Operating room design at The Cleveland Clinic Foundation

Cardiothoracic surgery unit

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■ The cardiothoracic operating room (OR) suite in The Cleveland Clinic Foundation is part of a complete cardiac unit. A catheterization laboratory and coronary intensive care unit (ICU) are below the OR level, and the postoperative ICU is directly above the OR level. Cardiology and postoperative wards are on other levels of the same building. The design of the OR is related in part to the function of the entire facility. The authors used fixed locations in the OR for surgical and anesthesia equipment. Thus, standard equipment is built-in and floor space is put to better use. Also, specially designed fixtures for infusion equipment are employed to facilitate both intraoperative management and patient transport between the OR and the ICU.

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THE DESIGN of the operating rooms (ORs) and intensive care units (ICUs) has a major effect on the daily work patterns in these areas. Effort spent in creating efficient designs and selecting the appropriate equipment may allow the suite to function without major renovation for 10 or more years. Conversely, design flaws apparent only after the suite is being used are difficult to rectify and are a persistent nuisance.

The evolution of OR design is slow, since the great expense and long expected life discourage experimentation. Criteria for good design are difficult to identify, and there are few objective measurements that can be applied to evaluate the final result. Despite the importance of the physical environment of the OR and ICU areas, there is little published material about their design. This paper identifies some criteria for a hospital section devoted to the care of patients undergoing cardiac or thoracic surgery and our implementation of methods to meet these criteria.

An OR must contain facilities for anesthesia, surgery, and nursing. Adequate space and outlets for utilities are the minimum requirements. One design approach is to regard all equipment as mobile both within the OR and from OR to OR. At the other extreme, the equipment may be regarded as an intrinsic part of the OR; while the apparatus may be removable, there are fixed locations for all equipment, which is built-in wherever possible.

Regardless of the design philosophy, all ORs for cardiac surgery contain the same general classes of equipment. There must be an adjustable OR table, surgical lights, storage space for consumables, a defibrillator, an electrocautery generator, an anesthesia machine, cardiopulmonary bypass equipment, and a source of temperature-controlled water for the heating blanket and bypass heat exchanger. Power and other utilities must be sup-

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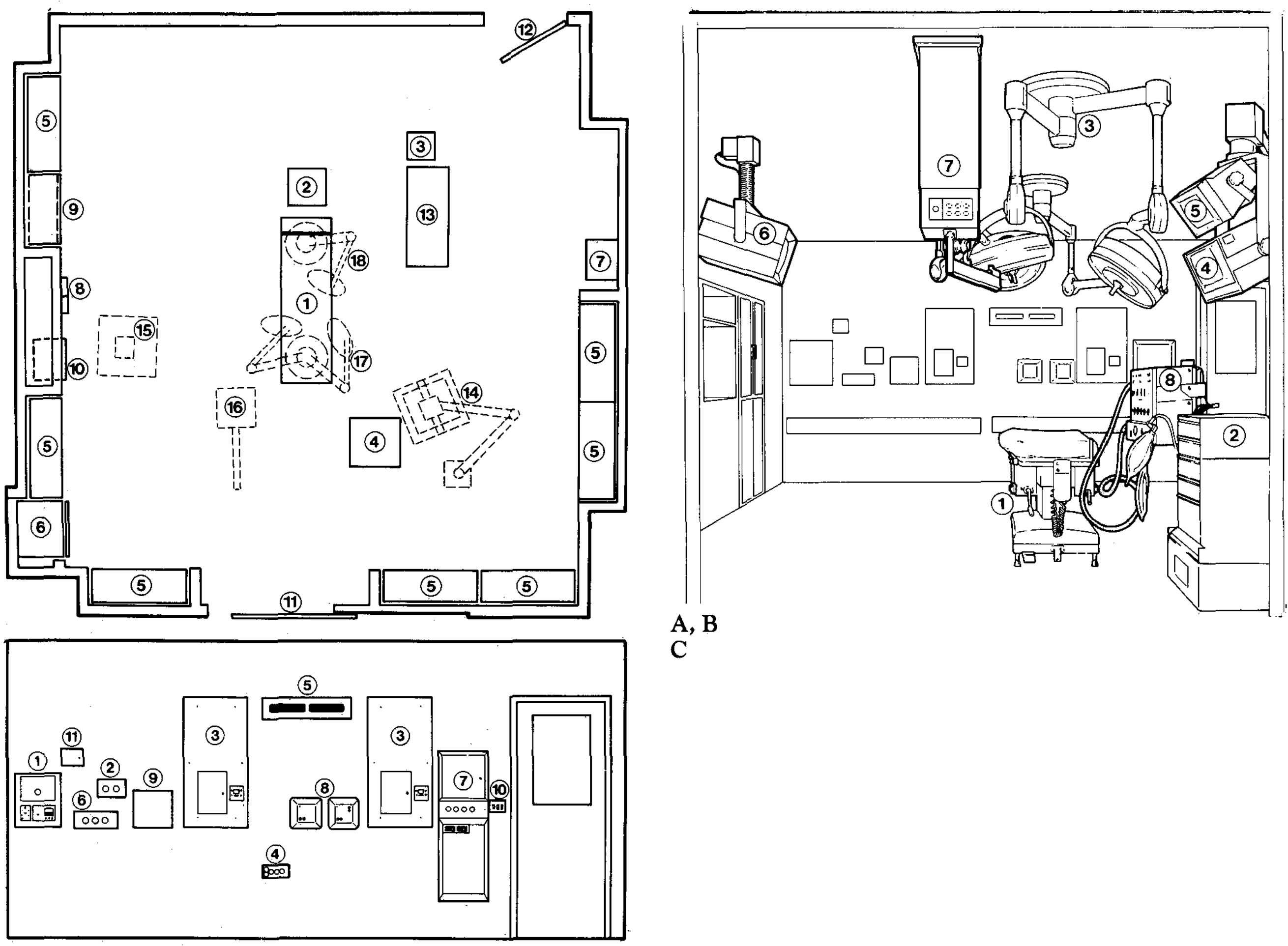

A, B
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FIG. 1A. Floor plan of an OR. 1 = OR table, 2 = surgical utility pedestal, 3 = perfusion utility pedestal, 4 = anesthesia machine pedestal and services, 5 = built-in cabinets, 6 = built-in warming cabinet, 7 = laboratory data printer, 8 = area for telephones, 9 = writing shelf and paperwork area, 10 = electrocautery generator, 11 = main door for patient transport, 12 = rear door to scrub area, 13 = area occupied by perfusionist and perfusion equipment, 14 = main monitor and display unit and the laboratory CRT display mounted on an adjustable arm, 15 = slave monitor display, 16 = ceiling-mounted column for the infusion rack, 17 = adjustable surgical lights, with two light heads on the mount above the head of the table, and 18 = a single light head on the mount above the foot of the table. FIG. 1B. View of OR from patient-entry door. 1 = OR table, 2 = anesthesia machine, 3 = surgical lights, 4 = main display and control unit for the monitor, 5 = laboratory CRT display, 6 = slave monitor display, 7 = ceiling-mounted column for the infusion rack and utilities, and 8 = patient ventilator. FIG. 1C. OR rear wall and fixtures. 1 = controller for heated and cooled water for the OR table warming blanket, 2 = room temperature and humidity gauges, 3 = transformers and indicators for isolated electrical power, 4 = electrical outlets, 5 = digital clock and timer, 6 = outlet and controller for compressed nitrogen to drive the surgical saw, 7 = controller and valve panel for heated and cooled water for the perfusion apparatus, 8 = surgical light controllers, 9 = patient monitor interconnect access panel, 10 = two-way relay switches for overhead lights, and 11 = warming-blanket shut-off valves.

plied. Provisions must be made for occasional use of other equipment, specifically intra-aortic balloon pumps and extracorporeal ventricular-assist devices. Equipment for conduction mapping, intraoperative echocardiography, and high-fidelity pressure recordings must also be accommodated.

When planning the layout of the ORs, we considered whether fixed or movable locations for the equipment would be best. In our previous ORs, the equipment was always used in specific locations; thus, there was no advantage to having movable equipment. The use of built-in equipment and fixed locations permitted cabling and plumbing to be routed beneath the floor or above the ceiling, allowing better use of floor space and easier cleaning, and minimizing the potential for malfunctions due to cabling damage and connector wear. Once the decision for fixed locations was made, specialized fixtures for infusion equipment with provisions for easy patient transport became practical.

DESCRIPTION OF THE FACILITY

The facility, including the ORs, the postoperative ICU, the acute laboratory, and offices, was constructed within a space limited by adjacent structures. An area of 58,000 square feet on each of two floors was available. This area now includes anesthesia and nursing offices, conference rooms, on-call rooms, a library, an engineering area, stockrooms, and preparation areas for sterile supplies. The ICU is located directly above the OR area; the floors are separated by a 5-foot-high utility space. The facility is intended to accommodate 5,000 patients undergoing cardiac or thoracic surgery per year. There are 11 operating rooms, 5 induction rooms, 45 ICU beds, and 6 beds for patients admitted on the day of scheduled surgery. A cardiology level, including a catheterization laboratory and a coronary ICU, is located directly below the OR level. A pair of elevators is used exclusively for patient transport between the cardiology level, the OR level, and the postoperative ICU level.

The ORs vary slightly in size, but all correspond to a basic floor plan (*Fig. 1*) and contain the same equipment (*Table*). The standardized equipment includes an electrically operated bed, an electrocautery generator (*Fig. 2*), an anesthesia machine with an automatic ventilator, a ceiling-mounted column for infusion apparatus, a wall-mounted controller for the heating and cooling blankets, and the cardiopulmonary bypass apparatus. Outlets for power, gases, temperature-controlled water, and other utilities are installed near the equipment to be served, either at the wall or in one of three utility pedestals. All cabling and plumbing for the pedestals are routed beneath the floor.

The electrically controlled OR table can be wheeled out for cleaning and used to transport patients from the induction room to the OR. Power is supplied from a "shoe" in the floor. The table locks into this shoe at a fixed location in the OR or induction room. Consequently, the table can be rotated so it is angled for entry to and exit from the OR. The table is occasionally rotated for the convenience of the surgeon performing endoscopy, but for all cases a single orientation of the OR table is satisfactory.

A utility pedestal is built into the floor at the foot of the OR table. Water for the bed heating blanket is piped beneath the floor from the wall-mounted controller to this pedestal. The pedestal also contains connectors for the electrocautery current, as well as the foot control switch and grounding pad; the cables from these connectors are routed in a conduit beneath the floor to the wall-mounted electrocautery generator. The pedestal also supplies electrical power, vacuum, and pressurized nitrogen for pneumatic equipment. The defibrillator is mounted on the pedestal, which required special fabrication of longer cables for both the internal and external paddles.

A utility pedestal that serves the cardiopulmonary bypass apparatus is built into the floor to the right of the foot of the table. This pedestal contains the controller and outlets for temperature-controlled water used in the heat exchanger. It also provides outlets for oxygen, air, carbon dioxide, and electrical power, as well as an inlet for the waste-gas scavenging system. A switch to activate the wall-mounted timer is incorporated into the perfusion pedestal. Connections to the bypass apparatus are made with short flexible cables and remain in place. The bypass

TABLE
LIST OF EQUIPMENT AND MANUFACTURERS

Operating table and power shoe	Model RC-2080 American Sterilizer Co. (AMSCO)
Surgical lights	Polaris American Sterilizer Co. (AMSCO)
Anesthesia machine	Modulus Ohio Medical Products
Ventilator	Model 2000 Engstrom
Electrocautery	System 5000 Bard-Davol
Warming-blanket controller	Model ORC-4401 Gaymar Ind.
Pneumatic tube system	Blood Transport System Colombo Sales & Engineering
Patient monitor	Model 7000 Marquette Electronics
Warming cabinet	Model 5520 Castle-Sybron
Perfusion pedestal equipment	Model 5745 Pemco Inc.

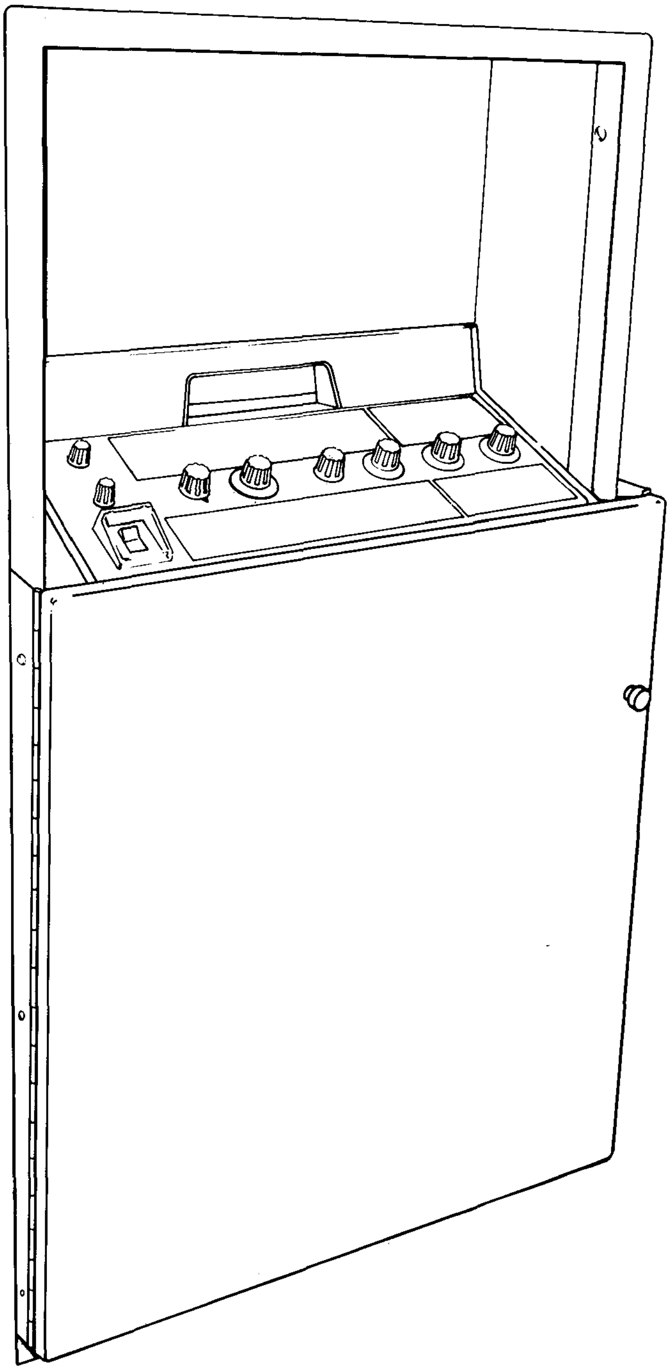

FIG. 2. Detail of electrocautery generator installation. The cabinet is built into the wall. Electrical connections are in the bottom of the cabinet. The control lines and electrocautery-current cable run through a metal conduit beneath the floor to the utility pedestal at the foot of the OR table. The hinged door permits removal of the generator for service. The generator output must be specifically tuned for the electrical characteristics of the cable in each room.

apparatus is arranged as a single assembly, and, when this unit is out of the OR, the floor is clear for cleaning.

The anesthesia machine is bolted to a pedestal to the right of the head of the OR table. The pedestal has front and rear electrical outlets and rear outlets from the hospital gas-distribution system for oxygen, air, and nitrous oxide. Connectors to a regulated vacuum and to the scavenging system are also incorporated into the pedestal. Short external hoses are used to connect the anesthesia machine and pedestal so that the entire unit may be removed for major service.

The anesthesia machine itself contains regulators for anesthetic gases, mounts for gas tanks, gauges, and a fail-safe system that removes nitrous oxide should the oxygen supply fail. The machine also functions as a chassis for mounting the ventilator and monitoring equipment and provides drawers and a work surface. The ventilator incorporates flow meters and a proportional gas mixer that is mechanically limited to no less than 20% FIO_2. A vaporizer is mounted on the ventilator. The gas circuit is non-rebreathing and the expired volume is captured and measured within the ventilator; this expired volume is displayed, and alarm limits for expired volume and inspiratory pressure are routinely used.

The electronics chassis, which contains input amplifiers for the monitoring system, is mounted on the side of the anesthesia machine. Inputs include an ECG (limb leads and a V lead), four transduced pressures, two thermistor temperatures, and thermistor inputs for thermodilution cardiac outputs. A four-channel chart recorder also is mounted on the anesthesia machine. The electronic components are connected with a cable to the main monitoring and display chassis, which is suspended from the ceiling above the anesthesia machine. A slave monitor display screen is suspended from the ceiling on one side of the OR. Cabling to the remote slave monitor runs above the ceiling panels. Each of the 11 operating room monitors and 45 ICU monitors operates independently, but the data from each monitor are available at a central location in the engineering area and at a second location in an ICU office. From these areas, recordings for research studies and limited troubleshooting of the monitors can be done.

Samples for blood gas, hematocrit, serum sodium, and potassium ion concentration determinations, as well as other acute-care laboratory tests, are sent to the laboratory from the OR through pneumatic tubes. The sending chamber for the pneumatic tube system is located near the OR service door. Samples are sent in carriers and arrive in the laboratory approximately 5 seconds after leaving the OR. The carriers are returned to the OR

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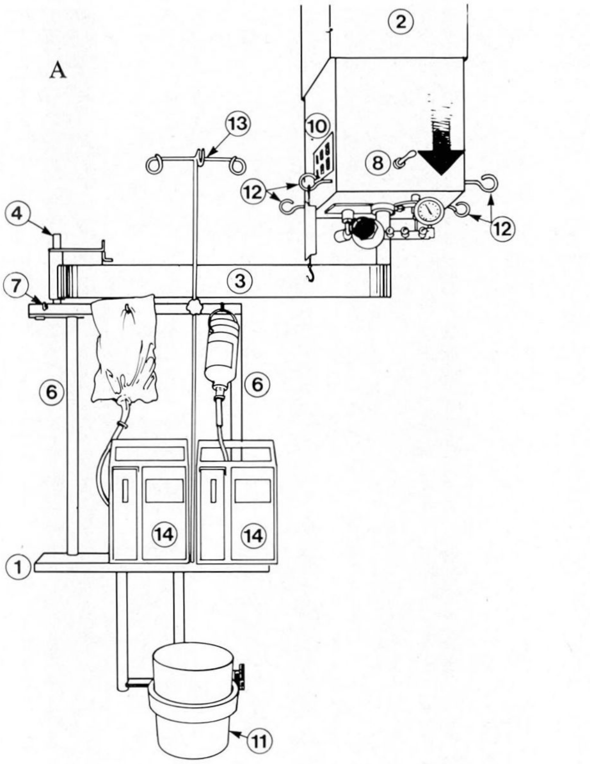

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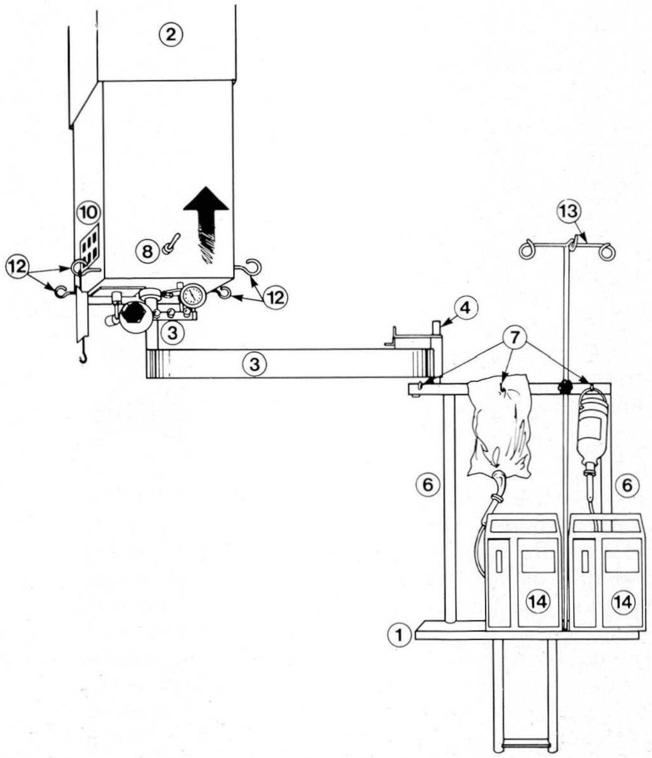

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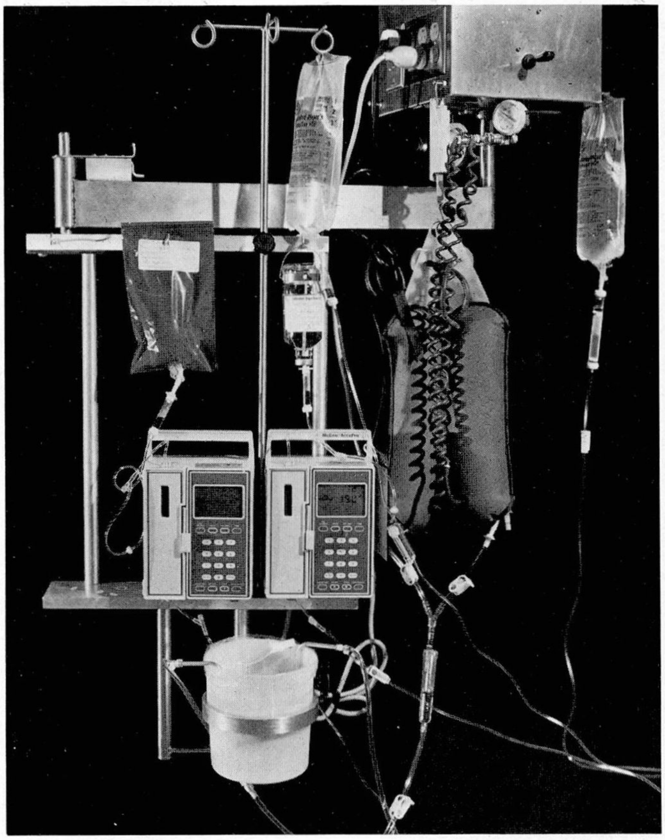

FIG. 3A. The infusion rack. 1 = the rack, 2 = ceiling-mounted column, 3 = rotating arm, 4 = rotatable detachable coupling, 6 = vertical bars for attachment of up to five infusion pumps, 7 = hooks for hanging infusion bags, 8 = valve handle used to control the internal pneumatic cylinder that determines column height, 9 = air-pressure regulator and manifold for operating pneumatic infusion pumps, 10 = electrical outlets, 11 = bracket and ice bucket used for the cardioplegia heat-exchange coil, 12 = additional stationary IV hooks, 13 = vertically adjustable IV post, and 14 = infusion pumps. FIG. 3B. The arm and rack as rotated for mounting onto the ICU bed. FIG. 3C. Infusion rack and column. The cardioplegia system is shown. Cold cardioplegia solution is pressurized by pneumatic infusion pumps supplied from the regulated air-pressure source, chilled by passage through an aluminum coil in the ice bucket, and passed through a bubble trap.

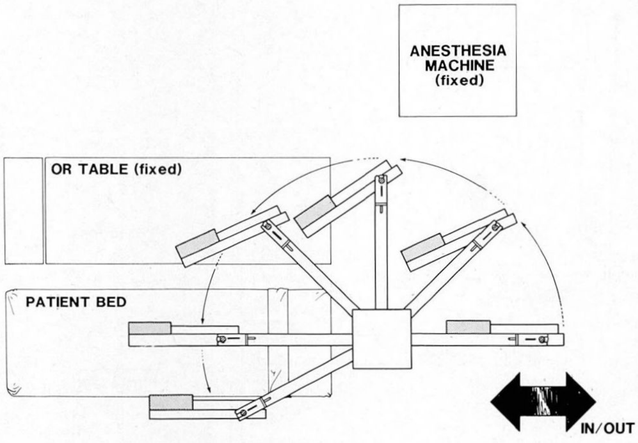

FIG. 4. Rotation of the infusion rack and column arm for transfers. To transfer the infusions to the ICU bed in the OR at the end of the surgical procedure, the column is raised to its highest position. As the column arm rotates, the rack also rotates at its mount to the column arm. When the rack is above the left side of the ICU bed, the column is extended downward, lowering the rack onto mounting posts on the side of the bed. Once the rack is resting on the bed frame, it is unlatched from the column arm. The column is then returned to its highest position, and the arm is rotated out of the way. The patient may then be transported.

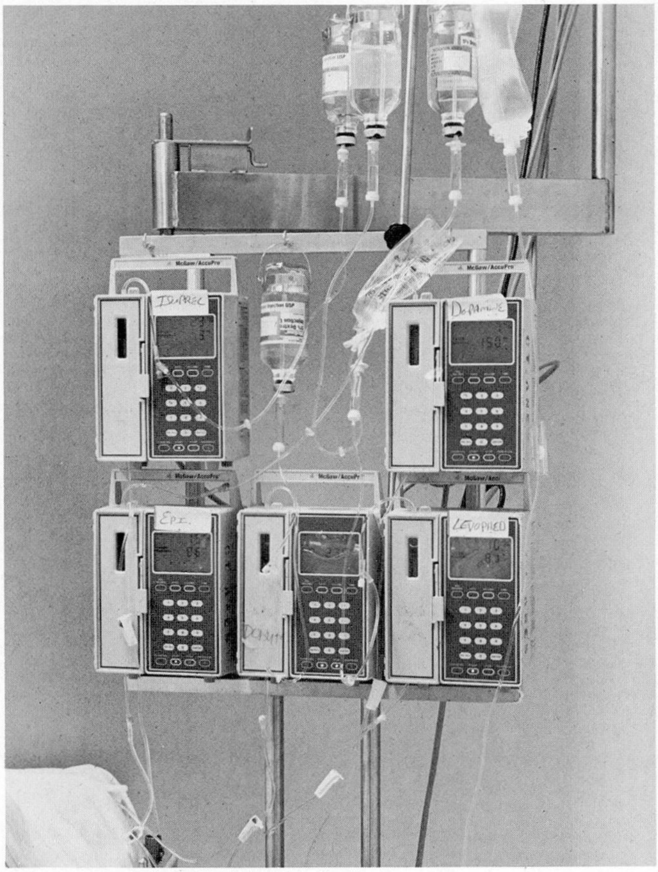

FIG. 5. The infusion rack in the ICU. The rack is raised from the bed by a ceiling-mounted pneumatic column, as in the OR. Posts for mounting the infusion rack are visible. Despite transfers, the rack always remains in approximately the same position relative to the patient, minimizing the tangling of infusion lines.

through the same tube system. Results are accessible via a CRT terminal mounted above the main monitor display, which is visible to the anesthesiologist, and a wall-mounted printer near the perfusionist's area. The results are typically displayed within 5 minutes after sending the sample.[1]

A specially constructed ceiling column supports a rack for infusions mounted to the left of the anesthesiologist (*Fig. 3*). The column can be raised and lowered by a lever that controls gas flow to a pneumatic cylinder within the column. This apparatus serves three functions: it supplies utilities, supports all IV infusion materials, and mechanizes the transfer of infusion materials with the patient to and from the ICU.

Electrical power and compressed air are brought from above the ceiling through the column to outlets at the lower end of the column. A rotatable arm at the bottom of the column terminates in a mechanical coupler, to which is mounted a rack. This rack has posts to mount up to five infusion pumps and has hooks for mounting fluid bags. All infusion equipment is mounted on this rack while the patient is in the OR.

To transfer the patient to an ICU bed after an operation, the rack is rotated until it is over the left side of the ICU bed (*Fig. 4*) and the column is lowered so the bottom of the rack fits onto mounting pins on the side of the bed. The rack is then detached from the arm and column. The infusion pumps and IV fluids remain attached to the rack and are transported with the patient to the ICU. A similar column-and-arm assembly in the ICU is used to lift the rack from the bed and to support the rack and infusion materials during the patient's ICU stay (*Fig. 5*).

A manifold with quick-connect fittings, a compressed air-pressure regulator, and gauge are mounted on the column (*Fig. 6*). The pressurized air facilitates use of the pneumatic blood-pump bags for infusion of blood or cardioplegic solution.[2,3]

The cabinets for anesthesia and surgical supplies are built into the walls and are constructed of stainless steel with glass doors.

In each OR, there is an outlet that supplies disinfectant solution and an inlet for a high-volume vacuum system for sweeping and removing the disinfectant solution. This system is used for cleaning the floors.

There are two large elevators for patient transport, which run only to three floors: the cardiology level, OR level, and postoperative ICU level. These elevators (13 feet deep and 7 $\frac{1}{2}$ feet wide) comfortably accommodate a patient bed, intra-aortic balloon pump, and an extracorporeal assist device, along with medical personnel. In each elevator there is an emergency drug kit, a portable defibrillator, and emergency lighting. There is an electrical outlet for the defibrillator, so the defibrillator battery remains charged without specific maintenance.

ASSESSMENT

In the 14 months the new facility has been in use, approximately 5,000 patients have undergone cardiac or thoracic surgery. The change to fixed locations for the equipment has been well accepted and has simplified the preparation of the OR.

Sometimes the cardiac patients require other major operations such as bowel resection, peripheral vascular procedures, and plastic surgery, which are performed in these ORs without difficulty. With this experience, we now believe that when designing a suite with more than three ORs, designating some of the rooms for specific classes of cases will provide real benefits, especially when specific equipment is built in.

Once the decision to provide fixed locations for major equipment is made, it becomes practical to use a mechanized rack to support the infusion equipment. This has eliminated the use of IV poles in the OR and minimized their use in the ICU. Transfer of patients from the OR table to ICU beds has been facilitated. Subsequent transport and reception of patients in the ICU are easily and safely managed with a minimum number of personnel. The emergency transfer of patients from the ICU to the OR is generally smooth since the infusion lines are more easily maintained.

There are no required carts for equipment, no cables or tubing on the floor, and no IV poles. This permits thorough and rapid cleaning.

We have saved an appreciable amount of usable floor space near the OR table. The floor area is approximately 20% less than our previous ORs. The current size is adequate to accommodate the teaching program and to comfortably permit concurrent use of two pieces of movable but bulky special equipment such as color-flow Doppler recorders and recorders for transvalvular pressure measurement.

In this facility, there is little clutter associated with instrumentation and equipment. As we manage more technology for treating patients undergoing surgery, it is important to avoid becoming physically overwhelmed by cabling, connectors, and wires. Currently, we are able to provide an environment where the typically complex case can be managed without distraction or inconvenience caused by the equipment. Thus there is time and attention available for safely testing and applying new technology.

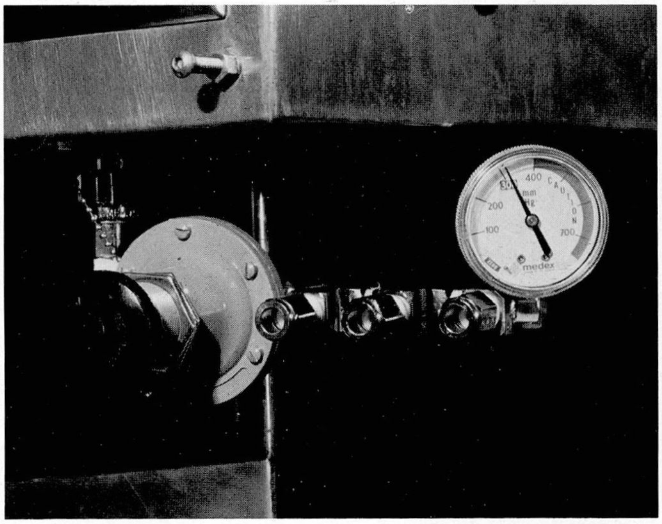

FIG. 6. Detail of the infusion and utility column. The regulator and pressure gauge, with the three-outlet manifold, supply pressurized air for infusion pumps.

Of the features built into these ORs, there are two that we do not recommend. The main monitor is mounted on an adjustable arm; a fixed arm would serve as well and would have been less expensive. Also, because modern monitors provide most of the functions once requiring a central station and because of reduced emphasis on arrhythmia analysis, central monitoring stations for nursing have recently been regarded as unnecessary.[4] The central stations in our system were intended to be used for the diagnosis of technical problems by centrally located technicians. However, minor problems usually are handled by the nurse or physician at the bedside. Correction of problems that do require a technician usually involves evaluation of the transducers or other connections to the monitor, so remote diagnosis is rarely practical. We also thought the central station would facilitate research projects by remotely recording data from the monitors. This application is not realistic, however, since most research requires close interaction with the data-collection process.

By contrast, the column-and-rack assembly has met most of our expectations. The intraoperative use of this system has permitted organization of the infusions required in complex anesthetics.[5] Attaching the rack to the ICU ceiling column arm is not as easy as we would like, since reasonably accurate alignment of the bed and arm is required while the rack is attached. A coupling that is more tolerant of misalignment would be a worthwhile improvement if the mechanism is not too elaborate.

This equipment was designed, assembled, and installed by engineers in the Department of Cardiothoracic Anesthesia. The custom metal components were fabricated by local machine shops. The cost of the components was similar to the cost of the IV poles and utility outlets that the assembly replaces, but construction and installation required substantial labor. These components are not available commercially, but we would recommend that consideration be given to installing this or a similar mechanism in any large remodeling project or new construction, even if custom fabrication is required.

The tube system for blood samples and the electronic reporting of results are also successful. Tube systems are now reliable and relatively inexpensive, since they use plastic conduit and electronic controllers. They are commercially available, although they are not commonly used in this application. The tube system was a late addition to our OR design, and, for expediency, one station was installed between each pair of ORs. It might have been better, and only a little more expensive, to have one tube station in each OR. The tube installation (and the ICU dumbwaiter, which serves the same function) is clearly worthwhile, eliminating at least one full-time orderly position that would otherwise be required and providing prompt service at odd hours. In institutions where the laboratory may not be able to transmit results electronically, reports could be returned through the same tube system, as we now do with the empty carriers.

The use of elevators to transport all patients right after surgery and other patients who are critically ill may not be ideal, but is unavoidable in this facility. Surprisingly, the elevators have been convenient. There have been no unusual difficulties during transport, and the emergency equipment in the elevators has not been used.

Architects involved in the design of ORs are familiar with various floor plans; air-circulation requirements; and provisions for piping, lighting, and electrical service.[6,7] The architect might prefer to simply copy old plans and to complete all consultation with medical personnel within several weeks.[8] Thus, it is important to recognize that the responsibility for having an efficient operating suite and ICU will rest not with the architect but with the hospital personnel who will use the facility.[9] We recommend that medical and engineering staff begin the process of equipment evaluation and design of custom components as early as possible. In our case, 18 months was just long enough to complete the task. The process of designing the new facility also required a re-evaluation of the way the operating rooms and ICU function and presented an opportunity to create new and better practices.

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