Critical-Care Medicine and the Acute-Care Laboratory

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Critical-care medicine today is practiced by anesthesiologists, internists, pediatricians, and surgeons. Outcome from today's management of critically ill patients is very good, yet associated costs are very high. Over one-half of the hospital costs of critically ill patients emanate from the intensive-care unit (ICU), although the ICU stay accounts for less than 20% of their time in the hospital. Outside of the operating room, the ICU is the most expensive location for patient care in the hospital, and laboratory tests are the most expensive single item. Plans for cost containment should incorporate the following: more effective data management, education of practitioners about appropriateness and costs of tests, conversion from laboratory measurements to appropriate in vivo and ex vivo measurements, and real-time utilization assessment. To provide high-quality, cost-effective critical care in the future, laboratorians and clinicians must work together today to meet the challenges of technology, data management, and staff education.

Critical-care medicine, caring for critically ill patients in a specialized environment by specialized individuals, has several goals. The foremost goal is to provide optimum outcome with minimized rates of morbidity and mortality, given the acute and chronic diseases of the patients. Equally important is the containment of costs in a manner suitable for maintaining high quality of care without making that care so expensive as to preclude some patients from receiving it. The technology, including laboratory measurements, that has brought us this far in the practice of critical-care medicine must be scrutinized closely for appropriateness and costs. Integration of these tests and monitoring of their utilization must be incorporated into the overall practice. Thus the challenge for critical-care medicine in the 1990s is the same challenge that all practitioners of medicine face: increasing demands for assurance of quality of care, management of risks, appropriate utilization, and cost containment. However, those of us in critical-care medicine will be under closer scrutiny than many, because of the high costs associated with critical care.

History

Intensive-Care Units

The practice of critical-care medicine is based in a special environment, the intensive-care unit (ICU), the history of which really begins with the development of the recovery room. Although the first general anesthetist was administered by Crawford W. Long in Jefferson, GA, in 1842, the need for special observation of patients after anesthesia and surgery was not recognized until the early part of the 20th century. In 1923 the first actual recovery facility was established at Johns Hopkins by Dr. Walter E. Dandy for post-operative neurosurgical patients (1). No further real advances were made until World War II, when the posting of many nurses overseas forced the centralization of postoperative patients in U.S. hospitals so that many patients could be recovered by a limited number of nurses. The recognition of the vital role of recovery rooms and the need for them in all hospitals then was advanced by the Anesthesia Study Commission in Philadelphia immediately after the war (2).

The development of ICUs and the practice of critical-care medicine were fostered by two diseases: polio and operable heart disease. During the 1952 polio epidemic in Denmark, 200 medical students daily manually ventilated 40 to 70 patients, some of them for more than three months (3). Fifteen mechanical ventilators were invented during this epidemic period (4). Polio centers were established in several countries, and many of these centers later evolved into respiratory-care units, admitting patients with causes of respiratory insufficiency other than polio. A special unit for bringing together special equipment and technically skilled people with critically ill patients began to be recognized as a means of optimizing resources, as well as enhancing outcome.

The next major evolutionary step in ICU development accompanied the advent of cardiac surgery. Given the positive experiences of trauma units during World War II and of the now ubiquitous recovery rooms, cardiac surgeons availed themselves of ICU facilities to support their burgeoning endeavors of the 1960s (5). Initiation and growth of cardiac surgery in the 1960s provided the stimulus for the marked growth of ICUs during this period.

Acute-Care Laboratory

The evolution of the acute-care laboratory, the predecessor for which is really the blood gas laboratory, also began with the Danish polio epidemic. When it was demonstrated that the high total CO₂ contents of the polio patients were not due to metabolic alkalosis but rather to respiratory acidosis, Dr. Poul Astrup, then head of the Clinical Chemistry Department at Blegdam Hospital, developed a technique to rapidly determine the partial tension of carbon dioxide in whole blood (6). He not only developed the method but also applied it to patients—sampling arterial blood, analyzing it in his laboratory, and returning to the polio unit with his results to adjust the patients' ventilators (7). Astrup, who occupied the first chair in clinical chemistry in Scandinavia, was one of the earliest acute-care laboratorians.

The Astrup technique for determining $p_{CO_2}$ was an indirect method: actually, only pH was being measured. The $p_{CO_2}$ electrode, which provides a more direct measurement of carbon dioxide tension, was developed by Stow in 1956 (8). Modification of the electrode by Sauerbruch in 1958 (9) produced the reliable electrode that we utilize today in both manual and automated analyzers.

The direct measurement of oxygen tension became clinically practical with the development of the polarographic electrode by Clark in 1957 (10). Modification, including

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addition of a gas-permeable membrane by Severinghaus in 1958 (9), produced the $P_{\text{CO}_2}$ electrode remaining in use today. Widespread application of laboratory tests to the care of critically ill patients dates from the clinical availability of results for blood gases in the 1960s. Growth in services offered and numbers of these laboratories paralleled the growth of cardiac surgery for the next decade.

Practitioners of Critical-Care Medicine

Many of the earliest practitioners of critical-care medicine were anesthesiologists, because the knowledge and skills needed in the ICU were an extension of their operating-room-based practice. Also, the fundamental tenet in anesthesiology practice—that a knowledgeable and skilled physician should always be available to patients requiring life support—also is the basic principle of practicing critical-care medicine. Dr. Bjorn Ibsen provided an example of the anesthesiologist's early efforts in critical-care medicine. As the principal consultant in anesthesiology early in the Danish polio epidemic, he provided both clinical support and teaching of intubation, positive- and negative-pressure ventilation, and monitoring of exhaled carbon dioxide, as well as arterial $P_{\text{CO}_2}$ and pH (11).

As both disease and trauma have increased the numbers of critically ill patients in the past two decades, other medical and surgical specialties have had practitioners become interested in caring for critically ill patients. The first formalization of this interest in the United States occurred with the founding of the Society of Critical Care Medicine (SCCM) in 1969 (12). The SCCM brought together not only physicians from different specialties but also nonphysician health-care professionals who were involved in caring for critically ill patients. The SCCM has served as a forum through which both knowledge and technology have been advanced. It has also served as the focal point to formalize education and credentialing in critical-care medicine.

In 1978, a task force under the auspices of the American Board of Medical Specialties (ABMS) began defining the knowledge and skills for the practice of critical-care medicine (13). In 1981, a Joint Committee on critical-care medicine was constituted with members representing the specialties of anesthesiology, internal medicine, pediatrics, and surgery, as well as SCCM (14); its goal was to develop a multidisciplinary examination in critical-care medicine. In 1984, however, the Joint Committee was dissolved, leaving each specialty board to examine and credential physicians in their respective discipline for the practice of critical-care medicine. In 1985, the ABMS approved examinations for certification of special qualifications in critical-care medicine for the American Board of Anesthesiology (Hartford, CT 06103), the American Board of Internal Medicine (Philadelphia, PA 19104), the American Board of Neurological Surgery (Houston, TX 77030), the American Board of Pediatrics (Chapel Hill, NC 27514-1651), and the American Board of Surgery (Philadelphia, PA 19103-1847).

The American Board of Anesthesiology took the lead, developing and administering the first Certification Examination in Critical Care Medicine in the United States in October 1986. Thereafter, examinations have been offered in odd-numbered years, producing 421 qualified physicians as of December 1989. The American Board of Pediatrics offered its first exam in July 1987 and will continue to do so every third year. As of the end of 1989, 182 pediatricians had been certified in critical-care medicine. The American Board of Internal Medicine offered its first examination in November 1987; it also will offer critical-care medicine examinations in odd-numbered years. As of December 1989, it had certified 1725 physicians in critical-care medicine (15). The American Board of Surgery began offering a subspecialty CCM exam in October 1989, at which time 508 physicians were certified. The American Board of Surgery will offer its examination annually. Of the five Boards that originally received permission from ABMS to offer subspecialty certification in critical-care medicine, only the American Board of Neurological Surgery currently does not offer an examination, having decided that such subspecialty certification is not necessary in their specialty.

Currently there are 136 training programs in critical-care medicine in the United States: 96 adult and 40 pediatric (16). Several thousand physicians in the United States thus far have trained in the subspecialty of critical-care medicine, and 2836 have qualified through subspecialty examinations to practice as of December 1989.

Evolution of Technology

Measurement philosophy, data management, and changing patterns in acute-care measurements produce great effects on both costs and outcomes. An increasing number of techniques are bringing us closer to measurement and assessment in real time. Although routine laboratory measurements and data management can be considered in terms of batch processing, daily reporting of results, etc., the laboratory measurements and data management for critical care are thought of in terms of observations or very rapid turnaround time. The ability of the critical-care practitioner to measure and comprehend blood pressure within 10 s or oxyhemoglobin saturation within 5 s are examples of such acute-care measurements. In the setting of critical illness, the critical-care practitioner does not differentiate between blood pressure and oxyhemoglobin saturation in terms of data needed for management of a patient in whom changes can produce increased morbidity or actual mortality within 60 s.

From the perspective of the critical-care practitioner who is managing acute pathophysiologic changes in a critically ill patient, turnaround time involves four activities: (a) to recognize a change in the patient, (b) to decide upon and obtain a measurement to assess that change, (c) to observe and comprehend the measurement results, and (d) to institute an appropriate change in management of the patient.

The following specific clinical example illustrates the evolution occurring in acute-care measurement technology today. Hypoxemia can result in brain damage, possibly resulting in a vegetative state in a previously healthy patient. Ten years ago, turnaround time for dealing with hypoxia would have included recognizing the change (e.g., cyanosis), deciding to measure $P_{\text{CO}_2}$ and (or) oxyhemoglobin saturation, ordering an arterial blood gas measurement, having the blood gas sample drawn and transported to the laboratory, analyzing the sample, and having the results transmitted back to the ICU, where the physician then would interpret the results and institute an appropriate change. All of this theoretically could occur in 5 min, but in reality most such determinations took longer. Contrast that sequence of events with the response to the same problem of cyanosis today. Using the pulse oximeter, the critical-care practitioner can observe the oxyhemoglo-
bin saturation, interpret the change, and institute an appropriate change in management within 5 s—a 60-fold improvement in time over the best performance previously available and well within the time frame needed to prevent hypoxemia from damaging the brain or other vital organs.

Data Management

Of course, not all of our acute-care laboratory measurements will evolve in the near future as rapidly as has the pulse oximeter. Therefore, data management, including the use of computers, is very important in the practice of critical-care medicine. In fact, practitioners of critical-care medicine have a long way to go to catch up to many of the advances in management of computerized laboratory data. However, laboratorians and the industry that supports them have largely ignored meaningful comprehension of the laboratory data by the practitioners caring for critically ill patients.

Laboratories’ uses of computers today are largely unrelated to patient care: admission, discharge, and transfer (82%); order entry (67%); signal acquisition from laboratory instruments (93%); and reporting results (90%) (17). However, going beyond tabular printouts or line-printer graphics is virtually unheard of for laboratory data-management systems. Actual plotting of data, including $x$-$y$-z graphic displays, is not available in the armamentarium of critical-care practitioners unless they develop a system themselves and manually enter the data for graphic display.

We have reached our human limit for comprehension of tabular data. Pertinent physiological, chemical, hematological, and other data may exceed 2000 data points per patient each day. Tabular presentation of these data does not promote the comprehension necessary to provide complete patient management. Only when these data are available in appropriate plots and graphic displays will comprehensive and significant advances in patient care be possible.

Effective data management will benefit not only patients but also practitioners and administrators. Critical-care practice in the 1990s is going to be like other medical practices, heavily influenced by cost containment, utilization review, and quality assurance. Data management must be designed to address each of these areas.

Intensive-Care Facilities and Costs

ICUs evolved from recovery rooms, but whereas recovery rooms have remained general patient-care facilities, ICUs have become specialized by age and by disease processes. There are approximately 6500 ICUs in the United States, comprising more than 86,000 beds; overall ICU bed distribution is neonatal (12%), pediatric (3%), coronary care (13%), and medical–surgical (72%) (18). Total ICU beds represent less than 7% of the more than one million hospital beds in the country.

Health-care costs for the past quarter century have risen exponentially, exceeding US$400 billion in 1986 (19). The rate of increase for number of laboratory tests per patient day have paralleled health-care costs, producing an exponential increase in costs for tests since 1940 (20). More than 50% of the total hospital bill for patients admitted to ICUs is generated from their stay in the units, even though this accounts for less than 20% of their hospital stay (21). In fact, during their ICU stay, critically ill patients generate more than 60% of their total laboratory charges (22). Of all the variable costs within the ICU, the diagnostic laboratory has been identified as the single most costly item per day (23).

Although laboratory costs are easily identified as one of the major causes of increasing ICU (and thereby hospital) costs of critically ill patients, it is no simple matter to reduce these costs. One approach to cost containment is to analyze laboratory costs on a supply and demand basis. On the supply side, costs include capital purchases, personnel, and disposables. However, it is not the supply side but rather the demand side that has produced the increase in laboratory costs in the recent past (20). The supply side has had a modulator in the person of the laboratory director, who deals with laboratory resources and determines availability of tests, but there is no analogous individual on the demand side in the ICU. Therefore, decisions about appropriateness of tests, which tests to order, frequency of ordering, etc., go unregulated. Also, there is no real-time feedback to physicians, nurses, or others concerning costs per patient or costs per diagnosis.

Historically, technology initiated the practice of critical-care medicine, but the practice itself and all of the benefits attendant to it have resulted from interested and willing individual practitioners being drawn to the bedside of the critically ill patient. Technology did not advance critical-care medicine practice; physicians applying the technology at the bedside did. Therefore, it must be the physicians at the bedside appropriately applying the technology who will ultimately control the associated costs.

Two problems extant in ICUs today exemplify the promulgation of increasing costs. First, when critically ill patients are cared for by physicians who do not remain at the bedside, tests can become an end in themselves, providing a bridge of objective data between the critically ill patients and the physician who cannot be present in the ICU to care for them. Second, when critically ill patients are cared for by non-critical-care physicians, excessive tests may be ordered in a “shotgun” approach to diagnosis and management, i.e., obtaining enough test results to increase the probability of determining what is wrong with the patient. Neither approach to caring for critically ill patients is acceptable from the points of view of risk management and cost containment. Besides increasing laboratory (and hospital) costs unnecessarily, the shotgun approach produces two other negative results. First, the physician focuses on the tests being obtained and not on the tests necessary to care for the patient. Second, batteries of tests will (by statistical probability) uncover test results that are out of normal ranges, thereby obliging the physician to make additional diagnostic interventions to ensure maintenance of quality assurance for the admission of that patient.

Laboratory costs for ICU patients not only can be contained but can actually be reduced, if the effort is made in overall management of critically ill patients in the ICU. In a study of 100 patients, Civetta and Hudson-Civetta (22) demonstrated continued quality of critical care and no difference in outcome while dramatically reducing costs. By implementing specific guidelines and providing cost feedback to practitioners during an eight-month period, they reduced laboratory tests by 42% and laboratory costs by 53%. Although length of stay in the ICU actually increased during their study, the contribution of ICU laboratory costs to total laboratory costs for each admission fell from 61% to 46%. Their extrapolation of annual savings for one 12-bed
surgical intensive care unit was US$2 million.

However, one must not develop false economies in critical-care medicine. Proposed changes in practice or in technology obligate clinicians, laboratorians, and administrators to consider the potential impact on short-term and long-term outcomes, as well as costs. For example, ICU costs, including laboratory costs, can be reduced by forcing earlier transfers to the floor. However, if this results in increased recidivism or increases the length of the total hospital stay, there will be no real savings, perhaps even significant losses. The same can be said for premature hospital discharge as well.

One of the keys to cost containment is more effective data management. Data acquisition and analysis in the ICU and the hospital must include information that permits overall assessment of costs and utilization. The need for a global view is illustrated by the change in measurement of oxygenation from arterial blood gas analysis to pulse oximetry. In hospitals where operating rooms, recovery rooms, and ICUs placed pulse oximeters in each patient-care location, capital costs certainly had a significant, though transient, increase. However, laboratory supplies and personnel costs should now be decreasing, the rate of decrease being somewhat a function of staff education about this new technology. An additional benefit is the reduction in occupational risk of infection to the health-care personnel who previously had to draw, transport, and analyze specimens for blood gases. Another benefit has been a reduction in liability insurance premiums in many institutions. Data-management systems ideally would have captured all of the information necessary to document and assess the ongoing benefits from a one-time capital expenditure for pulse oximeters. We can expect a myriad of such technological changes in the future, and competent financial management demands that the data-management systems capture relevant data so that future cost–benefit assessments can be quantified accurately.

**Critical-Care Medicine in the 1990s**

As the severity of illness in hospitalized patients and the number of critically ill patients increase during the next decade, critical-care practitioners, laboratorians, and administrators must reassess and change several aspects of the practice of critical-care medicine so that the advances of the past 30 years are not lost in a morass of spiraling costs. With concerted, combined effort, the practice of critical-care medicine will be different, yet effective, in the 1990s.

With the recent establishment of subspecialty boards in critical-care medicine, the specialty is now in a unique position to incorporate credentialling and quality assurance in the practice. Critical-care practitioners' provision of high-quality care for critically ill patients has been established, and their effectiveness in reducing costs of care has been demonstrated (22). Therefore, recognition and reimbursement of critical-care specialists are imperative if progress and cost containment are to be achieved. In tertiary, acute-care hospitals, critical-care physicians must be responsible for the care of critically ill patients in the ICU. The critical-care physician and the acute-care laboratorian must be knowledgeable of each other's field and must work closely together. This working relationship can assure that appropriate measurements are available and being ordered, that correct results are being provided and used appropriately, and that the technology is being applied in the most cost-effective manner possible.

As hospitals and physicians come under increasing pressure to reduce costs while continuing to deliver high-quality care, closer scrutiny and innovative techniques will be required in every facet of critical-care medicine. Technology not only will challenge our intellects but will also provide the tools to advance the delivery of critical-care medicine efficiently and cost-effectively. With critical-care practitioners and acute-care laboratorians in place in an institution, specific changes can be initiated to improve care, document quality assurance, and reduce costs.

Sound business practice dictates maintaining documentation that can be audited. A database should be established that maintains patient demographics, disease, severity of illness, intervention, and costs for all patients admitted to the ICU. If database resources are not already available in an institution, a simple database can be developed on a microcomputer with commercially available software for less than US$5000. Such a system can provide an essential ingredient for success: documentation to the hospital and medical staff that quality care is being maintained with cost-effective methods.

The database should be established with use of a system-oriented or problem-oriented medical record for all patients admitted to the ICU. Standard diagnostic coding such as ICD-9 (24) should be utilized. All therapeutic interventions should be documented with procedural codes, e.g., CPT (25). Every test should be obtained with a specific written order by a qualified physician. All standing orders and all PRN ("whenever necessary") orders for tests should be eliminated. In fact, with a critical-care physician continually present in the ICU, standing orders and PRN orders are illogical. An audit trail should link each test with the ordering physician and with a specific problem. Such links permit efficient, cost-effective utilization review, which has been shown to reduce laboratory tests by as much as 20% (26).

A severity of illness index and an interventional scoring system are mandatory adjuncts for quality assurance and utilization review in the ICU. One of the most significant mistakes made in evaluating health-care costs during the 1980s was the use of raw data without any moderation by concomitant severity of illness data or interventional scoring data. The Acute Physiology and Chronic Health Evaluation (APACHE) classification system is an established index for severity of illness, which permits comparison of costs and review of utilization among disparate ICUs, hospitals, and patient populations (27–29). Likewise, standardizing comparisons of interventions is necessary. The Therapeutic Intervention Scoring System (TISS) provides the means for reliable comparison of costs, resources, and outcome (30).

Real-time feedback about costs to the individual physicians ordering the tests is one of the most important features to be incorporated into a data-management system for critical-care medicine. Physicians learn diagnosis and therapy by taking care of patients. They will learn cost containment by having the costs immediately before them when they are caring for the patients. If a hospital's test-ordering system already is computerized, feedback can be produced at the time each test is ordered. Otherwise, physicians ordering tests can be given cost-based printouts each day from the microcomputer database system.

From the earliest measurements of blood gases, the acute-care laboratory has played a vital role in the evolu-
tion of critical-care medicine. Today, acute-care laboratorians and critical-care physicians face immense challenges concerning technology and its associated costs. Meeting these challenges requires better informational concepts, critical assessment of utilization of measurements, and education of practitioners about appropriateness and costs of tests. Cooperatively meeting these challenges requires integration of the laboratory data into the critical-care medicine database. Seamless data transmission must occur between the laboratory, the ICU, and the patient's medical record. Two- and three-dimensional graphic displays of data must be developed to permit comprehension of the extremely complex pathophysiological processes in critically ill patients. Last, but perhaps most important, cost feedback must be provided to practitioners as they care for critically ill patients. The monies saved with the last effort easily will pay for the other endeavors.

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