

Identification of Intensive Care Unit (ICU) System Integration Conflicts: Evaluation of Two Mock-up Rooms Using Patient Simulation

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To address increasing patient demands and acuity, the Calgary Health Region is renovating the intensive care units (ICU) at three of their adult acute care sites. Before finalizing the design plans, mock-up rooms were created at two of the sites according to several proposed room designs in order to identify potential issues during the design phase of the project. All necessary equipment was included within each of the two mock-up rooms so as to nearly replicate a functioning ICU. Evaluations of equipment, room layout and conflicts were accomplished using patient simulation of a cardiac arrest, an acutely ill patient, a palliative care patient and the admission of a new patient. Digital videos, think aloud audio tracks and extensive debriefing sessions were combined and analyzed. Specific category issues were identified including the articulating arms, visibility of the patient monitors, equipment usability, collisions with equipment, and communication issues. Elaboration of each issue and presentation of design recommendations is given.

INTRODUCTION

Intensive care units (ICUs) provide specialized services to patients who have a variety of acute and chronic conditions and diseases. The sophistication of medical equipment, procedures, and communication among healthcare providers (HCP) makes the ICUs a fertile source of adverse events and patient safety solutions (Donchin & Seagull, 2002). For instance, Donchin (2004) examined a specific ICU case that illustrates how technology, the medical staff and physical environment can impact patient information, communication and, ultimately, patient safety. A common problem of ICUs has been called the spaghetti syndrome, which refers to the tangle of tubes and wires originating from the plethora of medical equipment (Cesarano & Piergeorge, 1979; Imhoff, 2004). Reducing the number of tubes and wires would likely reduce clutter and tripping hazards and improve patient access. Critical incidents in the ICU most frequently involve airway management and invasive lines, tubes and drains (Buckley et al., 1997). Removal, incorrect positioning, obstruction and disconnection may result from accidental contact with tubes and wires leading to and from the patient and support equipment. The physical layout of equipment and the patient directly affects the potential for these critical incidents. However, available reviews and research provide limited information about how to limit the occurrence of these and related incidents by modifying the physical ICU environment (Uhlrich et al., 2004).

Towards this aim, Human Factors can provide guidance about new or renovated ICUs so that architects and designers can improve their designs in a compressed time frame. Construction and renovation of hospitals provide a unique opportunity to improve patient and health care professionals (HCP) safety and work efficiency. The specific objectives of

this research were to: 1) determine the adequacy of physical space in the proposed ICUs; 2) ensure that the medical equipment could be accessed and used during common and intense procedures; 3) identify potential unsafe conditions that may contribute to adverse events; and 4) provide timely feedback to designers and to develop generalized ICU Human Factors guidelines for ICU room design.

METHODS

Design Background

The Calgary Health Region (the Region) serves a population of 1.2 million. Twelve hospitals, of which four are comprehensive facilities, contain more than 2200 acute care beds. Due to rapid increases in population and large-scale changes to the Region's infrastructure, renovations to the ICUs at most of the comprehensive hospitals were funded. To ensure that the new ICU rooms and internal configuration designs met staff and patient needs, the Region built a mock up room at two comprehensive facilities according to the architect's blueprints. Input from nurses, doctors, technicians and others went into the specifications for equipment and room layout. Through a number of purchasing processes, the equipment that was to be used in the renovated rooms was integrated into each mock-up for evaluation.

A number of relatively new features were incorporated into the designs, including a nursing station adjacent to each pair of ICU rooms, a ceiling mounted patient lift, and two ceiling mounted articulating arms that were designed to hold necessary equipment (i.e., infusion pumps, physiological monitors, and ventilation equipment). The articulating arms are to replace stationary service columns and wall-mounted equipment currently in use. In addition, movement of the arms

will allow for quick changes to equipment placement, so that access to the patient, procedure carts and medical devices can be adapted to the patient and HCP needs.

The primary difference between the two mock-up rooms was the orientation of the patient in the room. At one site, the patient bed was positioned in the center of the room with the patient's feet pointing towards the door. At the second site, the patient was originally oriented diagonally to the doorway but access issues required staff to change this configuration. The patient was then oriented 45 degrees to the doorway with his/her feet pointed towards the nurses' workstation. The arms in either room were mounted to accommodate these patient orientations (see Figure 1).



Figure 1. Viewed from the nurses' workstation, a palliative Stan undergoes a procedure. Note the orientation of the patient relative to the observation station, the configuration of the arms, and the number of HCP and family members present.

Patient Simulation Scenarios

Four patient simulation scenarios were developed by a number of doctors and nurses to comprehensively test the integration of the equipment, physical environment and ICU HCP dynamics. The four scenarios were common to both evaluations and included an unstable patient with head trauma, an acutely ill patient, a palliative patient, and a new patient transfer. The unstable patient with head trauma went on to suffer a cardiac arrest and had a difficult intubation. The palliative care or end of life scenario involved family members, which were acted by members of the planning and development department. The acutely ill patient was

undergoing continuous renal replacement therapy (CRRT) due to Acute Renal Failure. The new patient was admitted to the ICU post-operatively after bowel resection and splenectomy following a motor vehicle collision. A script of the patient history, order of events (e.g., heart attack, difficult airway, etc.), operational equipment, and personnel were used to orchestrate each scenario.

Additional equipment was available outside each ICU mock-up room, including difficult airway management (DAM) carts, crash carts, CRRT machines, ultrasound equipment, and stretchers. When needed for a specific scenario, equipment was brought into the room.

HCP's, including intensivists, nurses, and respiratory technicians, volunteered from each hospital's ICU's to take part in the mock-up evaluation. Their primary task was to take care of Stan, their simulated patient (see Figure 1). All HCPs were introduced to the general nature of each scenario, the operation of the patient simulator, and the purpose of the ICU room evaluation. Once they understood the scope of the study, they were given an informed consent form to sign.

Simulation and Measurement Equipment

Patient simulation has mostly been used for training purposes (e.g., Gaba, 2004). However, patient simulation has also been used to evaluate the relative usability and safety of medical equipment, such as infusion pumps (Lamsdale et al., 2005). Here, patient simulation was used to systematically understand the interactions among previously un-integrated equipment, physical environments and HCP.

A Medical Education Technologies, Inc (METI) Health Sciences portable Human Patient Simulator (HPS) with a drug recognition system and remote laptop was set up and programmed to replicate the four scenarios described above. Stan was connected to a source of compressed air to operate various pneumatic responses, such as respiration and eye blinks. An operator, with the laptop and a parallel patient monitoring display, choreographed each scenario in accordance with the developed scripts. Vital signs from Stan, including arterial blood pressure, heart rate, oxygen saturation, pulmonary artery pressure, central venous pressure, and body and blood temperature were shown on a LCD monitor attached to one of the articulating arms (see Figure 2).

Video and audio recordings of the scenarios were captured using five digital video cameras positioned around the mock-up rooms. At the introduction of the scenarios, participants were asked to think aloud while they engaged in the required tasks (Ericsson & Simon, 1993). At the conclusion of each scenario, the HCPs who were involved identified any difficulties that they encountered with the equipment or room layout during the course of the scenario. Suggestions for improvements were also elicited. Each scenario lasted about 15 minutes with time between each for breaks and set-up for the next scenario. Participants were thanked for their time and debriefed.



Figure 2. The organization of the infusion pump arm is shown with patient monitor initially hidden. The monitor was relocated so that it was not obscured, but still could not always be seen due changes in the positioning of the arm.

RESULTS

Videotapes were digitized for analysis purposes. Specific think-aloud transcriptions and observed behaviors were tagged, based on two coders viewing of all of the scenario videos (see, e.g., MacKenzie & Xiao, 2007). Data from the video and audio recordings were combined with scenario debriefings to form analysis categories. Specific analysis categories included the articulating arms, visibility of the patient monitor, equipment access and usability, collisions between equipment and HCP, and communication issues. Analyses within each category were then undertaken.

The Articulating Arms

The articulating arms allowed access for HCPs and family to the head of the bed (HOB). The mobility of the arms provided adaptive physical space to accommodate necessary equipment, procedures and presence of HCP and family. With each scenario, participants became more adept at manipulating the arms. In the second mock-up evaluation, the functionality of the arms was limited by a compressor failure during installation immediately before the evaluation. As a result, movement of the arms was more difficult.

Compared to existing Region ICU rooms, the spaghetti syndrome was improved in that the amount of wires and tubes on the floor was significantly reduced as power and gas inputs were directly available on the arms. Large amounts of equipment on the arms reduced the accessibility to some equipment such as power outlets and Code Blue buttons and

increased collisions with protruding equipment, such as sharps containers and trays. Prioritization of necessary equipment by end-users is required due to limited available 'real estate' on the arms. Less critical or infrequently used equipment should be placed elsewhere in the room to reduce congestion on the arms. Suggestions include:

- *Code Blue/Code Red buttons* – should be wall-mounted near the cardiac arrest clock.
- *Sharps containers* – should be mounted on the wall to reduce bumps, potential spills, and needle stick injuries when bumped.
- *Work surfaces* – trays mounted on the articulating arms should be relocated to the corners of the room.

Placement of other equipment on the arms created the potential for physical harm to the patient, HCPs and family. For instance, storage of liquid biological hazards above critical computer equipment or in locations that were frequently bumped was problematic. Access to drawers under the ventilator equipment caused ventilator circuit tubing to be pulled away from the patient. Drawers should be repositioned for easier access.

Confusion between medical air and oxygen outlets is possible, given their close proximity on the articulating arms and non-standardized placement (Hill et al., 2006). On the right arm the oxygen was on the left and on the left arm it was on the right. The converse was true for medical air. The consistency of placement of oxygen and medical air on articulating arms, across ICU rooms and the Region is needed.

Overall, the organization, consistency and prioritization of equipment on each arm will require additional evaluation and iterative design steps.

Visibility of the Patient Monitor

Poor visibility of various monitors (i.e., physiological monitor, ventilator monitor, pump screens) was another issue common to both mock-up rooms and occurred numerous times throughout the various scenarios. The physiological monitor was mounted onto the articulating arm, which housed the infusion pump equipment (see Figure 2). The IV equipment hid the monitor and was often repositioned to access the patient. However, each time that the arms were repositioned, the visual angle of the monitor also changed, reducing visibility. The ventilator monitors were also difficult to see due to the low mounting height on the articulating arm.

Suggestions to mitigate these concerns included pairing the physiological monitor and the ventilator monitor at an elevated location on the ventilator arm, which moved less frequently. Repositioning the IV bags behind the infusion pumps alleviated concerns about visibility of pump screens. Incorporating redundant slave monitors on the wall near the foot of the bed would also ensure adequate viewing angles throughout the room by all HCPs.

Equipment Access and Usability

Accessibility of equipment in the room was a common issue that arose in both evaluations. While the articulating

arms are useful to maneuver mounted equipment so that additional equipment (e.g., CRRT machine and DAM cart) could be brought in for critical situations, the area around the bed quickly became congested. Consequently, staff were frequently forced to reach around equipment, assume unstable postures, and potentially contaminate supplies and clothing during procedures. At the second site, the patient bed was originally oriented diagonally to the doorway, exacerbating this difficulty. With the patient's head near the wall, space at the HOB to accommodate extra equipment, such as ultrasound equipment for vascular access (SiteRite) and procedure tables, could not be achieved without pushing the patient's bed away from the wall.

The patient lift was used during the admission of a new patient scenario. Although the lift was reported as easy to use, its mounting height did not always accommodate shorter HCPs. As well, non-optimal body postures were observed when placing patients into the lift, operating the controls, and removing patients from the lift. Reducing the likelihood of HCPs suffering back injuries in ICUs through the use of the lift and appropriate patient transfer procedures is important (Garg & Owen, 1992). The adoption of proper body positions could be included when teaching how to operate the lift.

Collisions between Equipment and HCP

Interaction between scenario space and time constraints resulted in staff bumping into mobile equipment, fixed surfaces and protuberances such as the sink and shelves. To better understand these issues, each scenario at the second site was evaluated using activity analysis to track where collisions occurred in each scenario and how changes in the articulating arm configuration affected flow (see Figure 3).



Figure 3. Activity analyses of the acutely ill (left) and head trauma scenario (right) with movement paths of the nurses (red), respiratory therapists (green) and doctors (blue) overlaid on a room schematic. Numbered circles represent collisions with equipment within the room. Note the differences in orientation of the arms and resultant pinch points in either layout.

When the flow of movement is constrained by the orientation of the arms, a pinch point is created that is dependent on the available space. When flow is open at the head of the bed, collisions predominately occurred at the pinch-point created between the respiratory equipment along the bed (Figure 3, left).. At this location, bumping equipment associated with airway management has the potential to disconnect critical tubes (Buckley et al., 1997).

When the orientation of the articulating arms pushed the IV equipment against the wall (Figure 3, right), access to the head of the bed was impeded and collisions resulted. HCP collided with the sink, garbage and IV pumps (Figure 3, right, #3, 4, 5). This pinch point, located in the lower left corner of the room, may also reduce the effectiveness of hand washing at the sink.

Communication Issues

At the first site, communication between the nurses' station and ICU rooms was impeded by a glass partition separating the two areas. A means for better communication was recommended. At the second site, an intercom system was installed on the wall behind the patient bed and connected to the nurses' workstation. However, usability issues associated with the mounting location and multiple communication modes hindered its potential benefits. A one-button push option that engaged open two-way communication was suggested by a number of nurses. Redundant visual indicators were also suggested outside the patient room to indicate in which room additional assistance might be needed. The functioning of the Code Blue button and patient call bell systems should be operationally distinctive and located separately from the intercom.

DISCUSSION AND CONCLUSIONS

Comparisons among the different rooms and equipment configurations identified common and unique design aspects that helped and hindered staff access and workflow. Importantly, the articulating arms reduced the number of cords and tubing that impinged on movement around the patient. When complicated procedures required additional space for equipment, the arms allowed for flexible re-configuration of equipment, improving space and personnel access around the patient.

Overall, input into design decisions that affected ICU rooms at the two renovated hospitals was somewhat limited. The timing of the mock-up evaluations and presentation of results to architects and contractors occurred after many critical decisions had been made. A third hospital ICU, which will be entirely new, may benefit from human factors input earlier in the design process.

Design Recommendations and Future Research

The following design recommendations are based on the analysis of the observed interactions among HCPs, the patient

simulator Stan and equipment associated with the specific scenarios used for evaluation.

1) Placement of the articulating arms should afford the greatest range of movement within a room. Thus, the patient bed can be viewed from the nurses' workstation, essential equipment can be positioned around the bed, or the patient could look out the window. Larger range of arm movement translates into greater flexibility in the room configuration over the life span of the room. Ideally, patient access and safety will benefit from an adaptive environment.

2) Equipment on the arms should not present a collision hazard or impedance when moving around the room. Contamination of HCP and other work areas can result from these collisions. Suction canisters, humidifiers, sharps containers, drawers, mounted trays and so forth should be mounted so that personnel can move around these items without conflict. Attaching covers or bumpers would reduce the consequence of striking these items, but may impede access to these items when needed.

3) The transmission of hospital-acquired infections may be reduced by decreasing the frequency of incidental contact between personnel and equipment within the ICU rooms. The addition of more flexible space may achieve this outcome but will require further systematic examination.

4) The placement and resultant visibility of the monitoring equipment is critical to the well-being of the patient. A number of positions were suggested, but not necessarily tested; namely, elevating the monitor on one of the arms, mounting the monitor on the ventilator arm that moves less frequently, slaving the monitor to the television, or adding redundant monitors at the foot or head of the bed.

5) Ease of communication from within and outside the room, such as the nurses' workstation or central nurses' station, requires that ease of use and privacy be balanced, which was not achieved at either site using off-the-shelf equipment. Additional usability testing and evaluation is suggested using appropriate methods (Patterson et al., 2006).

6) Optimization of the IV and respiratory therapy equipment on individual arms will require additional research. Placement of important equipment on the arms should be standardized (e.g., medical air and oxygen) within an ICU and across hospitals within a region.

7) A systems analysis of simulated scenarios before ICU rooms are built demonstrates the potential of the evaluation approach to avert some threats to patient safety.

8) Future study of optimal equipment placement, HCP interaction and room layouts should be undertaken with results contributing to the development of design guidelines for hospital ICUs.

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