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# Developments in hybrid operating room, neurointensive care unit, and ward composition and organization for stroke management

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## Abstract:

Stroke is the leading cause of adult disability in the US. Rapid diagnosis and treatment of stroke, in addition to efficacious rehabilitation, is invaluable. The present review aims to report the recent improvements in hybrid operating rooms (hybrid ORs), and in the organization of Neurological intensive care unit (NICUs) and dedicated stroke wards (SWs), which contribute to enhanced stroke treatment. A PubMed literature review was conducted in addition to the collection of other online media releases regarding recent organizational advances in stroke care. PubMed keywords included but were not limited to “neurological intensive care unit,” “hybrid operating room,” and “stroke ward,” while all other online information regarding recent advances in the physical organization was selected and synthesized in accord with its relevance. The current research indicates that hybrid ORs facilitate surgical innovation and improved patient care through the colocation of advanced imaging modalities and surgical capabilities. Moreover, the recent reorganization of NICUs and SWs may lead to better-quality initial treatment and rehabilitation. The present review also considers the current ER triage protocol for stroke patients, and it concludes with relevant considerations relating to the role of the physical hospital structure and organization in stroke care.

## Keywords:

Hybrid operating room, neurological intensive care unit, stroke, stroke ward

## Introduction

Stroke continues to be the leading cause of disability worldwide. As a result, it adds to an insurmountable cost to the local economy and continues to be an increasingly prevalent vascular disease. Over 7 million Americans  $\geq 20$  years of age have had a documented history of stroke which equates to a 2.5% overall.<sup>[1]</sup> However, by 2030, it is estimated that the prevalence of stroke will increase and significantly affect 3.88% of the US population  $\geq 20$  years of age.<sup>[2]</sup> Recent studies also indicate that the direct economic burden of stroke, primarily acute ischemic stroke, will increase from \$72 billion to

\$183 billion between 2012 and 2030; indirect economic costs that are associated with morbidity and mortality are projected to add up to another \$57 billion.<sup>[2]</sup> The substantial, impending increase in prevalence and cost of stroke necessitates a heightened focus on efficacious primary/secondary prevention, acute treatment, and rehabilitative care of stroke patients.

The present review focuses on the acute and rehabilitative care of stroke patients in the context of advancements in the neurology intensive care unit (NICU) and the stroke ward (SW) in addition to the recent development of the hybrid operating room (hybrid OR) and current emergency room (ER) triage methods of stroke patients.

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Currently, it is reported that approximately 35% of patients who suffer from stroke either fully recover or achieve a functional status with minor impairments.<sup>[3]</sup> Therefore, it becomes prudent to explore avenues that would ultimately augment functional recovery by virtue of enhanced pre- and poststroke care. Such factors improving immediate treatment during stroke or rehabilitation following stroke would greatly reduce the morbidity and the indirect individual societal costs associated with stroke.

It is well-documented that one of the factors influencing patient rehabilitation is the physical environment of recovering stroke patients.<sup>[4,5]</sup> As a result, various components of the NICU and SW ranging from the composition of care teams to the architectural features of the building have been considered for their potential to facilitate or hamper recovery from stroke.<sup>[6,7]</sup>

In addition, the evolution of the hybrid OR over the past two decades may enable a significant improvement in the surgical treatment of stroke patients. A hybrid OR may cost a hospital around \$5 million to implement<sup>[8]</sup> and is a combination of a traditional, aseptic operating room with high-quality medical imaging such as computed tomography (CT) and Magnetic resonance imaging scanners and angiography biplane X-ray.<sup>[9]</sup> In addition to reducing the cost of endovascular treatment of time-sensitive entities such as acute ischemic stroke,<sup>[10]</sup> the collocation of imaging and surgical equipment of hybrid ORs may also enable quicker surgical intervention and enhanced patient outcomes. This application becomes important, especially in the higher volume vascular and tumor centers, where an immediate imaging confirmation of a treated vascular pathology or confirmation of tumor resection is required.

## Methods

We conducted a literature review of information regarding the physical organization of NICUs, SWs, and the hybrid OR. Our search criteria included any information on the topic with particular attention to recent, relevant advances. PubMed was utilized as our primary source. A review of the current guidelines for hybrid ORs was also obtained from the Association of periOperative Registered Nurses.

### Triage of stroke in the emergency room

Efficacious triaging of stroke patients correlates with better patient outcomes. The treatment of stroke is time-sensitive, and accurate detection of stroke symptoms by paramedics or emergency staff at the point of contact is critical for effective, appropriate medical care.<sup>[11]</sup> The use of stroke recognition scales, such as recognition of stroke in the ER, have demonstrated

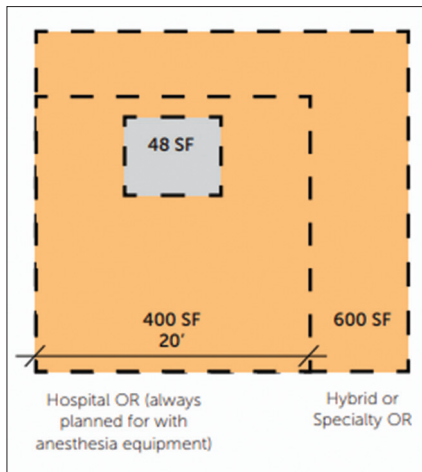
an 88% sensitivity which allows for highly accurate stroke detection and subsequent stroke management.<sup>[11]</sup> Additional scales that have been used widely include the Cincinnati Prehospital Stroke Scale and the Los Angeles Prehospital Stroke Scale. The organization of an ER also affects the triage of stroke patients. Previous research has reported that the reorganization of an ER by incorporating a CT and receiving prenotification from EMS reduced in-hospital delays from 1 h 3 min to about 7 min in addition to reducing the door-to-needle time from 1 h 28 min to 50 min.<sup>[12]</sup> Furthermore, incorporating the Acute Stroke Triage Pathway into stroke management protocol to rapidly identify patients eligible for intravenous (IV) tissue plasminogen activator (tPA) shortens door-to-CT and door-to-needle time by 11 and 18 min, respectively.<sup>[13]</sup> Additional factors that augment the initiation of stroke treatment include rapid availability of IV tPA in the emergency department as well as organizing a large-vessel occlusion alert to simultaneously notify multiple key players in the event of an intracranial large-vessel occlusion.<sup>[14]</sup>

A specialized unit with colocated surgical and imaging equipment, the creation of a dedicated unit for the treatment of stroke and other neurological disorders, and a reorganization of the SW based on chronology and stroke-trained personnel represent recent advances that may contribute to enhanced care of stroke patients. These advances have occurred in the (2) hybrid OR, (3) neurological intensive care unit, and (4) SW.

### Hybrid operating room

The hybrid OR is characterized by the presence of advanced imaging modalities in the context of a standard operating theater.<sup>[15]</sup> As a result of the variety of different technologies in one location, deliberate planning is necessary to ensure the proper functioning of the hybrid OR. This includes but is not limited to larger room requirements [Figure 1], efficient workflow, acoustic and visual considerations, radiation protection, and the type of imaging technologies used.<sup>[16]</sup> As many of these essential design considerations are interdependent, a multidisciplinary precise approach is paramount to the functional hybrid OR.<sup>[17]</sup>

The hybrid OR has great potential in supporting the current surge in endovascular and minimally invasive procedures in the treatment of stroke patients [Table 1]. Hybrid ORs can be used for various procedures including percutaneous and transcatheter aortic valve replacement, endovascular repair of aortic disease, endovascular angioplasty and stenting, brain tumor resection, and embolization of aneurysms. For stroke patients, the use of mechanical thrombectomy and other surgical cerebrovascular treatments is a current area of innovation.<sup>[18-20]</sup> Hybrid ORs can also be used for



**Figure 1:** Hybrid operating room floor dimensions. Compared to a traditional operating room, a hybrid operating room requires approximately 50% more floor space

penetrating head trauma and other hybrid neurosurgical procedures including hemorrhagic stroke.

Hybrid ORs offer a variety of advantages while presenting a few unique challenges. Although hybrid ORs have become integral in the majority of hospitals, one challenge is the initial cost which is estimated to be between 2 and 4 million dollars.<sup>[20]</sup> This cost must be recuperated, and to do this, the OR must be in constant use, so “reserving it for emergencies becomes difficult.” However, many studies indicate that the hybrid OR allows for reduced hospital costs and other positive cost-benefit outcomes.<sup>[10,21]</sup> Additional barriers include having the availability of simultaneous technological and nursing personnel to cycle between the OR and imaging setting. The advantages of hybrid ORs include patient safety, flexible use of surgical and medical resources, and increased teamwork among staff.<sup>[22]</sup> Hybrid ORs allow for real-time image-based monitoring during procedures and can facilitate a nearly instantaneous transition to a standard operating room if needed;<sup>[23]</sup> these novel abilities improve patient safety and augment better outcomes. At an administrative level, the hybrid OR may be used as a catheter laboratory or as a traditional OR which provides flexibility to surgeons and medical staff.

### NICU arrangement

A neuroscience intensive care unit (NICU) is a dedicated special care ward for neurological patients who require specialized postoperative care.<sup>[24]</sup> The origins of the NICU are difficult to delineate, but the units were likely created as early as the 1950s for patients who had suffered severe traumatic brain injuries and needed close monitoring for effective recovery.<sup>[24]</sup>

Today, the most common diseases treated in the NICU include acute ischemic stroke, brain hemorrhages

**Table 1: Essential design considerations of hybrid operating room**

Essential design considerations	Explanation
Room size	Additional personnel and portable or stationary imaging equipment require a larger operating room. For this reason, the Facility Guidelines Institute mandates that there must be a minimum of 600 sq ft of clear floor space
Workflow	The increased number of personnel also necessitates an increased focus on workflow; the placement of equipment, novel communication strategies, and projected imaging and surgical activity all influence workflow and must be consistently assessed
Acoustic considerations	There are a variety of technical difficulties that can arise as a result of acoustic disruptions; the room should be designed for the reduction of unnecessary noise
Radiation protection	The shielding requirements of MRI and CT necessitate radiation consultation to ensure patient and provider safety
Imaging technologies utilized	Employing any combination of MRI, CT, single-plane or biplane angiography, and fluoroscopy all impose restrictions on room size, workflow, acoustic sensitivity, and radiation

entailing intracerebral, subdural, subarachnoid, epidural hemorrhages, and brain trauma, among others.<sup>[25]</sup> The modern NICU has developed features to provide efficient care for the patients who are admitted. There are various setups of the NICU. For instance, the NICU at Northwestern Medicine Central DuPage Hospital is outfitted with rooms that provide 360° access to patient beds, the main caregiver station that provides a direct line of sight to all patient rooms, as well as concealed equipment and dimmable lights.<sup>[26]</sup>

These features maximize caregiver access to patients in addition to patient comfort. Furthermore, these NICUs can capture prolonged electroencephalogram (EEG) recordings, which may be required by patients who suffer from seizures or need intracranial pressure control. Continuous EEG capturing allows caregivers to continually monitor cerebral functions of patients and has enhanced the quality of care given.<sup>[27]</sup> Other features of modern NICUs include specially trained physical and speech therapists, dedicated trauma teams, and advanced technology specifically designed to care for patients with severe neurological injuries such as multimodal monitoring with cerebral pulse oximetry and cerebral microdialysis. Patients who spend time in an NICU undergo more invasive monitoring, received more nutritional support, and received less IV sedation when compared to those in a general ICU.<sup>[28]</sup> NICUs were also found to reduce the length of stay for patients with neurological pathologies.<sup>[29]</sup> These advanced care techniques may result in the decreased mortality rate and favorable patient outcomes when compared to

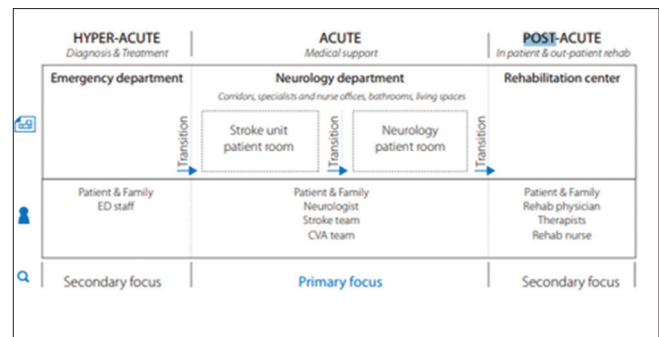
general ICUs for intracerebral hemorrhage.<sup>[28,30]</sup> The 2005 data based on the Trauma Audit and Research Network showed a 26% increase in mortality for patients being treated in a general ICU for traumatic brain injury when compared to the NICU.<sup>[31]</sup> Further work also indicates lower mortality for cases such as intracerebral hemorrhage, subarachnoid hemorrhage, and ischemic stroke.<sup>[31]</sup>

NICUs are dedicated to providing specialized care to severely ill neurological patients. Aside from enhanced patient outcomes, NICUs have also been shown to be more cost-effective when compared to general ICUs.<sup>[32,33]</sup> Despite the many advantages of the NICU, the limiting factor is access to them. These units are yet to become mainstream, with there being 73 current NICU units in the US, leaving 32.6% of the population about 90 min away from the NICU using ground transport.<sup>[34]</sup> Access to NICUs is still limited which may suggest an increased emphasis on NICU development. Encouraging pathways of formalized neurocritical training to physicians and nurses will further augment the availability of NICUs to a broader population base.

### Stroke ward

Daily physical activity has many benefits to individual health. However, previous studies have demonstrated that physical exercise plays a role in the recovery of neurologic function via a specific signaling pathway.<sup>[35]</sup> As physical activity may enhance recovery after neurological injury, the physical environment of patients who suffer debilitating neurologic injury has been considered following such injuries, namely stroke.<sup>[36]</sup> Stroke requires rapid treatment to limit the extent and severity of brain damage; previous studies have found that every minute of delay may contribute to the destruction of 1.9 million cerebral neurons.<sup>[37]</sup> tPA is an effective treatment for acute ischemic stroke within 4.5 h of the initial onset of symptoms with greater amounts of time decreasing efficacy which further highlights the significance of time in treatment.<sup>[38]</sup> According to the current research, it is possible to begin stroke treatment within 20 min of patient arrival with effective preparation; despite this, delays can reach up to 60 min in the US.<sup>[6,37]</sup>

Organization of a SW may be integral in facilitating a reduction in delay time for stroke diagnosis and treatment in addition to effective recovery and rehabilitation following cerebral injury. A feasible organization of a SW has been proposed which aims to reduce delay, facilitate recovery, and organizes the was into three phases: the hyperacute section which focuses on diagnoses and treatment, the acute section which focuses on ongoing medical support, and the postacute section which focuses on rehabilitation [Figure 2]. The streamlined process of transferring patients as they

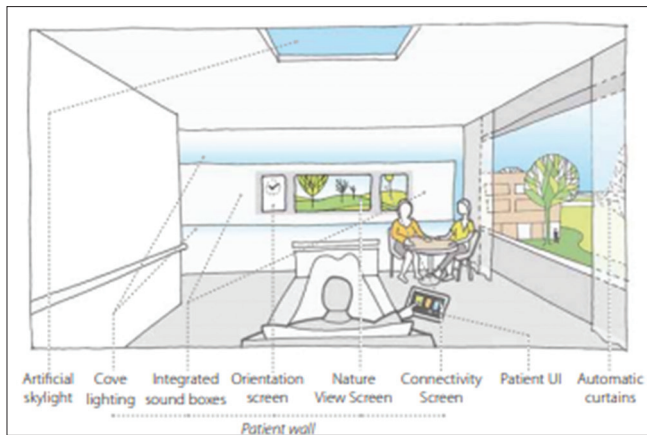


**Figure 2:** Three-phase organization of stroke ward. A design featuring hyperacute, acute, and postacute stroke ward organization is displayed, in addition to the location and to the medical professionals guiding each stage

progress through the stages of stroke recovery may improve patient care.<sup>[39]</sup>

Further, the division of the SW allows more precise control over the specific physical environment in each section which may affect recovery.<sup>[35]</sup> Previous studies have demonstrated that certain stimuli such as lights and noise can trigger aggression and restlessness in recovering stroke patients.<sup>[38]</sup> The elimination of as much of the irritating stimuli as possible may result in enhanced patient care. However, there is an important balance between the clinical environment and the patient's personal environment: the personal environment allows the patient to rest, socialize, and maintain a level of physical activity, whereas the clinical environment allows the care team to effectively tend to the patient [Figure 3].<sup>[39]</sup>

It is evident that the timeline of the stroke of each patient has a direct correlation with the balance between personal environment and clinical environment (e.g. the postacute section may require less urgent patient care). The establishment of dedicated rehabilitation centers and areas for family interaction in addition to the current areas for patient care may result in an improved balance between personal and medical care. The inclusion of windows, plants, and furniture in personal areas has been shown to enhance the perception of a personal environment and should be included as architectural features.<sup>[39]</sup> Further research suggests that patients in a SW are more active when there is a combination of single and multibed rooms when compared to single alone, which may be attributed to increased social interactions and the absence of a feeling of loneliness.<sup>[4,5]</sup> In addition, the availability of the various realms of therapy such as physical, occupational, speech, and recreational therapy within stroke units has augmented recovery in poststroke patients. Stroke units also allow for a smooth transition of these therapy services within the inpatient setting to inpatient-dedicated rehabilitation centers and subsequently to the outpatient setting.<sup>[40,41]</sup>



**Figure 3:** Multibed room in a stroke ward for clinical and personal use. A theoretical patient room design focused on the care of the patient in addition to their physical rehabilitation, supported by an area for social interaction and adequate space for medical intervention

Furthermore, stroke units allow for a multimodal clinical approach with access to telemetry monitoring with cardiology services, PEG tube management by gastroenterology, as well as specific customized recommendations by the physiatrist regarding discharge therapy disposition.<sup>[42]</sup>

## Summary

### Hybrid operating room

A higher level of preparation is necessary for the implementation of a hybrid OR. The various imaging capabilities necessitate greater attention to the requirements of the technology which includes personnel to run it, protection from emitted radiation, and consideration of technical parameters such as acoustic interference. In addition, the hybrid OR must consider the additional personnel and components required for the wide range of procedures that may be performed in an endovascular procedure and a standard operating room. The advanced imaging modalities coupled with the greater procedural capabilities have been and will continue to support surgical innovation and enhanced patient care. With a multidisciplinary, detailed approach, hybrid ORs have the potential to improve patient safety, reduce hospital costs, and provide greater flexibility to physicians and administrators.

### Neurology intensive care unit

NICUs employ a variety of personalized, targeted technology and strategies to provide enhanced patient care. Physical features of the NICU such as dimmable lighting and built-in patient monitoring in addition to the composition of the care team are two primary vehicles for delivering care to modern, severely injured neurology patients. Despite the demonstrated advantages of NICUs in the care of neurologic injuries and conditions, their use remains limited to one-third of the US population.

## Stroke ward

The creation of SWs that consider time restrictions of injury in addition to patient environment may drastically increase the quality of care that patients receive. By utilizing a three-phase organization of the SW and implementing architectural features consistent with the current research surrounding the role of the physical environment in rehabilitation, the recovery of patients suffering from acute ischemic stroke may be improved.

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## Conflicts of interest

There are no conflicts of interest.

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