

Organization of a Neuroscience Critical Care Unit

Historical Perspectives and Vision for the Future

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Of greater human interest than the details of design and equipment [is] ... the need to appreciate the emotional strain to which members of the ... [critical care] staff are exposed when, hour by hour, their whole attention is focused on patients who are immediately and constantly dependent on their vigilance. (1)

INTRODUCTION

Medical historians date the beginning of neurocritical care back to the 16th century. In delineating the history of critical care, some quote biblical passages, philosophers, and historians, and ethicists indicate historically early end-of-life discussions, and attempts at resuscitation and artificial ventilation (2). Pictorial illustrations of early artificial respiration devices and descriptions of resuscitation practices appear primitive and comical (3). However, these devices and methods set the foundation for significant advances in the 19th century. In the first half of the 20th century, when neurologists were challenged by the poliomyelitis epidemics, they had the groundwork for the first large-scale use of mechanical ventilation (4). Modern neurological intensive care began with the use of respiratory care principles established during European poliomyelitis epidemics and expanded into a broad field that encompasses all acute and serious aspects of neurological and neurosurgical disease (5).

As the development of neurocritical care was defined by historical events, so too were the roles of neurosurgeons, neurologists, and neuroanesthesiologists in the field. When the American Academy of Neurology (AAN) was founded, most poliomyelitis victims primarily received their care from neurologists. Dr. A. B. Baker, a founding AAN member and vocal proponent of neurosciences, strongly advocated for the role of neurologists in the care of polio victims and other critically ill neurological patients (4). During that time, the issue of infectious disease as the precipitating factor or secondarily related to the neurologic critical illness was debated. Baker contended that neurologists of his era provided more comprehensive care than infectious disease specialists. Because of patient acuity, early 20th century neurology practices required critical care medicine. Neurologists performed tracheotomies, rigid bronchoscopes, and other minor surgical procedures (4).

Early neurologists played an active role in the instruction of critical care skills. Neurologists not only played an active role in neurocritical care training and development of neurocritical care as a specialty, but they also played key roles in growth of general critical care. In the 1970s, Dr. David Jackson, a neurologist at Case Western Reserve University, directed one of the first general critical

care training programs. While furthering general critical care, he also instituted the American Academy of Neurology's annual course in critical care.

History demonstrates a fluctuation in the level of interest and degree to which neurologists have participated in the care of the critically ill. Once the vaccine for poliomyelitis was discovered and incidence of poliomyelitis rapidly declined, neurologists returned to general neurology consultation (4). However, a resurgence of neurology interest in critically ill patients became apparent when Dr. Allan Ropper, internist and neurologist, founded the neurological–neurosurgical critical care service at Massachusetts General Hospital in the late 1970s. In 1983, Ropper was one of the authors of the first American textbook of neurocritical care. Other early neurocritical care training programs were founded by internist–neurologists, such as Dr. Daniel Hanley at Johns Hopkins, Dr. Matthew Fink at Columbia, and Dr. Thomas Bleck at the University of Virginia.

Interest in the potential benefits of neurosciences critical care units (NSUs) has also increased. Challenges that face the new generation of neurologists and critical care physicians are the rapidly aging population, increase in neurosurgical volumes, and rapid advancement of acute therapies for neurological and neurosurgical patients. Neurointensivists must be trained to enhance medical care by combining the knowledge of neurologic disease and intraoperative care with techniques of intensive care.

Arguments regarding the necessity of neurospecialty trained intensivists have been ongoing throughout American and European literature (6–8). Those arguments in favor of NSUs tend to highlight trends toward more accurate and efficient practice patterns designed for neurological and neurosurgical patients (7). The assertion is that the care of neuroscience patients requires training in clinical physiology of intracranial pressure (ICP), cerebral blood flow (CBF), brain electrical activity; systemic abnormalities and medical complications of nervous system diseases; postoperative care; and management of neuromuscular respiratory failure. Acute stroke, intracerebral hemorrhage (ICH), brain death, ethical dilemmas of severe neurologic illnesses, and neurologic features of critically ill medical patients now fall well under the auspices of neurosciences intensive care.

Critical care has an important and permanent place in neurological and neurosurgical research, education, and practice. In the past, neurocritical care was only useful for cardiopulmonary support while nervous tissue recovered. Now, therapies for brain resuscitation and brain-sparing methods impact outcomes in neurological and neurosurgical emergencies. Specific advances in monitoring of electrophysiological and intracranial physiological indices brought laboratory physiology to the bedside and allowed standardization of diagnosis and prognosis. Modern NSUs are not only a place for sick neuroscience patients but also a place to incorporate advanced medical technology with understanding of the organ dysfunction that follows brain and nerve failure.

HISTORICAL PERSPECTIVES

Development of Medical and Surgical Intensive Care Medicine

Close observation of critically ill patients dates back to ancient time; however, with the advent of modern technology, monitoring functions and evidence-based clinical care are recent phenomena (9). Along with improved technology, clinicians better understand the needs of patients with acute, life-threatening illnesses or injury. Health providers' personal papers and autobiographies can be used to trace the emergence of the "grouped patient" approach to care. Nurses were some of the first to appreciate that very sick patients receive more attention if they are grouped together. In the 1860s, Florence Nightingale wrote about advantages of establishing separate areas of the hospital in which patients recovered from surgery.

Intensive care units had their origin in the postoperative recovery room. The first surgical intensive care unit (SICU) was also the first NSU. In 1923, Dr. W.E. Dandy created a three-bed unit for the postoperative neurosurgical patients at the Johns Hopkins Hospital in Baltimore, Maryland. The con-

cept of intensive care units further developed during World War II. Areas designated as “shock wards” were established to resuscitate and care for soldiers injured in battle or undergoing surgery. Historically, the fluctuation in demand for nursing care and the supply of nurses greatly facilitated the development of such units. Directly after World War II, there was a nursing shortage that sparked a nationwide initiative to recruit and train nurses (10). In the meantime, grouping of postoperative and seriously ill patients in recovery rooms to ensure attentive care was necessary.

When the polio epidemic struck Europe and the United States, healthcare providers were confronted with staggering fatality rates. Interest in improving treatment of patients dying from respiratory paralysis fueled scientific and medical endeavors. Initially, many patients with bulbar poliomyelitis were treated with iron lungs. At the peak of the epidemic, the supply of iron lungs could not meet the demand. In response, the European market answered the challenge with the invention of positive pressure ventilation administered through an endotracheal tube, popularized in Denmark (11). The Denmark experience stimulated research in automated machines capable of intermittent positive pressure ventilation and during the 1950s, development of mechanical ventilation led to organization of respiratory intensive care units in many European and American hospitals. Not surprisingly, care and monitoring of ventilated patients proved to be more efficient when patients were grouped in a single location (12).

There was a flurry of medical advances during the two decades that followed the polio epidemic. Higher expectations and standards for rate of survival lead to formation of designated areas in hospitals for continuous physiologic monitoring and life-saving interventions. In 1956, the first external defibrillator and synchronized direct-current cardioversion to treat refractory tachyarrhythmia was introduced. Peter Safar and W.B. Kouwenhoven advanced care of the critically ill patient to a new realm when they introduced the combined technique of rhythmic lower sternal pressure and mouth-to-mouth breathing, which we now refer to as cardiopulmonary resuscitation (CPR; 13).

Technological inventions and special triage areas were only the first steps toward improved outcomes. In 1942, the fire at Boston’s Coconut Grove nightclub, one of the worst civilian disasters in American history, marked a unique time in the history of intensive care. Advances in the areas of burn care, resuscitation of shock, use of antibiotics, and understanding metabolic response to injury resulted from the Boston experience (14). During the mid-1960s, resuscitative techniques with intravenous fluids and blood products for shock were improved allowing for increased patient stability and evacuation to facilities that were suitably equipped to address their needs. By the late 1960s, health care witnessed a rapid spread of resuscitation and surgical techniques and the creation of recovery rooms in nearly every hospital. Coincidentally, in 1958, only 25% of community hospitals with more than 300 beds reported having an ICU but by the late 1960s, close to 95% of all acute care hospitals in the United States had some sort of critical care unit (15).

In the 1960s, the government began to pay for the health services of poor and elderly patients through Medicaid and Medicare. These programs enabled access to health care for a larger segment of the population and allowed hospitals to purchase the cutting-edge technology. More specialized units came into favor and cardiologists emerged as the directors of coronary care units. As a result, by the end of the 1960s, the mortality rate of cardiac patients was reduced 20%. Early successes of specialty-trained intensivists have evolved into evidence-based, outcome studies that show that units managed by specialty-trained intensivists with protocol based care result in better outcomes (15,16).

Development of Neuroanesthesiology and Medical Monitoring

In the 1960s, neuroanesthesiology developed as a definitive subspecialty. During this development, advances and standardization of methods to measure CBF, cerebral oxygen saturation, ICP, electrophysiology, and neurochemical indices were introduced (17). With these contributions from general anesthesiologists and neuroanesthesiologists, ICUs became a gathering place for expensive technology to supplement and improve the cardiopulmonary support patients received. Professor

Andrew Hunter, the author of the first book on neuroanesthesia, is considered one of the pioneers in his field. Unfortunately, the earliest minutes of the historic discussions and accounts of the developments are lost. However, much of the progress in anesthesia from the “rag-and-bottle inhalation era” to the use of intravenous anesthetics, neuromuscular blocking agents, ventilators and monitoring can be credited to anesthesiologists like Maurice Albin and Thomas Langfitt. Concurrently through co-operative efforts with surgeons, such as Cushing and Halsted, thoracic and neurosurgical anesthesia were revolutionized, cardiac surgery became possible, and resuscitation with intravenous (IV) fluids, blood, and plasma was further developed (18).

Development of Intravenous Techniques and Nutrition

Early efforts in cardiac resuscitation and critical care included assessment and management of volume status and were markedly advanced by development of IV techniques. Neurologic patients present with a combination of derangements. Patients with hypertensive crisis have high blood pressure but may be volume-depleted. Alternatively patients with spinal shock and dysautonomia may have normal blood volume but are hypotensive due to vasoparalysis. The pulmonary artery catheter and echocardiography has assisted intensivists with determination of vascular volume and cardiovascular function. Vascular resuscitation essential for maintenance of cerebral and spinal perfusion pressure involves use of vasopressors and inotropic agents guided by these monitoring techniques (*see also* Chapters 8, 10, and 13).

Nutrition was an often-overlooked aspect of critical care illness. Through the years, nutritional status, including energy and protein requirements, has been carefully correlated with outcomes in neurologic patients. Intensivists now recognize syndromes associated with the phenomena of underfeeding and overfeeding. Experience with IV nutritional therapies led to a better understanding of the increased caloric demands of neuroscience patients, particularly after head trauma (19–22). By virtue of their condition, many neuroscience patients are at greater risk for aspiration (*see also* Chapter 11). Because enteral feeding is still favorable, nasogastric and percutaneous gastric tubes came into use. Occasionally, total parenteral nutrition is necessary for patients in coma with poor gut motility. Nutritional consultation and services are an integral part of the NSU design and staffing providing specialized formulations for the catabolic brain injured patient (*see* Chapter 14).

Development of Hygiene Guidelines and Infection Control

Despite fastidious attention to sterile technique, infections occur. In distinction to other ICU patients, an NSU patient rarely has open wounds, fractures and markedly altered skin barriers. The risk of wound infection after craniotomy is low (23). Infections usually occur in lung, bladder, blood, and brain or meninges after trauma, surgery, or placement of extraventricular devices. Infections within the CNS are particularly difficult to treat given the generally poor antibiotic penetration of the blood-brain barrier (*see* Chapter 29).

Critical care nursing has played an important role in the development of infection control standards. Florence Nightingale observed that hand washing reduced the spread of infection. The European Prevalence of Infection in Intensive Care (EPIC) study conducted by the European Society of Critical Care Medicine suggested that minimizing the nurse-patient ratio reduced spread of ICU-acquired infections (11). Institution of infection control standards for monitoring strict hand washing, use of sterile technique during bedside procedures, and patient isolation have become as important as pharmacotherapy. Adequate amount of appropriate supplies must be on hand in each room to reduce the traffic between patients and supply areas. However, careful calculations for supply requirements are necessary to avoid waste from contamination.

Care of the critically ill and immune compromised has incorporated the use of broad-spectrum antibiotics. Unfortunately, the repeated use and misuse of antibiotics has resulted in antimicrobial resistance (24). Future ICU design and construction must facilitate safety and infection control

requirements. Staff education should target infection control as management of infection can lead to shortened length of stay, improved outcomes (25), and increase ICU throughput.

Development of NSU as a Subspecialty

Over the past two to three decades, ICUs caring for neonatal, trauma, burn, cancer, neurologic, and postoperative cardiac patients have evolved. The argument is made that care in specialized units is of a higher quality because of focus on the special needs of the patients. Recent reports suggest that outcome is improved in stroke patients cared for in stroke units (26,27) and ICH patients cared for by specialty-trained physicians and nurses in NSUs (7,28). As technology supporting more advanced and invasive care of brain injured patients has improved, a specific and in-depth knowledge base has become a sought after commodity. As a result, the number of specialty ICUs for care of neurological and/or neurosurgical patients has been growing rapidly. Training programs have grown in number to meet the need for specialty-trained physicians and nurses (7). An important development has been the foundation of the Neurocritical Care Society in February 2003. This society is an international organization composed of healthcare workers from various disciplines interested in caring for critically ill neurological and neurosurgical patients. We anticipate a promising future for further NSU growth and research.

ORGANIZATION

Admission, Triage, and Discharge for an NSU

The success of intensive care is not measured only by statistics of survival, as though each death were a medical failure. It is measured by the quality of lives preserved or restored, the quality of the dying of those whose interest it is to die and by the quality of relationships involved in each death. (29)

Patients admitted to an NSU usually have one or a combination of the following abnormalities: altered level of consciousness, mechanical ventilatory insufficiency, loss of airway protective reflexes, risk of rapid deterioration in neurologic function, or cardiovascular instability associated with neurological injury.

In 1977, Marsh et al. listed stroke, head injury, brain tumor, post-hypoxic encephalopathy, and admission for immediate postoperative observation as the most common admitting diagnoses. Less commonly admitted patients were those with spinal cord injury, status epilepticus, myasthenia gravis and various infectious, and metabolic and hypertensive encephalopathies. Although admitting diagnoses have not changed, emergence of new means of diagnosing and treating acute neurological diseases increases the number of patients that are candidates for NSU care.

Acute management of stroke, until recently, was characterized by supportive therapy alone. Although advances in cardiorespiratory care have allowed improved outcomes, it has taken new therapies directed at the brain to improve function. For example, patients with vertebrobasilar territory infarcts uniformly died before techniques to support ventilation and treat cardiovascular collapse. Now with these techniques, patients live to be candidates for intra-arterial thrombolysis and neuroprotective drug trials (*see* Chapters 17 and 18). On the other hand, aggressive therapies, such as intravenous, intra-arterial or combined tissue plasminogen administration have led to increased risk of hemorrhage. Judicious blood pressure control (29) and close observation can modify this risk by specially trained staff. Sequelae of ICH and subarachnoid hemorrhage (SAH) are more likely to be identified and result in early and directed medical and surgical interventions in an ICU staffed by individuals specifically trained in the area of neuroscience. Head trauma patients are also more likely to have better outcomes in a specialty ICU (30).

In the past, neurologic and neurosurgical intensive care developed in parallel. However, common pathways of brain and whole body response to a variety of inciting neurological injuries have brought these two disciplines closer. Neurologists' interests in acute medical care and neurosurgical concen-

tration on new operative techniques have resulted in new expansive knowledge, making collaboration necessary for the future. A multidisciplinary team comprised of a combination of neurologists, neurointensivists, neurosurgeons, and neuroradiologists is frequently seen in the NSUs of the academic medical center of today.

The intensivist is unit/hospital based and can serve many roles including medical direction, consultant, triage, and manager of ICU resources. The administrative role of the intensivist includes teaching, institution of protocols for health outcome improvement, reduction of length of stay and readmission, and maintenance of staff milieu. Protocols are being established as guidelines for unit functions and bed control. This allows for the appropriate nurse staffing and bed availability. Several studies have looked at various aspects of admission, discharge, and triage. Hyman et al. designed criteria that have been adapted and further expanded (31). These criteria are summarized in Tables 1–3. Sample detailed admission, discharge, and triage criteria for an actual NSU are presented in Chapter 1.

Design of an NSU

Design of modern ICUs present unique challenges to both physicians and administrators in the current health care environment. Cost-effective and cost-beneficial design is essential for all ICUs. There are specific needs of the neuroscience patient that necessitate both financial and human resource investments.

The NSU can be a geographically separate area of the hospital or housed within a multispecialty unit. Number of beds should be based on referral and admission patterns as well as available staffing. Adequate floor space for traffic patterns, and easy movement through the unit and around patients are required. Ideally designed NSUs provide for the best visualization of monitors and direct patient observation. Unique floor plan design including windowed walls and remote camera monitoring provide high-frequency visibility.

Present-day design mandates private rooms or adequate space between patients to provide privacy and confidentiality. Experts have reported the necessity of a minimum of 200 to 330 ft² per bed area (32,33) to accommodate ancillary equipment. Floor space should allow for positioning of bed and equipment to facilitate traffic, workflow patterns and access to the patient from all angles (Fig. 1). Specific to NSUs, the room layout must allow 270–360 degrees access to the head because of frequent minor surgical interventions and cerebral monitoring (Fig. 2). Adequate supplies of oxygen, air, suction, electricity, and lighting are clustered, along with back-facilities in the event of supply failure. In addition to routine monitoring and call/signal systems, NSUs should include systems that do not depend on patient-generated activation. Systems activated by ventilator disconnect, motion detectors, and video observation should be considered.

Design can facilitate fluctuations in patient acuity. As the acuity of patients increases, a higher nurse to patient ratio (1:1, 1:2) is required and more personnel may need to be at the bedside. Concomitantly, the nurse-to-patient ratio may need to transiently decrease (1:3) for lower acuity patients. Therefore, the floor plan becomes important to ensure multiple forms of visibility of patients and changing staffing patterns. There are several architectural models to consider (Fig. 3). Staffing, projected occupancy and constraints of the building floor plan determine the ideal layout. Most ICUs were built into an existing building footprint and configuration was limited. Rectangular design with a central nursing station limits visibility at the ends. The need for storage and conference space limits patient directed care resources. Family waiting and grieving areas were never planned and are located in other areas of the hospital. Perhaps the best designs take advantage of circular array of beds around a central nursing core. However, circular designs do not necessarily fit well in hospital floor plans.

Staffing of an NSU

Several models of care (e.g., open vs closed ICUs, resident/fellows vs physician extenders, nurses only) are used throughout the country, with varying degrees of success. Although all care models

Table 1
NSU Admission Criteria

1. Postoperative patients who need neurological and cardiopulmonary assessment at least every 2 h; patients may be admitted directly from the operating room or recovery room
2. Patients needing brain and/or spinal cord assessment more frequently than every 2 h
3. Patients with uncontrolled seizures requiring assessment at least every hour
4. Patients who need frequent monitoring or treatments unavailable in general care areas (electrocardiogram, invasive pressure monitoring, drug infusions, respiratory monitoring, mechanical ventilation, and so on)
5. Overflow from other intensive care areas; these patients may not always have neurological diseases

Table 2
NSU Discharge Criteria

Discharged to	Patients
General care floor	There is no neurological change for 24 h, seizures are controlled with medications, metabolic homeostasis is present, intravascular volume is adequate; there is no life-threatening arrhythmia or hemodynamic instability, respiratory status is stable, assessments and therapies (e.g., suctioning) are required every 4 h or less, care withdrawn for comfort measures
Intermediate care unit	There is no life-threatening arrhythmia or hemodynamic instability, but may still require intermittent IV bolus of antiarrhythmic or antihypertensive agent. Respiratory status is stable but requires ventilatory support or frequent respiratory treatment; intracranial monitoring is stopped

Table 3
NSU Triage Criteria

1. When the NSU census is full, the unit director generates a triage list of patients who could be adequately managed on an alternate level unit.
2. If the NSU is full, and all possible patients have been transferred to a general or intermediate unit, any patient needing NSU should be referred to an alternate ICU with close NSU follow-up.
3. It may be preferable to triage more stable patients to other ICUs to make space for a more acute NSU patient.

may work, the ideal model for a given ICU can be found only through ongoing performance improvement (34). There are several standard staffing issues in the design of any NSU.

All intensivists have knowledge of acute circulatory, respiratory, and metabolic disturbances and general skills required for advanced cardiac life support, cardioversion, intubation and ventilator management, and insertion of invasive hemodynamic monitoring. There is debate regarding the role of general critical care physicians versus specially trained neurointensivists in NSUs. Both models can work but optimally the general intensivist should have special training in neuroscience and neuroscientists have taken the time to train in general ICU issues through a formal fellowship. Neurocritical care physicians are especially adept in discussion of cerebrovascular pathophysiology and complex end-of-life issues. With experience in defining brain death and prognosis in severe brain injury, currently neurocritical care specialists are leading the way as an interface for organ procurement and donation.

Observational studies of ICU directors identified five characteristics that were thought to result in effective leadership: clinical credibility; an active clinical presence in the unit; a supportive approach

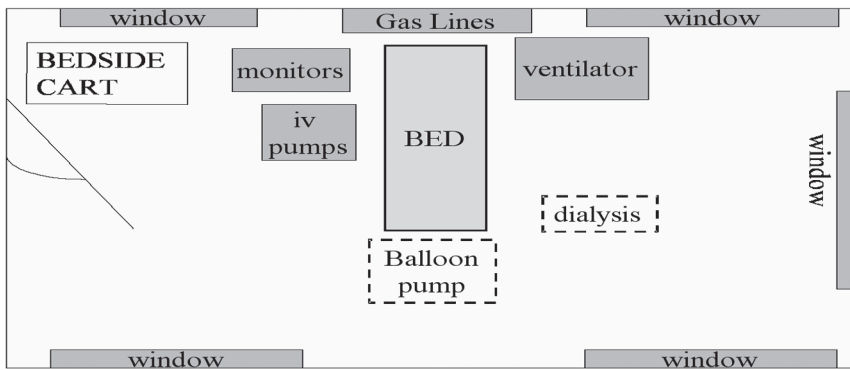


Fig. 1. General ICU bed orientation.

that encouraged input and suggestions; an ability to accept responsibility and be accountable; and a dedication to continuous teaching, improvement and excellence in patient care (34).

Staffing should facilitate training of junior staff members in different aspects of intensive care. Both physicians and nurses depend on a hierarchical model of transferring knowledge and experience. Given the high turnover of personnel in ICUs this approach serves to insure a ready supply of developing practitioners. Even those who agree that neuroscience specialty training is essential are unclear as to what standardized criteria should be introduced into training programs. National standards and a curriculum are under development.

Efficiency and core proficiency of any NSU depends on a central core of nurses with neurocritical care training. This may be one of the most difficult staffing issues faced in the NSU. Care of neurological and neurosurgical patients requires perseverance as they often do not improve and the gratification of successful outcome is rare. The nursing profession is exhibiting a severe shortage in qualified caregivers and the average age of critical care nurses is over 40 yr. Aging of the experienced nursing cohort will worsen the staffing shortages in the coming years. Despite the rise of professional and academic standard of nurses, the profession continues to lose its appeal for a variety of reasons including shift work, lack of employment benefits, and increased interest in administrative positions and out-of-hospital job opportunities. Recruitment and retention of nursing staff must play an integral role in staffing and budget planning (*see also* Chapter 33). An expansion of the role of advanced clinical nurses could potentially increase job interest as well as improve care in the setting of limited staffing. Thus, when there is a limited in-house medical staff, no full-time medical director, or only nominal medical leadership, expansion of nursing roles is essential (11).

Staffing of an ICU demands special relationships within the ICU team and with other teams in the hospital. There is ongoing debate about whether ICUs require a dedicated, full time team. Some referring physicians will wish to be involved in decisions of any magnitude and others to leave management entirely to the ICU team. This dynamic is typically characterized as “open” and “closed” unit management designs, respectively. Lustbader and Fein (35) describe advantages and disadvantages of each design as follows:

Open Unit

Advantages

- May have ICU Director
- Private physicians manage cases
- May be appropriate for smaller nonteaching hospitals
- Intensivist may be involved in case (as a consultant)
- Greater private physician satisfaction

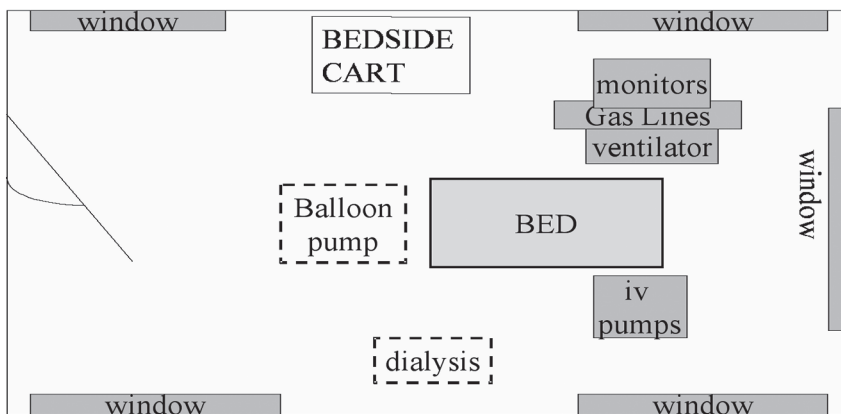


Fig. 2. Ideal NSU bed orientation.

Disadvantages

- Frequently lacks team leader
- Variable coverage nights and weekends
- Intensivist may not be involved in the case
- Physicians manage cases
- Less efficient and prolonged ICU length of stay

Closed Unit

Advantages

- ICU Director
- Single intensivist manages all cases and is team leader
- House staff usually present
- Improved efficiency and reduced length of stay
- Reduced resource utilization
- Facilitates protocols (weaning, medication)
- Formal ICU rounds
- Greater nursing satisfaction

Disadvantages

- May cause physician conflict
- No pre-existing relationship with patients and their families
- May not have details and nuances of patient's medical history
- May alienate referring physicians
- Primary physician may not want patient back on transfer from ICU to floor

Favoring an open system is increased continuity of care as patients are moved to and from ICU and general wards. However, several studies have shown that closed units result in a decrease in morbidity and mortality rates (36,37), average ventilation time, length of stay (38,39), and cost (40). In addition, most of the stated disadvantages to a closed system can be easily resolved with a concerted effort to communicate with referring physicians, patients and families.

FUTURE DESIGN: EVERYTHING FROM TELECOMMUNICATION SYSTEMS TO ROBOTICS

With the advent of affordable and more portable technology, changes will occur in the structure and function of ICUs. Units were created as quarantined areas of the hospital in times of epidemics and were kept separate to cluster patients in areas where high-cost monitoring and specially trained personnel could be concentrated. With the advancement of the information age, some of these physi-

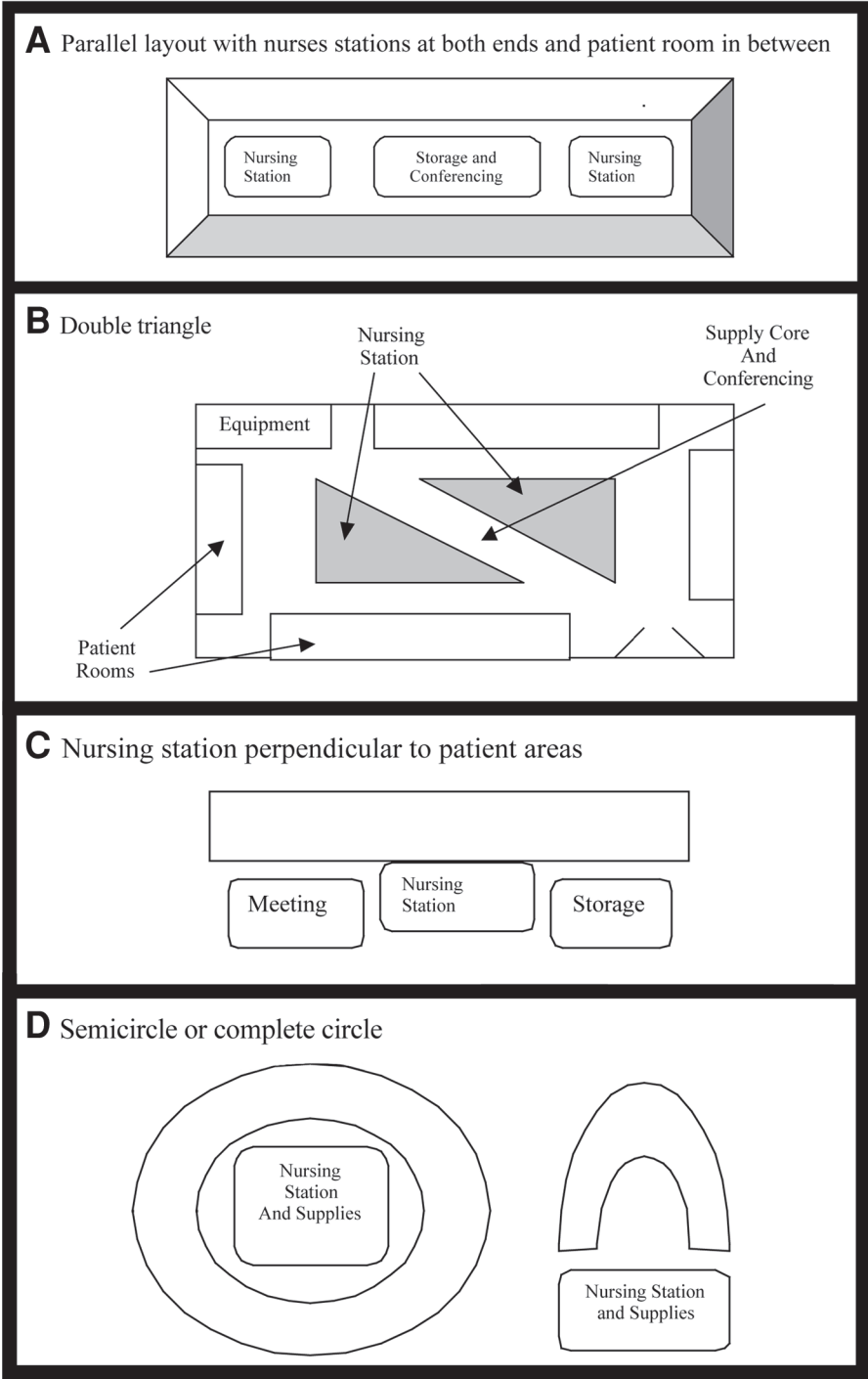


Fig. 3. Different ICU designs.

cal barriers may disappear. Education is online and available for all medical professionals making all healthcare workers more informed. There may be a time when every patient in a hospital is “wired” and information transmitted wirelessly to remote stations for monitoring of a variety of health parameters by nurses and hospitalist physicians trained to recognize signs of worsening. Critical care may be delivered on site in wardrooms capable of being converted to a high-monitored setting with the flip of a switch.

Rapid advances in telemedicine have paralleled the growth in general medicine. In 1897, the telephone was used to help diagnose croup in a child. Einthoven used an ordinary analog phone in 1910 to transmit electroencephalograms and electrocardiograms. In 1959, the US government helped fund the first functional telemedicine program, providing outpatient psychiatric patient care and medical education in Nebraska (41). Several other projects were initiated throughout the 1960s and 1970s. These earlier efforts were hindered by the high cost of technology, poor image quality, and increased time required to train medical personnel. During the past two decades, considerable improvements in telecommunication devices (including powerful computers with high-speed connections, satellite systems, and digital technology) have again resurrected interest in use of this exciting and valuable adjunct to practice and delivery health care, particularly in rural areas (42). In addition, there has been broader usage in neuroscience (43).

Preliminary studies provide data that demonstrate favorable outcomes. Telemedicine reduces mortality, length of stay, ICU complications, and costs when remote interventionist provides care in comparison to care not directed by an interventionist. There are no studies regarding use of telemedicine in neurocritical care specifically. However, the Telemedical Emergency Neurosurgical Network (TENN) was developed in the early 1990s. Collected data suggest a potentially exciting role for neurocritical specialists. The clinical efficacy and cost effectiveness noted in the TENN study suggest an immeasurable promise for new relationships between intensivists, community providers and “at-risk” underserved populations (44).

Several large medical centers have adopted computer-based monitoring systems. The first of which was seen at Case Western Reserve University Hospital in the 1970s. Now, these systems are frequently used to assist in record keeping and collection of medical data for research. Such systems also function as flowsheets for charting purposes and minimize use of paper records and daily notes. These offer a more accessible, legible, permanent, and legal record of medical data. As these systems are placed at the bedside, nurses will spend more time and attention on patients (45).

Neuroscience has been at the forefront of technology since the creation of the CT scanner. The need to transport critically ill patients has decreased by having portable CT scanners housed in the ICU. Magnetic resonance imaging and positron emission tomography scanners are being built in proximity to ICUs. Robotic surgical devices are appearing in hospitals across the country. It will not be long before detailed neuroanatomic knowledge will be programmed into robots at the bedside to guide invasive techniques formerly done in the operating rooms and interventional suites. Robots will play important roles in hospital and ICU daily operations to perform routine fetch and carry tasks, handle difficult and hazardous materials, assist healthcare professionals to provide improved standards of treatment and care, and perhaps solve the shortage in healthcare workers associated with the advancing age of the population (46).

The high cost of health care will continue to change the face of care delivery and reimbursement. Consolidation of hospitals has occurred throughout the country. Regional provision of critical care services is likely to become the norm. As provider organizations come to control a large number of beds in a geographic area, centralization of critically ill patients in well-managed, technologically sophisticated, and specialized ICUs will become more attractive than less efficient alternatives. Institutions will need to opt for practice patterns that demonstrably lower costs and improve outcomes (36).

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