). The cannulation procedure required the surgeon to insert the cannula into the major blood vessels (the inferior and superior vena cava and the aorta) on either side of the heart. The cannula that was inserted into the aorta was referred to as the aortic cannula, while the cannulas inserted into the inferior and superior vena cava were referred to as the venous cannulas. The venous cannula and the aortic cannula differed in shape to accommodate differences in the structure of the blood vessels into which they were inserted. It was important to carefully place the cannulas and the lines running to the CPB machine to ensure that they did not become dislodged. The aortic cannula, which connected the CPB machine via tubing to the aorta, was placed first, in case the patient needed to be transfused quickly. It was through this line that oxygen-rich blood was pumped. It was often the practice to place two cannulas in the vena cava, one in the SVC and one in the IVC. Oxygen-poor blood flowing from the body was then directed away from the heart, through these cannulas and to the CPB machine.

The actual process of inserting the cannula involved the following steps:

- inserting a suture thread around the portion of the blood vessel into which the cannula was to be inserted. This area was referred to as the cannulation site. Often in the case of aortic cannulation, two suture lines were placed around the cannulation site. Once this was completed, both ends of each suture line would extend away from the cannulation site. These lines were known as purse-string sutures.

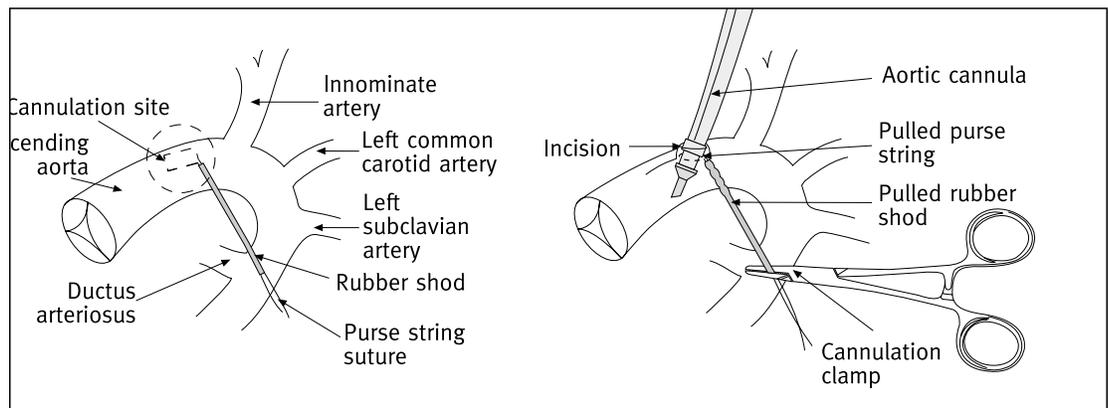


Diagram 3.4 Aortic cannulation

(left) Preparation of aortic cannulation site showing placement of single purse string sutures.
(right) Aortic cannulation site showing aortic cannula inserted and secured in the aorta.

- placing rubber sleeves, referred to as shods, over the suture line. These sleeves would facilitate the tightening of the suture lines at a later point in the cannulation.
- making an incision. At this point the surgeon would make an incision in the cannulation site with a scalpel.
- inserting the cannula. The tip of the cannula was then inserted through the incision into the blood vessel.
- tightening the purse-string sutures. The sutures were then tightened or snugged by pulling on them on the ends that extended through the shods. When they were tightened, they were held in place with clamps.

At this point the cannula would be connected to the line from the CPB machine.

Cardioplegia It was extremely difficult, if not impossible, to operate safely and quickly on a beating heart, particularly a tiny heart that might be beating at more than 100 times a minute. The heart therefore had to be stopped from beating. This was accomplished by the infusion of a high-potassium solution into the heart's coronary arteries, from a machine known as a blood cardioplegia device.

The stopped heart was deprived of oxygen and nutrient-rich blood and was at risk of damage. Injecting cooled oxygenated blood (that was mixed with the potassium solution) into the coronary arteries therefore provided the stopped heart with protection from this damage. The solution injected was known as a cardioplegic solution and provided what was known as myocardial protection. Because the cardioplegic mixture was extremely cold (approximately six degrees Celsius) it reduced the heart's metabolic state to the very lowest possible point once it had been arrested. Cardioplegia allowed the heart to maintain its energy stores and could also prevent the heart from beating for twenty to thirty minutes before an additional dose was required. During bypass, the EKG monitor would normally show a flat line. Any sign of electrical activity represented the need for further cardioplegia. It might be necessary to provide an additional dose of low potassium solution to maintain the arrest. To assist in this it was the perfusionist's role to remind the surgeon at intervals of approximately 20 minutes when the last cardioplegia had been provided. The surgeon decided, in consultation with the perfusionist, if another dose was to be given. The perfusionist would actually switch on the infusion, administer the solution and record the volume given.

ACIDOSIS

One of the conditions that often occur in children with congenital heart problems is acidosis. This is the accumulation of an abnormally high level of acidity, or low level of alkalinity, in the body fluids, including the blood. There are two general types of acidosis: metabolic acidosis and respiratory acidosis. Metabolic acidosis occurs when the body takes in too much acid, makes too much acid, or does not excrete enough acid through the kidneys. Respiratory acidosis occurs when the body retains carbon dioxide, which the body senses as an acid (carbonic).

Acid can come from increased production, usually of lactic acid, or when the body shifts into 'anaerobic' metabolism. This most often occurs when blood flow to the tissues decreases, and the tissues then shift from aerobic (with oxygen) metabolism to anaerobic (without oxygen) metabolism. When tissues are poor-

ly perfused with blood, they do not use as much lactic acid as they normally do; this also contributes to an increase in the amount of lactic acid in the blood. In addition, severe acidosis may itself lead to reduced blood flow to the tissues, because the acid impairs the heart's ability to contract normally.

As the acidosis becomes worse, the patient starts to breathe faster and take deeper breaths, as the body tries to compensate for the excess acid. Finally, the heart weakens and the patient may progressively lose consciousness.

There are a number of approaches to treating acidosis. These involve increasing blood flow to the tissues by strengthening the heart, countering the acidosis by treating the child with bicarbonate and providing general supportive treatment in the form of oxygen and fluids.

ON-BYPASS

Following cannulation and the administration of cardioplegia, the bypass machine was connected to the patient through the cannulas and took over the heart's functions. This was the start of bypass and was known as 'going on pump'. After going on pump, the surgeon might need to operate inside the heart (referred to as intracardiac) and would therefore need to stop the heart.

The surgeon would take a special instrument, called an aortic cross-clamp, and use it to pinch or seal off the aorta. No blood from the heart could therefore go past the clamp and out to any part of the body, including the brain. The blood supply to the body and brain was then entirely from the CPB machine via the aortic cannula, with blood returning to the CPB machine via the venous cannulas, without passing through the heart's ventricles. The length of time that the cross-clamp was completely applied to the aorta would be recorded. This time would be known as 'cross-clamp time'. Another term was 'total ischemic time', which meant the time that the body was without blood flow and oxygen delivery during periods of circulatory arrest and profound hypothermia. (In medical terms, lack of blood flow is known as 'ischemia'.)

The heart would then be stopped and preserved with cardioplegic solution. The end of 'cross-clamp time' would be when the cross-clamp was partially or completely released. Even partial release of the clamp would allow some oxygen-containing blood to flow to the brain and other organs.

Blood Throughout the bypass portion of the procedure, blood would accumulate in the surgical field. The surgeon or his assistant would suction this blood away to allow the surgeon to see the operative site. This blood was filtered, added to the reservoir in the CPB machine and returned to the body. When required, additional blood could be transfused into the patient, through either the CPB pump or the IV lines. When necessary, bags of packed red blood cells were brought into the OR. These bags would usually be kept in a special refrigerator down the hall from the operating room. Before any blood was administered to the patient, it would be double-checked by members of the OR team to ensure that it matched the patient and the patient's blood type. Some blood products, such as fresh frozen plasma, would have to be thawed if they were required, while others, such as blood platelets, would have to be kept warm and agitated gently, to prevent them from congealing.

The HSC did not, as a matter of course, maintain a large supply of blood at the hospital. Blood products were kept by the Red Cross at its Winnipeg facility. Whenever a surgeon ordered blood products for an operation, the hospital had to request those products from the Red Cross ahead of time. The Red Cross, in turn,

would approve the request and then arrange for delivery of the blood to the hospital in time for the procedure. If an emergency occurred and blood was needed quickly, the hospital did have a small supply of blood it could use. However, occasionally it was necessary to arrange for blood products to be delivered specially from the Red Cross—often by taxicab.

Throughout the operation the patient's blood would be tested (usually hourly) to check the hemoglobin concentration. The times when the blood was drawn and when the tests were conducted were usually noted on the chart.

Ventilation The anaesthetist was responsible for ensuring that a patient was properly ventilated during the operative procedure. Once the patient was on bypass, the anaesthetist would stop ventilating the patient, since the blood would receive its oxygen from the CPB machine. During these times, the ventilator would be turned off and the oxygen supply from the anaesthetic machine would be turned down, with just a small amount of oxygen being delivered down the endotracheal tube. With the ventilator turned off during surgery, the lungs would not balloon into the area around the heart and block the surgeon's view of the heart.

Before weaning The process of discontinuing bypass and allowing the heart to take over the pumping of blood throughout the patient's system was referred to as 'weaning from bypass'. In order for the patient to be weaned from bypass successfully, everyone involved in the operation—the surgeon, anaesthetist, perfusionists and nurses—had to work in a co-ordinated fashion.

Before weaning from bypass, the anaesthetist would suction the endotracheal tube, to remove any secretions that might have accumulated. In addition, a drug might be given to those patients whose airways might be sensitive to suctioning. (In medical terms they were said to have 'reactive airways'.)

Monitoring lines After an operation was completed, it was vital for the doctors and nurses caring for the child to be able to monitor the state of performance of the child's heart. To facilitate this, the surgeon would place monitoring lines in the child's heart before closing the chest. These monitoring lines were referred to as 'transthoracic lines' and were eventually connected to monitors in the ICU.

The surgeon would have to decide whether or not to place these monitoring lines before weaning the patient from bypass or if the lines could be placed after bypass was discontinued.

Usually the surgeon would insert the transthoracic lines in the atria and the pulmonary artery after decannulation (removing the cannula). These lines measured atrial and pulmonary artery pressures. The scrub nurse would hand the surgeon a sterile set of high-pressure lines. After inserting one end of the line into the heart chamber, the surgeon would hand the other end of the line to the anaesthetist, who would connect it to a transducer. The line with the transducer attached would then be available for the ICU staff to use when the patient arrived in the unit.

WEANING FROM BYPASS

Before the patient was weaned from bypass, the surgical team had to ensure that the patient was in optimal condition. Close attention had to be paid to the monitors and the condition of the repair. The anaesthetist had to ensure that the patient was well anaesthetized and relaxed. The anaesthetist also had to be ready to deal with any consequences that might arise from coming off bypass.

This included having special drugs ready to support the circulation. If there were concerns about the heart's ability to contract forcefully, inotropes (drugs that helped the heart to contract) might be given. If the patient's blood pressure was too low, the anaesthetist might administer a vasoconstricting drug, such as neosynephrine, to raise the pressure. If the blood pressure was too high, vasodilators (drugs that dilated blood vessels) would be used to dilate the vessels and thereby reduce the pressure that the heart was pumping against.

COMING OFF BYPASS

Patients were 'taken off' bypass in a gradual but sequential manner. The patient had to be rewarmed to normal temperature, the heart once more had to start beating, ventilation of the patient was restarted, the perfusion was brought to an end, pacing wires were inserted, the heparin was reversed and the heart canulas were removed from the patient.

REWARMING

The rewarming period was begun by increasing the temperature of the blood being perfused through the arterial line to approximately 8–10 degrees Celsius above the venous blood temperature. Often vasodilators were given to produce a smooth and even rewarming process.

STARTING THE HEART

Before taking the patient off bypass, the surgeon needed to start the patient's heart beating again at a rate that was appropriate. In some cases, the heart would not beat fast enough. In other cases, the heart might need to be stimulated (with a small electrical shock) in order to start beating.

RESTARTING VENTILATION

Ventilation was usually restarted during rewarming, once the heart was closed.

STOPPING PERFUSION

When the cardiac action had reached a satisfactorily vigorous state, bypass would gradually be discontinued. Once the heart had taken over from the machine, the venous lines connecting the CPB to the heart were clamped.

INSERTION OF PACEMAKER WIRES

The surgeon would insert pacemaker wires at this point. The pacing wires were put in, even if the operation seemed to have gone well. Drugs might be administered to help increase the heart rate.

REVERSING THE HEPARIN

With the patient still heparinized, the team would then wait and monitor blood pressure and other vital signs. At this point an echocardiogram might be done to assess the repair. If all signs were appropriate, protamine would be administered to reverse the heparin. When the protamine was given, the anaesthetist needed to advise the perfusionists, because the perfusionists had to stop suctioning blood from the patient's

chest cavity. If they did not, blood containing protamine might then be taken into the pump, with the risk of a blood clot in the pump.

DECANNULATION

When the surgeon was satisfied with the movement of blood through the heart, with the pressures in the chambers of the heart, and the blood pressure and heart rate (medically referred to as hemodynamics), the perfusion cannulas could then be removed. The cannulas were still in place when the protamine was given. However, with the administration of protamine, the chance of clots forming around the cannulas increased and the cannulas had to be removed.

The surgeon would first take out the venous cannulas, leaving the aortic cannula as the last to be removed. It was important that the surgeon inform the operating team when he was about to remove the cannulas, as this could cause hemodynamic changes. In addition, there could be bleeding and the patient might need to be transfused quickly through the aortic cannula.

POST-BYPASS

Once the cannulas were removed, the patient was then completely separated from the bypass machine and was considered as being 'off pump'. The surgeon would then check the suture lines for any bleeding and ensure that any shunts or other tubes were patent. If all was satisfactory, he could then begin to close the patient's chest. A chest X-ray might be taken at this time to give the surgeon and anaesthetist information about the condition of the lungs and the placement of tubes and lines. At the same time, the nursing staff would complete their charting and phone the intensive care unit to inform them as to the expected time of arrival of the patient and the patient's general condition.

The post-surgical phase

In the post-surgical phase, the patient would be prepared for transport to the intensive care unit. Once the anaesthetist and surgeon had determined that the child was stable enough to transfer, the patient would be moved to the unit and cared for there.

POST-SURGICAL CARE

The NICU and the PICU

After an operation, the patient was taken to an intensive care unit. There were two ICUs where pediatric cardiac cases might be sent: the neonatal intensive care unit (NICU) and the pediatric intensive care unit (PICU). Both units were staffed by specially trained intensive care nurses and each had a doctor on duty who specialized in intensive care medicine.

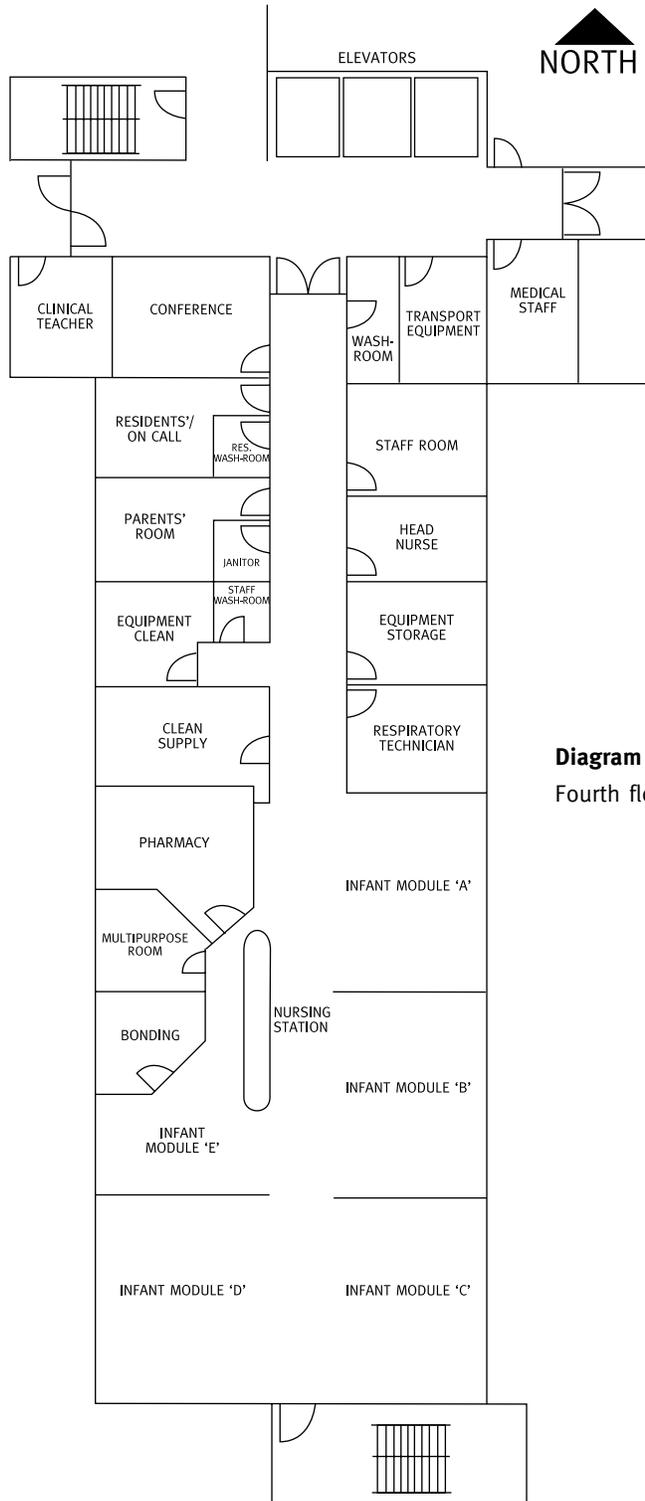


Diagram 3.5 Neonatal intensive care unit
Fourth floor, Winnipeg Children's Hospital

The NICU

The neonatal intensive care unit (NICU) at the Health Sciences Centre was built in 1985 on the fourth floor in the older part of Children's Hospital, one floor above the Pediatric Intensive Care Unit and the Children's Hospital's operating rooms. The NICU was an eighteen-bed unit that provided intensive care for babies less than six weeks of age.

The NICU medical staff consisted of doctors, referred to as neonatologists, who specialized in the care of the critically ill newborn. During 1994, staff neonatologists were on call in the NICU every two months for a week at a time. On-call neonatologists were responsible for all medical care within the unit, including being present for briefings when new patients were admitted, as well as monitoring any critically ill babies who needed to be managed closely.

Neonatologists in the NICU also had responsibility for the care of newborns in the intermediate care nursery at the Women's Pavilion. Staff neonatologists were expected to provide medical care on the Pavilion's labour floor and in the resuscitation room if required. To meet the demands associated with those responsibilities, there were two neonatologists on call in the NICU at all times, one of whom was usually a resident.

Pediatricians whose patients were transferred into the NICU continued to be involved in their patients' care, but the NICU medical team essentially took over treatment of the child.

The PICU

The pediatric intensive care unit (PICU) was located on the third floor in the south wing of the old part of Children's Hospital, just down the hall from the operating room. The PICU had a total of thirteen beds: eight for acute care patients and five for chronic patients. The unit dealt with children aged from six weeks of age to eighteen years of age.

Critically ill patients received one-to-one nursing care, while for other less ill children the ratio was two-to-one. The area for chronic patients was also called the pediatric extended care unit (PECU). This was separated from the rest of the PICU by a door.

Both the PICU and the NICU were staffed by persons with specialized training and dealt with children with a wide range of serious medical problems. Care was not restricted only to children who had undergone pediatric cardiac surgery. In addition, while certain procedures could be performed in the units, the units had to be specially prepared—for example, by obtaining all necessary equipment.

Preparing for intensive care

Up to one hour might pass from the time the patient's chest was closed until the patient was delivered to the intensive care unit. A bed would be brought from the ICU for the patient, rather than moving the patient to a stretcher and then to a bed in the ICU. The patient was carefully moved from the operating table to this ICU (portable) bed. Part of the difficulty in moving the patient was that each patient usually had six or more monitoring lines. The OR staff would detach the lines from the monitors and then reattach them to portable monitors. After this was done, the anaesthetist needed to check the various monitor readings and alter drug therapies in response to any changes in the patient's condition.

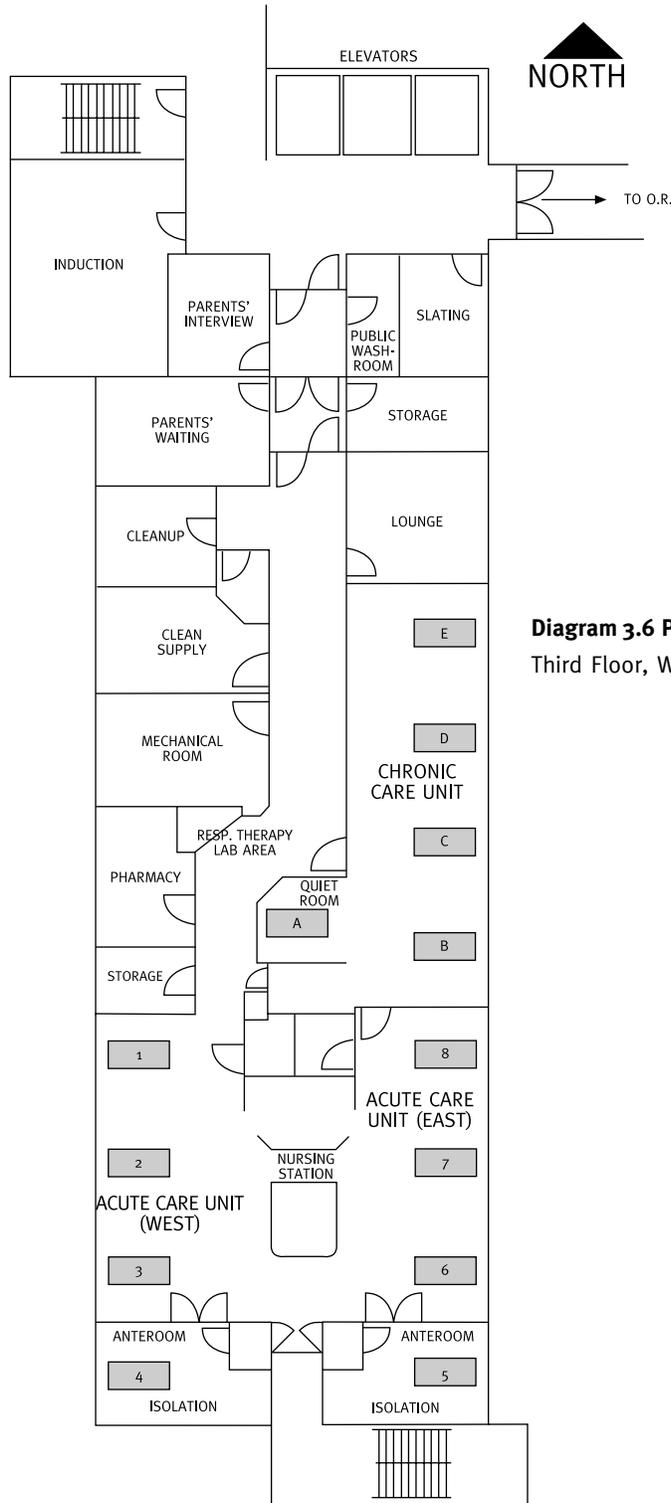


Diagram 3.6 Pediatric intensive care unit
Third Floor, Winnipeg Children's Hospital

Before the patient left the OR, the nurses would phone ahead and brief the ICU as to the outcome of the operation and what preparations needed to be made to receive the patient. The transfer of the patient from the operating room to the ICU was done under the supervision of the anaesthetist, who continued to monitor the patient until the ICU staff assumed care and responsibility.

Transfer to the Intensive Care Units

After the patient arrived in the ICU, an assessment was quickly made to determine stability of the child's condition. All lines were connected to permanent monitors in the unit. Some patients might be breathing on their own by that time and could have the ventilation tube removed (or be 'extubated'). In more complex cases, the patients would continue to need artificial ventilation. After vital signs were measured, reports were given to the ICU staff. If the patient was stable, the operating team would hand over responsibility for the child. If the patient was not stable, the operating team would usually continue to participate in care.

Responsibility for care

Only medical staff from the intensive care unit could write medical orders for patients transferred into the ICU. This policy was put in place in order to avoid the potential for confusion and danger that could arise in the event of conflicting directions written by separate doctors. Private pediatricians or consultants were allowed to note in the chart what they wanted done for their patients, but before any treatment was carried out by a nurse or a resident in the unit, such a request had to be confirmed by a staff doctor. If there was disagreement over a particular course of treatment, doctors, as professionals, were expected to work their problems out. However, if there was ongoing disagreement, the unit doctors would make the final decision about treatment.

