THE COMPUTER IN CARDIAC SURGICAL INTENSIVE CARE*

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When the computer was introduced into the intensive care unit in the early 1960's, many believed that monitoring of critically ill patients would be revolutionized. Expectations were running high as this new era of intensive care monitoring emerged. The Federal Government proclaimed in 1970 that the ICU computer had come of age, and through a mysterious selection mechanism each of several medical centers was awarded a million dollar computer system, along with the associated monitoring equipment and computer programs. Their charge was to employ these systems in the ICU to reduce costs, improve the quality and distribution of care, enhance teaching, reduce staff requirements, and lower mortality. Many millions of tax dollars later, much to the disappointment of everyone involved, clearly all of these projects had been able to achieve only marginal clinical success.

Many problems contributing to technology's failure to fulfill expectations were pinpointed. Few, if any, could be considered indictments against the computer per se. In retrospect it appears that insufficient effort was allocated to identifying needs and defining requirements resulting in premature implementation of poorly designed systems unsuited for the clinical care of critically ill patients. Elsewhere productive application of computer technology was being achieved.

In 1964 because of anticipated increases in case loads and a growing shortage of nursing staff, Dr. John Kirklin, than at the Mayo Clinic, spearheaded a joint project with the IBM Corporation to explore the feasibility of employing a computer based system to automate the measurement and charting duties and perhaps certain therapeutic interventions performed by the nurses in the care of patients following open intracardiac operations. During the phase in

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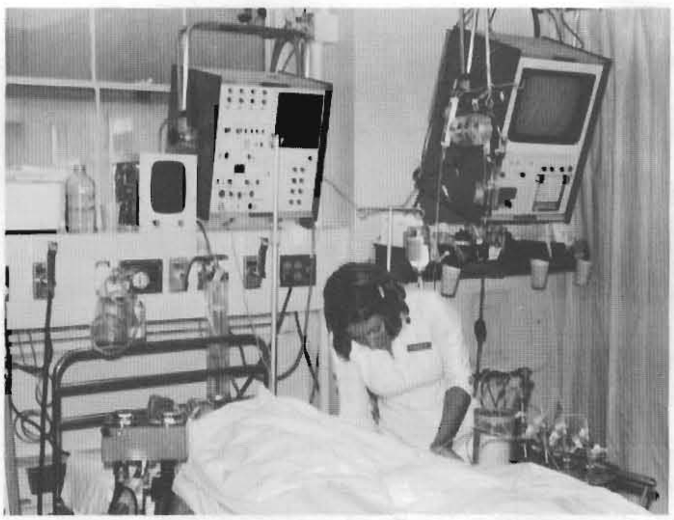
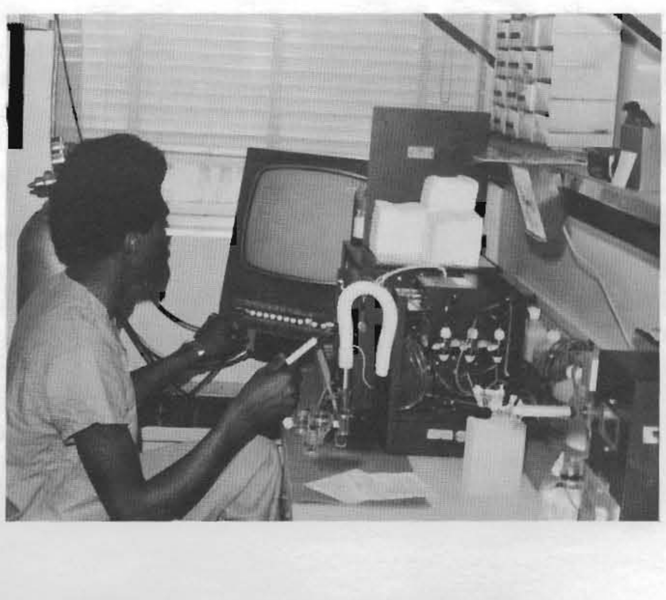
Mr. Louis C. Sheppard, Associate Professor of Surgery, Assistant Professor of Information Science, and Associate Professor, School of Engineering scans the system message log.

Mrs. Janice Shotts, Programmer Analyst, reviews tabular listing of clinical measurements automatically prepared by the system for inclusion in the hospital record.



Ms. Pat Carraway, R.N., at the patient's side in the ICU, inspects chest drainage tubing. The computer terminal, measurement services and electronics modules which are connected to the computer can be seen in the background and at the side of the bed.



Mr. Arthur Johnson, CICU technician, analyzes arterial blood samples and enters the blood gas results via the computer terminal in the lab adjacent to the ICU.

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practically impossible to influence according to Mr. Lawton. Although Senator Kennedy's subcommittee last year reported to the floor legislation which would have required all medical school graduates to serve two years in a medically underserved area, Congressman Rogers thinks this unnecessary, for it would cull out a class of citizens for the first time since the Civil War to perform mandatory non-military service.

Mr. Lawton said, "our legislation as opposed to Senator Kennedy's legislation is trying to influence these problems without getting into the problem of mandatory service of physicians in the United States." Mandatory service is repugnant to Congressman Rogers and to the majority of the subcommittee. Mr. Lawton thinks the House will not agree to this type legislation this year.

Earlier, Mr. Lawton stressed the quid pro quo that Congress enacted to require medical schools to increase enrollment in order to receive money. The quid pro quos have now been modified by the Congress in the House bill that should reach the floor of the House in June (HR-5546, Congressman Rogers' bill). There are options, for Congress recognizes that increasing the number of physicians is not enough. The schools may either increase enrollment or conduct remote site training programs not near tertiary care centers nor large urban hospitals but in either ghetto areas or rural areas, using faculty members to conduct this ambulatory care type of education.

The only requirement for a medical school is that at least 50% of the graduates receive at least six weeks training at these sites. The University of Washington has trained students in Alaskan villages. There is evidence there that a vast number of their students are going into the primary care specialties and into areas of 10,000 people or less.

The second piece of the health manpower bill which current students have escaped is "the pay-back provision." Mr. Lawton told the students that the only kind of education in the United States that received a direct subsidy from the federal government was health education.

Mr. Lawton stated, "your education cost the American taxpayer $12,000 per student per year, of which you are paying $1,600 in tuition – a miniscule part of what it cost the taxpayer to train you." Much of that part comes from the federal government as $2,000 is paid to the medical school for each student enrolled.

The position of the administration that the medical profession is the highest paid profession in the United States gives rise to the question of why should the federal government give capitation support to medical schools whose people are going to be earning so much money later on?

Mr. Lawton said that in order to answer the administration's argument, the legislation would require the student to repay to the federal government the $2,000 per student per year that the school has received for the students education. An option provides that the student may serve on a year for year basis in a critical health manpower shortage area designated by the Secretary of HEW. The Congress sees no reason to increase to any great extent the present subsidy by the federal government to most schools for training medical students who do not meet the acute national needs.

The third attempt of the Congress to satisfy the gross health manpower problem is a funding of what is called Area Health Education Centers. There are eleven area Health Education Centers in the United States today which involve the training of both undergraduates and graduate students in smaller community hospitals. Mr. Lawton said that the best center is located in North Carolina where they are training both undergraduates and graduate students in smaller community hospitals. The Congress has authorized special money for this type of training in the bills that Congressman Rogers subcommittee has reported out.

Two other special project grants that the legislation contains are first, a new program to finance family medicine departments that stand on their own and that have comparable faculty, clinical time, and number of hours with other major clinical departments in the medical school.

The second funding mechanism continued this year is the residency training program that is funded under the program in family medicine. There is money in this bill for training in family medicine and Congress does not intend to get into debate as to what is primary medical care. It sees family medicine as a way of enhancing general practitioners, more good faculty and well-trained students who have demonstrated a willingness to render primary care in underserved areas.

The final most important provision Mr. Lawton discussed was the program designed to control and plan the medic. residency programs in the United States. There is a surplus of residency training programs and a surplus of positions which are not properly balanced according to the needs of the country. Most are located in urban areas which demonstrate little if any need for more positions. The total number of postgraduate physician traineeship positions far exceeds the number of graduates of United States medical schools. Mr. Lawton pointed out that the balance among the positions is badly skewed away from primary care and it is badly skewed toward the subspecialties, the surgical residency programs and the non-patient care specialties.

In 1974 there were 1.7 first year residency training positions for every graduate in United States medical schools. The total excess amounted to more than 21,000 first year positions. The percentage of trainees in the primary care specialties is substantially lower than the percentage of practicing physicians in the primary care specialties.

Mr. Lawton said that the legislation will limit foreign medical graduates' ability to convert their visas after coming to the United States for training and getting into medical residency training programs whether they are properly trained or whether they can speak the English language. At last, for the first time, legislation controls and limits the number of residency training programs and will control the production of specialists with appropriate emphasis on geographical location. It will also keep some foreign medical graduates from entering the United States.

The controls are: The present number of first year residency training programs in the United States is 170% of the number of U.S. medical graduates. This number under the legislation would be reduced to 155% in 1978, 140% in 1979 and 125% in 1980. There are guidelines established to influence which residency programs that should be retained or established.

These guidelines are as follows: First, medical residency training programs would have to be accredited like medical

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which the ICU procedures and operations were intensively analyzed, it was con- ned that certain therapeutic measures and their indications were formally structured so that decisions could be made and interventions controlled logically based upon numerical measurements applied within the framework of rules and limits. Because Dr. Kirklin always organized his care procedures in this way, the feasibility of directly involving the system in delivery of care was a certainty.

Near the end of 1966 when Dr. Kirklin assumed his duties in the UA School of Medicine, he assembled a small team of specialists within the Department of Surgery to carry on with the project to automate tasks in the care of the cardiac surgical patients in University Hospital. The principal thrust of this work was to relieve the nurses of time-consuming routine not directly related to patient care. From the outset the focus has been on mechanizing clinical tasks which were repetitive and well defined so that computer system could be used to reduce the work load.

After modest beginnings eight years go the system has grown such that today monitoring modules and other specialized equipment for eight beds in the Cardiac Surgical ICU of the University of Alabama Hospital are connected to computer systems. During the first 24 to 48 hours following open heart surgery, the computer automatically takes the measurements on all eight patients every two minutes, displays and stores the current values, retrieves past data for review at bedside on command, and tabulates the data in printed form to be included in the patients' hospital records, relieving the nurses of many measurement and charting duties.

Commercially available medical electronics and sensors are employed frequent measurement of heart rate, intra-arterial pressure, right and left atrial pressure, and rectal temperature. Chest tube drainage and urine output are measured by weighing devices constructed in the hospital laboratory.

The infusion of blood is automatically controlled by the computer system in a closed loop feedback mode. The procedure utilizes left atrial pressure and chest drainage with rules derived from the relationship between stroke volume and left atrial or left ventricular filling pressure. The infusion pump delivers a 20 ml dose of blood when actuated by the computer. The infusion is automatically repeated if needed at two minute intervals. This unique clinical involvement of the computer in direct delivery of care has been successfully utilized in the day-to-day postoperative care of patients since October of 1967.

Recently we began using a computer controlled pump for the automated infusion of vasoactive agents to reduce and regulate mean arterial pressure in selected patients exhibiting elevated pressure associated with hypertension or increased afterload.

Cardiac output is measured intermittently in patients by the indicator dilution method. The computer is directed to acquire the dilution curve and calculate the cardiac output.

The bedside computer terminal permits communication with the remote computer for the display and retrieval of clinical data, entry of blood gas measurements and pressure limits for blood infusion, the revision of measurement status, and the control of the computer in measuring cardiac output.

Patient status analysis, decision-making regarding treatment, and selection of interventions are aided by programming which incorporates standardized patient management procedures in the computerized analysis of the data. Current patient measurements are matched with rules which suggest the appropriate therapeutic interventions such as pacing, isoproterenol, trimethaphan, epinephrine, blood infusion, reoperation, sodium bicarbonate, lasix, digoxin, etc.

Since routine, repetitive tasks which are well defined have been relegated to the system, the nurses are able to devote a higher percentage of their time to direct patient care. Consequently, more patients can be served with the existing nursing staff than would be possible without the system and the CVICU technicians. Compared to the usual manual methods of measurements, the automated measurements are more accurate, more reliable, and more consistent. Furthermore, loss of data due to oversight, distraction, or work load has been eliminated as a problem. Trends in the patient's condition can be assessed more accurately from the automated measurements. The past data can be retrieved more quickly by way of the bedside terminal than by search through the patient's chart. Physicians trust the computer generated data more than the data transmitted by people. The explicit nature of the system reduces the tendency to apply judgment unnecessarily in those situations which have well defined decision-making rules. The care of the individual patient is not compromised by the need for the nurse to temporarily assist with a crisis elsewhere in the unit.

The patient's postoperative course in the crucial early hours following surgery is more stable because the computer controlled blood infusion is more objective, less eratic, and more intense than with manual methods. Because of the consistency of the automated technique, continuation of blood infusion beyond 7 am is usually unnecessary. As a result seventy-five to eighty-five percent of the patients remain connected to the automated system twenty-four hours or less. The average duration is twenty-five hours per patient. Normally after the patient has been extubated, the intracardiac and intra-arterial catheters have been withdrawn, and the chest drainage tubes have been removed, he is returned to his hospital room. This usually occurs by noon of the day following surgery. However, if respiratory care must be continued or if anti-arrhythmic, vasoactive, or inotropic drugs are still being administered, the patient is usually moved to a non-automated bed and may remain in the unit for an additional twenty-four hours.

Measurement of cardiac index has been contributed to earlier initiation of therapeutic intervention. Experience indicates that estimation by the usual clinical criteria is considerably less reliable than indicator dilution measurement in some cases clinical judgment may be totally misleading. Without knowing by measurement the cardiac output, the physician may unwisely defer the decision to intervene with aggressive therapeutic measures until clinical evidence of low cardiac index becomes apparent.

The extra cost of the bedside electronics and computer system (less than $100 per patient day) is small compared to the total hospital bill for open heart surgery. The short mean length of stay

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Pathology department chairman named

Dr. Jack Charles Geer of Columbus, Ohio, who has been professor and chairman of the Department of Pathology of The Ohio State University College of Medicine and associate pathologist of Davidson Laboratories in Columbus, will assume his new responsibilities as professor and chairman of the Department of Pathology in the Schools of Medicine and Dentistry of The University of Alabama in Birmingham (UAB) in August. He will have responsibility for the combined Departments of Anatomical and Clinical Pathology.

Dr. Geer, who has won numerous awards for medical student teaching in general pathology at Louisiana State University and Ohio State, will contribute significantly to the education and training programs for physicians and dentists, according to Dr. James A. Pittman Jr., dean of the School of Medicine, and Dr. Charles A. McCallum, dean of the School of Dentistry.

A native of Galesburg, Illinois, Dr. Geer earned his B.S. degree in chemistry and his M.D. degree from Louisiana State University, where he was selected as the outstanding senior medical student. He received the J.A. Majors Award for Scholastic Achievement in Pathology and the George W. McCoy Award for interest and aptitude in the field of parasitology.

Dr. Geer received the Distinguished Faculty Citation from Louisiana State in 1964 and a Citation for Teaching in Basic Medical Sciences from Ohio State in 1972. He has held numerous academic and administrative appointments at Louisiana State, The University of Texas South Texas Medical School, and Ohio State.

Dr. Geer, who has a distinguished record in cardiovascular pathology, earned board certification from the American Board of Pathology in 1960 and is a member of the American Heart Association, the American Society of Experimental Pathologists, and the American Association of Pathologists and Bacteriologists.

Drs. Pittman and McCallum said the Medical Center is fortunate to have a man of Dr. Geer's caliber assuming the administration leadership of the Department of Pathology.

RECENT FACULTY PUBLICATIONS

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Grimm, R. H., Jr., Shimoni, K., Harlan, W. R., Jr. and Estes, E. H., Jr. "Evaluation of patient-care protocol use by various providers." *New Eng. J. Med.* 292:507-511, March 6, 1975.

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Montes, L. F. and Parker, J. M. "Punch excision technique for removing basal cell epithelioma." *Geriatrics* 30:65-67, March, 1975.

Pappas, D. G. and Wolcott, G. T. "Clinical observations of tympanometric findings in external otitis." *Eye, Ear, Nose and Throat Monthly* 54:101-103, March, 1975.

Pittman, J., Brattain, M. G., Weiler, A. and Pretlow, T. G., II" "Concanavalin a binding of human colon and colonic tumor." *Fed. Proc.* 34:846, March 1, 1975. (abstract)

Polhill, R. B., Jr. Pruitt, K. M. and Johnston, R. B., Jr. "Assessment of alternative complement pathway activity in a continuously monitored hemolytic system." *Fed. Proc.* 34:982, March 1, 1975. (abstract)

Rackley, C. E. "Advances in cardiovascular techniques now suitable for use in the coronary care unit of the community hospital." *Ala. J. Med. Sci.* 11:181-186, July, 1974.

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(between one and two days) in the Intensive Care Unit suggests that care is enhanced and a dollar savings ($80 or more per patient for each day saved) is realized through early discharge from the Intensive Care Unit.

The application of technology and system engineering techniques to the delivery of health services has made possible the successful implementation of a computer based system which has been used in the care of 6000 patients during the critical early hours following heart surgery. The University Hospital has been able to manage the continually increasing number of cardiac operations without proportionate growth in the nursing staff.

Hopefully the experience at UAB will serve to place in perspective what can be achieved through enlisting the aid of the computer in caring for critically ill patients. Widespread acceptance must be preceded by careful analysis of the ICU requirements followed by judicious application of the appropriate technology.

THE APPLICATION OF COMPUTERS TO THE MEASUREMENT, ANALYSIS, AND TREATMENT OF PATIENTS FOLLOWING CARDIAC SURGICAL PROCEDURES

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SUMMARY

For the past ten years we have been using computer based systems in the clinical care of 9000 patients during the early hours following open intracardiac operations. Automated techniques have been applied to measurement, analysis, therapy, and record keeping functions in the Cardiac Surgical Intensive Care Unit (CICU) at the University of Alabama Hospital.

INTRODUCTION

In recent years the care of patients critically ill following cardiac surgical procedures has become more and more demanding. Consequently more sophisticated techniques must be employed as scientific investigations yield greater understanding of the pathophysiology, measurement technology advances, and care procedures become more complex. The application of highly structured patient care procedures[1] within systems composed of biomedical electronics and digital computers[2] has made a significant contribution to the management of the additional workload imposed by these problems.

FUNCTIONAL DESCRIPTION OF THE SYSTEM

Biomedical instrumentation and computer systems are employed in the care of critically ill patients during the early hours following open heart surgery.[3,4,5] Ten of the twelve beds in the Cardiac Surgical Intensive Care Unit (CICU) of the University of Alabama Hospital, Birmingham, Alabama, are interconnected with computer systems to assist the nurses and the physicians in the surveillance and treatment of these patients. The computer automatically takes the measurements on all ten patients every two minutes, displays and stores the current values, retrieves past data for review at bedside on command, and tabulates the data in printed form to be included in the patients' hospital records, relieving the nurses of many measurement and charting duties.

Commercially available medical electronics and sensors are employed for frequent measurement of heart rate, intra-arterial pressure, right and left atrial pressure, and rectal temperature. Chest tube drainage and urine output are measured by weighing devices constructed in our laboratory.

The infusion of blood or albumin is automatically controlled by the computer system in a closed loop feedback mode.[6,7] The procedure utilizes left atrial pressure and chest drainage with rules derived from the relationship between stroke volume and left atrial (or left ventricular filling) pressure. The infusion pump delivers a 20 ml volume when actuated by the computer. The infusion is automatically repeated if needed at two minute intervals. This unique clinical involvement of the computer in the direct delivery of care has been successfully utilized in the day-to-day postoperative care of patients since October of 1967 (8500 patients).

For two years we have been using computer controlled pumps for the automated infusion of vasoactive agents (eg. sodium nitroprusside) to reduce and regulate mean arterial pressure[8] in patients exhibiting elevated pressure associated with hypertension or increased afterload (480 patients to date).

The bedside computer terminals permit communication with the remote computer for the display and retrieval of clinical data, entry of blood gas measurements and pressure limits for blood infusion, the revision of measurement status, and the control of the computer in measuring cardiac output.

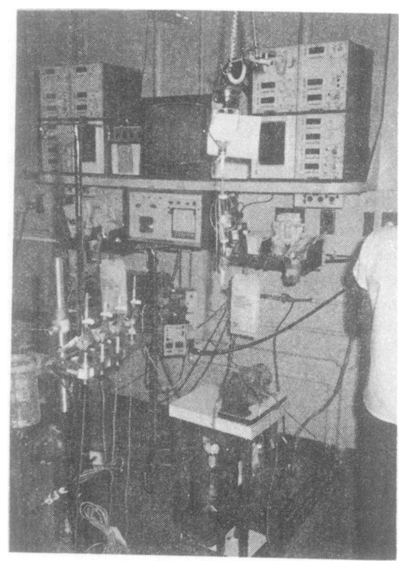


FIGURE 1 The bedside non-fade oscilloscopes, preamplifiers and signal preprocessors are positioned on a shelf between each pair of beds. Centered between these clusters are the display unit and the keyboard for activating computerized functions, entering data, and reviewing the measurements. Adjacent to the keyboard is a two channel strip chart recorder.

CLINICAL USE OF THE SYSTEM

Transducers are cleaned, sterilized, and calibrated and devices are readied by the technician to receive each new admission to the CICU. At the end of the operation, the patient is transferred to the CICU and connected to the transducers and devices. Chest tube drainage and urine output collection containers are affixed to the weighing devices within the protective frame and the tubing is anchored by clamps. Automatic acquisition of the measurements is activated by way of the bedside terminal and appropriate limits for the automated blood infusion are specified after the unit of blood has been readied for computer controlled pump administration. If the patient is, or becomes hypertensive, or requires afterload reduction, a solution of sodium nitroprusside (50 mg in 250 ml D5W) is infused by an IMED pump, which has been modified to facilitate computer control of the rate of infusion (ml/hr), to reduce the mean arterial pressure and maintain the MAP near the desired level (eg. 100 mm Hg $\pm$ 5).

At two minute intervals the automated measurements are acquired and displayed at the bedside. Measurements for two patients are combined in a single display because the video monitors are positioned between each pair of beds. Hence, the right-most column of measurements applies to the patient who occupies the bed on that side of the display and the left-most column of numbers applies to the patient in the bed on that side of the display.

Blood gas analyses are performed when ordered by the physician. Conventional blood gas analyzers are used to measure oxygen saturation (SO_2), hemoglobin (Hb), oxygen and carbon dioxide tensions (PO_2, PCO_2), hydrogen ion concentration (pH) and serum potassium (K^+) in arterial samples drawn from the radial artery. Venous oxygen tension ($P_{\bar{v}}O_2$) is measured in pulmonary arterial or right atrial blood samples. These data, along with the inspired oxygen fraction (F_IO_2) are entered manually via the keyboard and are used to calculate base excess (BE) and alveolar oxygen partial pressure (PaO_2) by accepted formulae.[9] The base excess is automatically evaluated by a computer program which calculates the appropriate quantity of sodium bicarbonate to be administered if a base deficit greater than 3 meq/l is detected.

Cardiac output (l/min) is measured in selected patients by the indicator dilution technique. The dilution curve is obtained by injection of a bolus of indocyanine green dye into the right atrium and withdrawal of blood from the pulmonary artery (brachial artery in infants) through a cuvette densitometer using a syringe pump. The computer is programmed to sample the time course of the dye concentration and computer the cardiac output, cardiac index (l/min/m^2), and stroke volume (ml).[5] The result is stored on the disk storage unit for retrieval by the physician to use in therapeutic decision making.[1]

Automatically acquired measurements such as the hemodynamic variables are transferred from core to the disk storage unit at five minute intervals. Manually entered data and data derived therefrom, such as the blood gas measurements and base excess, are logged to the disk after verification by the CICU technician who enters the measurements. Computer aided measurements such as cardiac output are stored as directed by the technician.

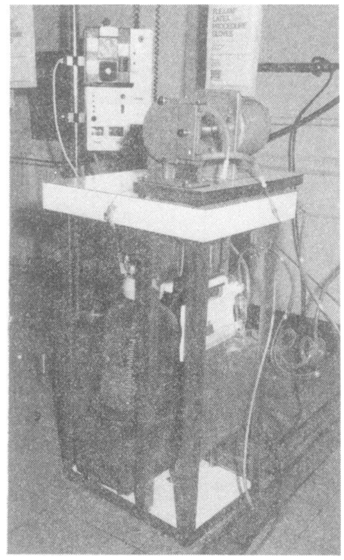
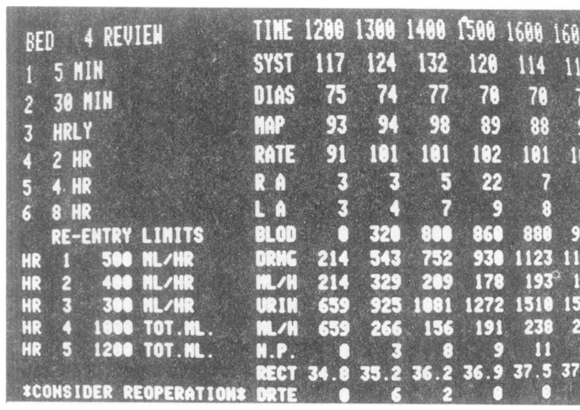


FIGURE 2 Chest tube drainage and urine output collection containers are affixed to the weighing devices within the protective frame. The computer controlled blood (or albumin) infusion pump is positioned on top of the frame. Sodium nitroprusside is administered by the computer controlled IMED infusion pump mounted on the stand behind the frame.



BED 4 REVIEW	TIME	1200	1300	1400	1500	1600	1604
1 5 MIN	SYST	117	124	132	120	114	116
2 30 MIN	DIAS	75	74	77	70	70	72
3 HRLY	MAP	93	94	98	89	88	91
4 2 HR	RATE	91	101	101	102	101	101
5 4 HR	R A	3	3	5	22	7	7
6 8 HR	L A	3	4	7	9	8	9
RE-ENTRY LIMITS	BLOD	0	320	800	860	880	900
HR 1 500 ML/HR	DRNG	214	543	752	930	1123	1129
HR 2 400 ML/HR	ML/H	214	329	209	178	193	193
HR 3 300 ML/HR	URIN	659	925	1081	1272	1510	1527
HR 4 1000 TOT.ML.	ML/H	659	266	156	191	238	238
HR 5 1200 TOT.ML.	N.P.	0	3	8	9	11	11
	RECT	34.8	35.2	36.2	36.9	37.5	37.5
CONSIDER REOPERATION	DRTE	0	6	2	0	0	0

FIGURE 3 Previous and current values of the automated measurements are retrieved and displayed in tabular form on demand. Included are the limiting values which are applied to the chest tube drainage measurements. In this particular instance, the fourth hour (1600) total (1123 ml) exceeds the limit (1000 TOT. ML.) resulting in the recommendation to "*CONSIDER REOPERATION*".

Tabular listings of the clinical data are printed as each full page of measurements accumulates. Once each day these records are inserted in the patients' charts. Since most patients are transferred from the CICU to a semi-private room on the day following operation, less than 24 hours of data storage is required for the majority of patients.

Previous and current values of the automated measurements are retrieved and displayed in tabular form on demand. Excessive rate of blood loss for a single hour, two hours, and three hours in succession, and cumulative loss at hours four and five (also hour six for infants) constitute the basis for recommending reoperation. If any value exceeds the appropriate limit, the recommendation to "*CONSIDER REOPERATION*" is displayed.

An instantaneous set of measurements can be obtained on demand and consolidated with the acid base balance, cardiac index, and respiratory data by retrieval of the most recent measurements stored in the disk files. This combined display allows rapid assessment of the present status of the patient.

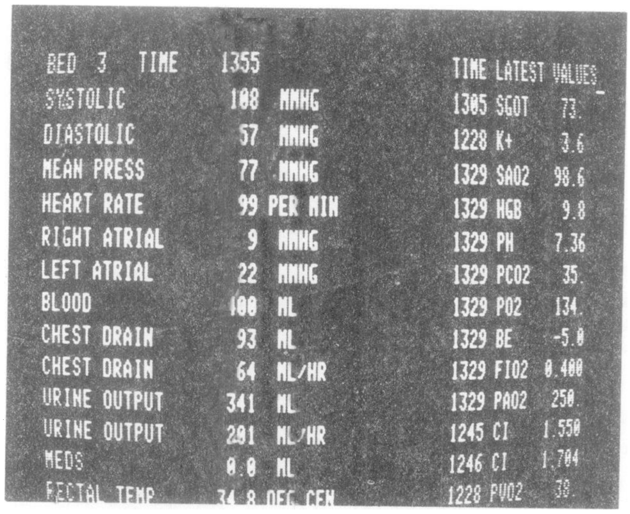


FIGURE 4 An instantaneous set of measurement can be obtained on demand and consolidated with the acid base balance, cardiac index, and respiratory data by retrieval of the most recent measurements stored in the disk files.

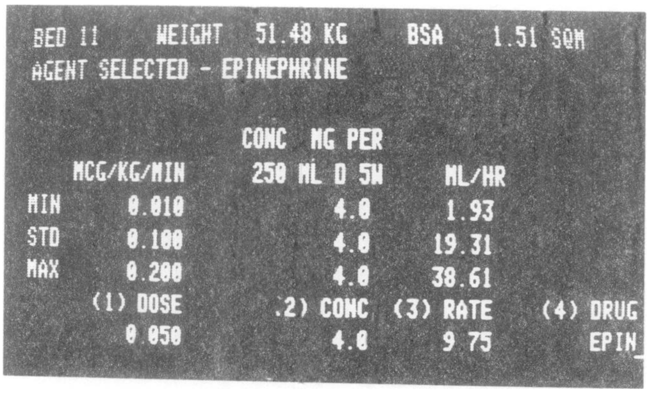


FIGURE 5 The ml/hr values for a 51.48 kg patient are displayed for the minimum, standard, and maximum dosages (μg/kg/min) of epinephrine. Options (1), (2), (3), and (4) allow the nurse or physician to manipulate the dose, concentration, rate of infusion or agent.

AUTOMATIC CONTROL OF INTERVENTIONS

Based on our experience, cardiac output, mean arterial pressure (MAP) and end-expiratory left atrial pressure (LAP) are important variables which should be considered in the further assessment of cardiac function following operation.

The left atrial pressure of 8500 patients has been regulated automatically by a closed loop feedback technique which employs frequent measurement of LAP and computer control of an infusion pump. The limiting value for LAP is specified by the physician or automatically set by the system. A 20 ml volume of blood, albumin, or packed cells is infused each two minutes unless the measured LAP exceeds the limit. If after infusion of 250 ml of blood/m^2 of body surface area, the LAP fails to increase above the limit, the total volume of blood to be infused is adjusted to a multiple (typically 2, 2.5, or 3) of the cumulative blood loss measurement to prevent over-infusion.

The blood pressure of 480 patients has been controlled automatically with a computer programmed proportional-integral-derivative (PID) controller which is augmented by a decision table to limit the incremental increase of the rate of infusion of peripheral vasodilating agents and to bias the controller in favor of decreasing the rate of infusion. For nitroprusside the MAP measurement (P) is fed back to calculate the error term (e) at one minute intervals by subtracting P from the set point (P_D , the desired pressure). The derivative term is computed by subtracting the previous error (e') from the present error (e). Since considerable MAP variation is inherent in the process, permanent off-set is not a problem; therefore, the integral of the error is not required. The computer controlled infusion pump is adjusted to maintain the error near zero by increasing, holding constant, or decreasing the rate of infusion an amount specified by the proportional and derivative actions computed from the error term and its rate of change.

CALCULATION OF DRUG DOSAGES

The manual administration of pharmacologic agents requires the computation of dosages according to a specified protocol for each drug. These protocols have been implemented on the computer system to aid the nurses and the physicians in the error-free determination of the correct concentration and infusion rate for a specified dose (μg/kg/min) of a particular drug. In this example the minimum, standard, and maximum dosages are shown for epinephrine. The respective concentrations in 5% dextrose in water solution and infusion rates (ml/hr) are shown for a 51.48 kg patient occupying bed eleven in our unit. Selection of option one or option two allows manipulation of dose or concentration to calculate rate of infusion; option three permits computation of dose for any specified rate, and option four allows the nurse or physician to select one of the agents sodium nitroprusside, trimethaphan camsylate, isoproterenol, dopamine, norepinephrine, epinephrine, or xylocaine.

REVIEW OF TEN YEARS CLINICAL EXPERIENCE

The information provided by the system yields a clear picture of the status of the patient and allows the physician to proceed to the correct decision more quickly than in the non-automated situation because measurement frequency is greater (at two minute intervals rather than 30 min), no values are missing, and the measurements are reliable.

Because the system has relieved the nurse of many routine time consuming tasks, he or she is able to devote 25% more time to direct patient care.

Hence, the combined effects of the system appear to contribute to more rapid stabilization of the patients than in non-automated intensive care units.

The patients are usually transferred from the CICU to semi-private rooms the morning following the day of operation, unless respiratory care must be continued, circulatory assist devices are in use, or antiarrhythmic, vasoactive, or inotropic agents are still being administered. Hemodynamic stabilization is usually achieved during the first eight to sixteen hours after operation and following extubation, the atrial and arterial cannulae are removed; chest tubes are withdrawn at mid-morning. The patient is then transported to a semi-private room and the instrumentation in the CICU is prepared to receive a new case.

We believe that the computerized system has contributed to a 50% reduction in the length of stay in the CICU for the majority of the patients (from 48 hours or more to 24 hours or less). The added cost of the operation of the system is less than the difference between the daily charge in a comparable non-automated CICU and the cost of a semi-private room. Therefore, two days in a non-automated unit would be expected to cost more than one day in our unit plus the subsequent day in a semi-private room.

Our experience over the past ten years clearly shows that the computer can be effectively integrated into the health care delivery system for the observation and treatment of critically ill patients.

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