Identifying and Reducing Errors in Perioperative Anesthesia Medication Delivery

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Abstract

Purpose: The goal of the Operating Room Systems-based Medication Administration error Reduction Team (OR SMART) patient safety learning laboratory was to study the anesthesia medication work system in order to identify the characteristics of technologies and interventions that might feasibly reduce anesthesia medication errors.

Scope: The work was conducted at two large urban academic medical centers: Johns Hopkins (JHU) and the Medical University of South Carolina (MUSC). We sampled across many different types of anesthesia work, understanding the challenges of work-as-done and applying systems safety principles and evaluation frameworks.

Methods: Sources of data were varied, with formal interviews, formal and informal observations, use of video observation data, word-of-mouth and ad-hoc conversations, hospital and national databases, and information from local incidents. Clinically embedded human factors professionals at both hospital sites facilitated informal sources of data. We explored the variable definitions of error; individual and organizational variability in decision making; how syringes are used, stored, and moved within an operating room (OR); and challenges in non-OR (NORA) anesthesia. The Systems Engineering Initiative in Patient Safety was deployed to model the systems of delivery. From this work, we were able to identify more than 100 possible interventions, which were then prioritized through a series of discussions and workshops.

Results: We identified medication icon labels as a method to improve awareness; a syringe holder hub to improve perioperative medication managements; academic detailing to improve reporting of complications; and eight workspace design guidelines to improve OR design. Significant benefits of medication label icons were found in simulation, with high use in practice observed. The syringe hub demonstrated a high degree of acceptability at one site but substantially less at another. Reporting of complications increased significantly with academic detailing. A virtual reality evaluation of the OR design guidelines that incorporated the icons and syringe hub interventions found that situational awareness, visual monitoring, and available workspace were subjectively improved.

Key Words: medication delivery, decision making, human factors, error, harm, safety, systems

PURPOSE

In the United States, medication errors and adverse drug events cost the average teaching hospital $5.6 million annually, half of which are thought to be preventable. During an anesthetic, frequencies of medication errors range from 1 in 20 to 1 in 407 anesthetics. The goal of the Operating Room Systems based Medication Administration error Reduction Team (OR SMART) patient safety learning laboratory was to study the anesthesia medication work system in order to identify the characteristics of technologies and interventions that might feasibly reduce anesthesia medication errors:

- Failures of intention - making the wrong diagnosis and prescription.
- Failures of execution - failures to deliver the drug that was intended ("five rights")
- Performance-shaping factors - the conditions in which the work is conducted

AIM 1: Explore solutions to failures in diagnosis, selection, and prescribing of intraoperative anesthesia medication. Hypothesis: The cognitive and decision-making processes that underlie appropriate selection of the drug, dose, timing, and route for anesthesia medications can be understood using direct observation of anesthesiology work and focused stakeholder interviews to understand the information gathering strategies of anesthesiologists.

AIM 2: Develop methods to reduce failures in the preparation, administration, and recording of intraoperative anesthesia medication. Hypothesis: Process mapping, task analysis, failure modes and effects analysis, and usability analysis can be used to model the medication delivery process and then develop, predict, and explore the effects of innovative technological and task-based interventions on safe medication delivery performance.

AIM 3: Understand and improve workspace design and safety culture to influences anesthesia medication selection and delivery. Hypothesis: Workspace and organizational factors that influence anesthesia medication selection and administration can be understood and improved through redesign of the work environment and incident reporting.

SCOPE

Study Population and Clinical Context. The work was conducted at two large urban academic medical centers: Johns Hopkins (JHU) and the Medical University of South Carolina (MUSC). We sampled across many different types of anesthesia work, including operating room (OR) and non-operating room (NORA) anesthesia as well as both pediatric and adult procedures.

Medication Errors and Injuries. A medication error can be described as "any error involving the prescribing, ordering, selection, or administration of a medication." Around 80% of anesthesia medication errors reach the patient, with around 30%-40% leading to some form of adverse event or harm. A medication error in the perioperative setting is three times more likely to result in harm that in non-perioperative settings.

The 'Systems' Approach to Safety. It is now recognized that healthcare systems create errors through a complex mix of factors that shape human performance. It is mismatches between these challenges in work demands (as defined by the design of the system) and human abilities that predispose errors that lead to accidents. The Systems Engineering Initiative for Patient Safety (SEIPS) model is a useful for framing human/system interactions in healthcare. It approaches the Input-Process-Output model by considering people, tasks, tools and technologies, physical environment, organization, and external environment.

Understanding "Work As Done." A systems safety approach benefits from what really happens in the complex, sometimes chaotic, unpredictable domains of clinical care work.

Successful processes, technologies, and other interventions need to be designed with the real clinical complexities of work in mind. Ethnography has demonstrated particular value in understanding work as done in general and the implementation of patient safety interventions in particular.

Evaluation Framework. The relationship between process (individual errors) and safety outcomes (adverse events) is non-linear. Clinical processes can be fraught with errors without leading to an adverse event, but morbidity and mortality are sometimes unavoidable. Consequently, the evaluation of safety practices based only on patient outcomes requires large sample sizes and is not ideal for studying the individual components that comprise a comprehensive safety management system. Our evaluations were therefore multi-dimensional; based on surrogate measures of clinical performance and process, rather than specific clinical outcomes; and geared to find not only negative behaviors and deviations from performance but also positive, safety-creating performance.

Impact of COVID on the Research. The global COVID pandemic had a number of impacts on the research at a critical stage. It prevented the Clemson team from travelling to either of the two clinical sites, also halting onsite observations and focus groups at MUSC and JHU by any team member. This meant that, for example, repeating MUSC observations and studies at JHU, as planned as part of the Clemson work, did not happen. This also had a wider impact on peripheral team members, including the JHU design team student who found it difficult to continue participation. We were able to adapt in a number of ways. First, we used existing databases or data sources, such as the FDA-MAUDE database (for exploring device failures) and existing video recordings of OR work (which was used for the syringe movement study). We also used other data collection approaches, such as surveys, and remote ideation approaches, such as the MIRO online post-it note application. Overall, it impacted our project in terms of the development and implementation of interventions, for which there might have been more if we had not been locked down, and in terms of multi-site data collection and implementation. However, we feel that overall this did not detract from the quality or volume of the work and simply drove a different emphasis.

METHODS

Sources of data were varied, with formal interviews, formal and informal observations, use of video observation data, word-of-mouth and ad-hoc conversations, hospital and national databases, and information from local incidents. One key strength of the research team was having clinically embedded human factors expertise at both hospital sites that facilitated the less formal, or legally protected, sources of data. This identified a range of organizational features, including:

- The dynamic decision making that is required (decisions are not made at a single moment, but is part of ongoing decision / action / monitoring loop).
- The diverse information sources used to make decisions
- The potential unreliability of those data sources and the trust placed in them
- The diversity of approaches to decision making
- The lack of storage, preparation, and holding space for drugs
- The visibility, layout, and excess movements found in different ORs
- Error-inducing designs that are not recorded anywhere
- Limited systems thinking
- Highly variable definitions of error
- Lack of clarity over what and when to report as an incident
- Under-reporting of incidents
- Poor visibility of medication labels
- Regulatory frameworks that could limit the ability to “do the right thing” locally.

The detailed analysis, interventions and evaluations were conducted within this general conceptual and data collection framework. The project was then managed with themes and sub-studies focused on the major goals of the three aims, with the systems engineering process – problem definition, design, development, and implementation – and final holistic evaluation conducted in Virtual Reality.

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Problem Definition

Definitions of “Error” and Harm

The multiple ways in which patient safety-related events are represented and defined can create confusion around how frequency rates are determined, how causation is understood, and how interventions should be designed to improve patient safety. Our analysis found that “medication error” is defined in multiple ways that focus solely on patient outcome, causation, or both, which can lead to problems with synthesizing, interpreting, and overall sense making in relation to anesthesia medication safety. A definition of “medication error” should include a causation component that represents the depth of causative factors outlined in modern systems view representations of safety as well as a patient outcome component that focuses on harm and the potential for harm. Creating a standardized set of definitions for patient safety-related terminology in the context of anesthesia would aid our ability to build a body of knowledge in this area.

DECISION MAKING: Information Sources

Much of the literature on medication administration failures in anesthesia has focused on what the provider has done wrong. In reality, the multitude of factors that contribute to a medical decision are much more complex. The relationship between decision making and information sources, particularly medical devices, was analyzed with a systems approach to demonstrate how fallible information sources have the potential to lead to harm in anesthetic patient care. We sought to explore the information sources that anesthesiologists use to make different perioperative decisions, the ways in which those information sources might be inaccurate or misleading, and the strategies that they use to resolve ambiguity and reduce the opportunities for their decisions to be misled.

Decision making in anesthesia relies on the provider’s ability to integrate information from a wide variety of sources and use that information to predict outcomes. We explored how 19 different anesthesia decisions (n=7 preoperative, 7 intraoperative, and 5 postoperative) were informed by a range of devices, technologies, and information sources. Different information sources were used for different decisions, and not all sources are viewed as equally useful or reliable.

Providers reported using the EHRs, anesthesia monitor, and vital signs monitoring more often than other information sources.

Devices and other information sources regularly fail or are unreliable in common or predictable ways. All providers reported being more cautious and less trusting after the device malfunctions. When devices were described as inaccurate or fallible by providers, many of them reported still using the device. When asked what machine they trusted most in these situations, providers reported trusting the anesthesia monitor and vital signs monitor over other devices. Prioritization and integration across multiple sources, and specific behaviors to enhance the reliability of the data sources at the outset, based on experience and trust, help to avoid the consequences of unreliable or failing equipment.

DECISION MAKING: Individual Variability

Clinicians are generally aware that there is variability in how their work can be done, yet it is difficult to quantify or describe these differences in ways that are useful for clinician and engineering teams to design and implement supportive tools and interventions. The objective of this study was to elucidate this divergence between anesthesia providers by highlighting their variability in how they anticipate problems, seek information, and take action during a case. Using vignette-based interviews conducted with anesthesia providers in order to examine the variability in their cognitive processes of managing a case, our results were used to shed light on the impact of individual variability on decision making and medication delivery.

We found two primary converging strategies: (1) seeking information from sources that were likely to inform anticipated problems and (2) seeking to take preparatory actions in response to anticipated problems. This is consistent with prior studies. There were also many instances when the participants diverged from one another. At times, variability was mainly due to divergence in problem anticipation. For example, providers anticipating that the patient may be cold sought information from different sources, and took different actions, than providers who were instead anticipating that the endotracheal tube may be placed incorrectly. However, there were several instances in which information seeking and action taking varied even when participants anticipated the same potential problem or complication.

Our findings suggest that we cannot consider one of (1) information seeking, (2) problem anticipation, or (3) action taking to be the predominant cause of variability in the management of a case; an anesthesia provider may diverge in just a single component, or they may diverge in every component.

DELIVERY: Drug Use and Dosing

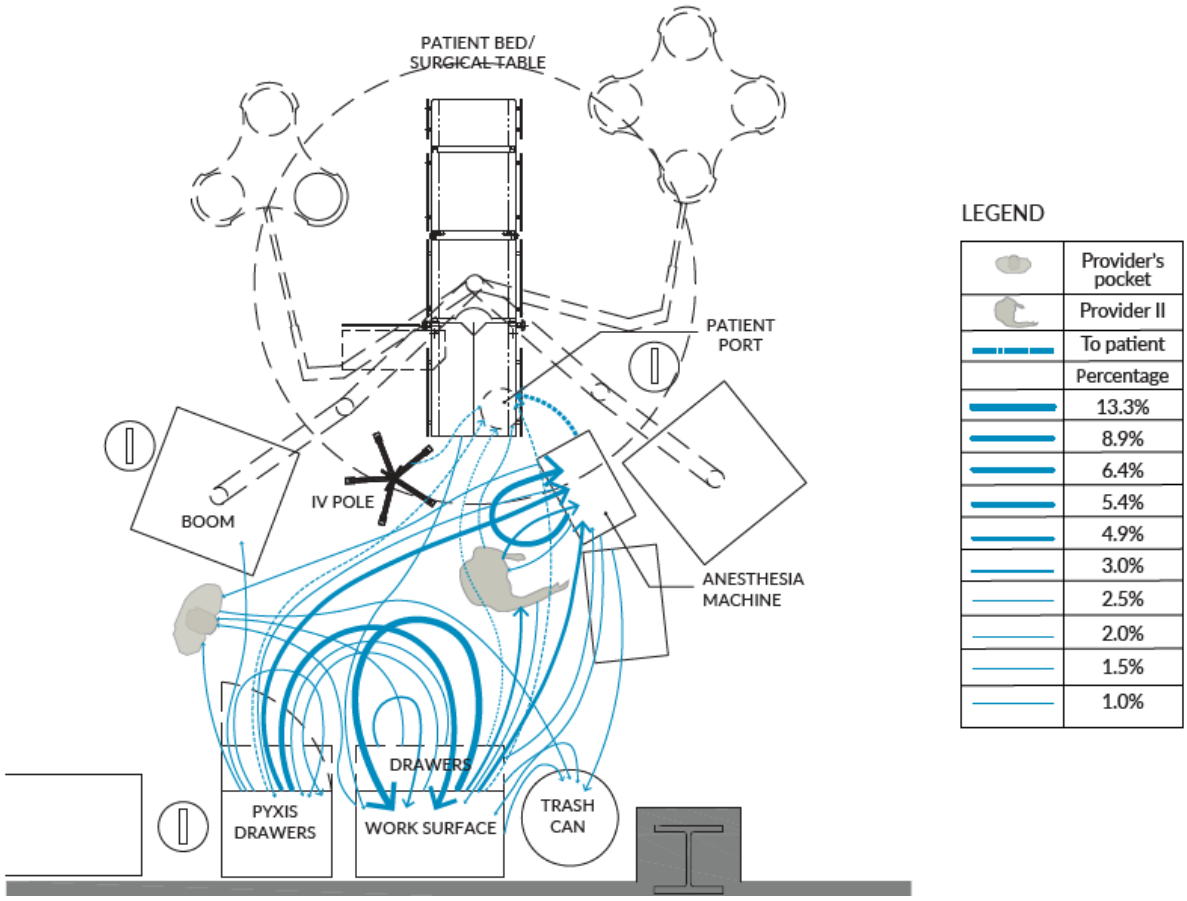
Data for this analysis were compiled from the Epic Medical Record and other system databases in a large mid-Atlantic health system. The dataset initially consisted of 535,190 anesthesia cases that occurred at five hospitals (coded as hospitals A, B, C, D, and E). Only cases in which the patient received general anesthesia and the patient was intubated were included. Additionally, pediatric cases, cases with an ASA score of 5 or 6, and cases with missing or nonsensical information were excluded. To create a set of comparable cases between hospitals, data were further limited to only include cases that were in a service line that had at least 50 cases at each hospital. The final data set consisted of 97,832 cases.

We identified large, significant difference in usage rates between hospitals for midazolam (max difference of 48.4%), vecuronium (43.2%), and lidocaine (40.7%); smaller but still statistically significant difference for fentanyl (8.9%) and ondansetron (7.9%); and no difference in utilization of propofol between hospitals. Similarly, the median dose of medications varied per hospital. Overall, this work finds medication use and dosing to be highly variable, with each medication dose being the result of a complex interaction among the SEIPS factors.

Practitioners and institutions each have their own unique methods of practice; thus, any implementation of standard practice is 1) variable depending on which practitioner and hospital the standard practice is based on and 2) likely to be resisted by other practitioners and hospitals with different practices. Furthermore, the complexity of the anesthesia system leads to the potential for standardization at any number of the many steps in the anesthesia process, and, so far, it is unclear which of the many aspects of anesthesia could or should be standardized. This work serves as an example for how we can investigate variability and use that knowledge to inform standardization.

DELIVERY: Syringe Movements

Understanding how syringes are used, stored, and moved within an operating room (OR) is critical to design interventions that help reduce the risk of adverse events that also support the anesthesia work. Our study aimed to examine how syringes and medication move through the environment and the anesthesia work area and are used for medication administration within anesthesiology delivery.



We conducted an observational study of 14 laparoscopic surgeries with nine Attending Anesthesiologists. There were four camera views of the operating room, with one camera focused specifically on the anesthesia work area. The interoperative surgery duration for the 14 surgical cases was on average 75.6 minutes (standard deviation=44.8 minutes). In total, there were 203 medication-related events that involved a syringe. These syringe events mainly occurred during the intraoperative phase (65%), followed by preoperative phase (31%) and postoperative phase (3.9%). On average, 14.5 syringe movements occurred in each case. For the cases included within this study, the syringe movement rate was about 7.7 times per hour (or 0.129 times per minute) on average. Of the 203 syringe movements, the medication was directly administered to patients in 48 (23.6%) of these events. We estimate that there were approximately 4.2 syringe movements for each medication administrations across these cases.

When a syringe was used to administered medication to the patient (either through the IV pump or the patient port), it was picked up from one of eight locations in the work area: anesthesia machine, work surface, pyxis drawer, work surface drawer, another provider, IV machine, patient bed, and pockets.

Our studies suggested that the final location of syringes and vials in each event varies and includes irregular location, such as patient bed and provider's pockets. Future work should track individual syringes and investigate providers' decision-making strategies to design interventions that reduce the risk of patient harm while supporting provider resilience in providing care.

CONTEXT: Incident Reporting

It is well acknowledged that incident reporting under-represents the frequency of events, possibly by a factor of 20. What is less well acknowledged is that certain types of events are more likely to be reported than others, and, within each type of event, different levels of risk and harm yield different reporting frequencies. This is partly a consequence of the very well acknowledged effects of hindsight and outcome bias, but it also extends to the ability to discern 'right' from 'wrong,' which is far easier when considering administration (a heavily proceduralized activity, in which deviations before harm are observable) than prescription (cognitive, unobservable, and only identifiable as problematic in retrospect).

Analysis is also a function of what is reported and the limitations of the classification systems, rather than a true reflection of what happened in each case. Not all clinicians are equally aware of just how tasks, technologies, workspace, and organization interact to influence their performance, so details are often omitted from the reports themselves. Moreover, causality is neither linear nor deterministic, so classification systems that require attribution of complex, interacting, multifactorial events to a single causal factor are by their nature simplistic and misrepresentative. Thus, the attribution of these events offers little insight into the causes, and even less as to the solutions. This is not to say that there is no value in these reports and data, but rather we need to extend our understanding and assessment of these events and fully recognize their deficits.

CONTEXT: Operating Room vs Non-Operating Room Anesthesia

Non-operating room anesthesia (NORA) describes anesthesia delivered outside a traditional operating room (OR) setting. NORA cases have increased significantly in the last 20 years and are projected to account for half of all anesthetics delivered in the next decade. In contrast to most other medication administration contexts, NORA is performed in high-volume, fast-paced environments not optimized for anesthesia care. These predisposing factors combined with increasing case volume, less provider experience, and higher-acuity patients increase the potential for preventable adverse events. A review of the literature from January 1, 1994, to March 5, 2021, was conducted. After completing abstract screening and full-text review, 30 articles were selected for inclusion. These articles suggested higher rates of morbidity and mortality in NORA cases compared with OR cases. This included a higher proportion of death claims and complications attributable to inadequate oxygenation and a higher likelihood that adverse events are preventable. Despite relatively few attempts to quantify safety concerns, it was possible to find a range of systems safety concerns repeated across multiple studies, including insufficient lighting, noise, cramped workspace, and restricted access to patients. Old and unfamiliar equipment, lack of team familiarity, and limited preoperative evaluation are also commonly noted challenges. Applying a systems view of safety, it is possible to suggest a range of methods to improve NORA safety and performance.

We also surveyed anesthesia providers (anesthesiologists, residents, and certified registered nurse anesthetists [CRNAs]) at an 864-bed academic medical center with a high NORA case volume. The survey explored perceptions of the frequency of critical incidents in NORA, gathered descriptions of these incidents, and examined different causes (e.g., environmental, organizational, personal, and teamwork/communication). The survey was sent to 174 anesthesia providers at the MUSC; we received responses from 94 providers, resulting in a response rate of 54.5%. Of the 94 respondents, 43.6% reported experiencing a near-miss or patient-harm event.

Half of the participants, 21 (51%), experienced near-miss events multiple times a year, but only six participants (14.6%) experienced multiple harm events a year. The frequency of near-miss and harm events did not differ by years in practice. Of the 27 participants who responded to the survey question, only 33% formally reported the event(s) through the institution incident reporting system.

Although anesthesia providers elaborated a broad range of system issues in NORA care, the risk factors rated by providers as 'highly likely' to contribute to an incident were related to the NORA physical environment. This included cramped workspaces, limited access to the patient and equipment, and lack of standardization across NORA settings. Non-operating theatre anesthesia suites may be 'small, dark, and cramped' with restricted access to patients during some procedures. Redesigning suites, workspaces, and the distribution of tasks within them may be critical to improving safety and quality of care. Additionally, coordination and communication issues noted by anesthesia providers in the open-response section, including lack of support during preoperative processing and lack of information needed for the anesthetic plan, are also amenable to intervention. Understanding the unique challenges associated with providing anesthesia care in NORA settings is critical to improving system safety and patient outcomes.

Design

Systems Modelling

Systems analysis is an important method for understanding how success or failure in medication delivery is delivered via the components of and interactions between the different parts of the anesthesia system of work. We developed a systems model founded in the SEIPS 2.0 framework to describe the anesthesia medication delivery process. We also applied the SEIPS 101 tools, which reveals the anesthesia medication delivery system to be complex and non-linear, involving multiple people, devices, information sources, locations, and outcomes. Completion of the key assessment, diagnostic, preparation, delivery, and monitoring tasks requires the coordination and integration of multiple electronic devices, supplies, information, and medications. Multiple patient, family, personal, professional, organizational, and regulatory outcomes need to be met. Patient interactions, specific teamwork activities, and technologies that aid in provider decision making and medication delivery act as facilitators. Barriers usually stem from the broader work context, such as lack of familiarity with workspace, providers or devices; unwillingness to collaborate; and uncertainty, time pressures, workspace design, and device functionality.

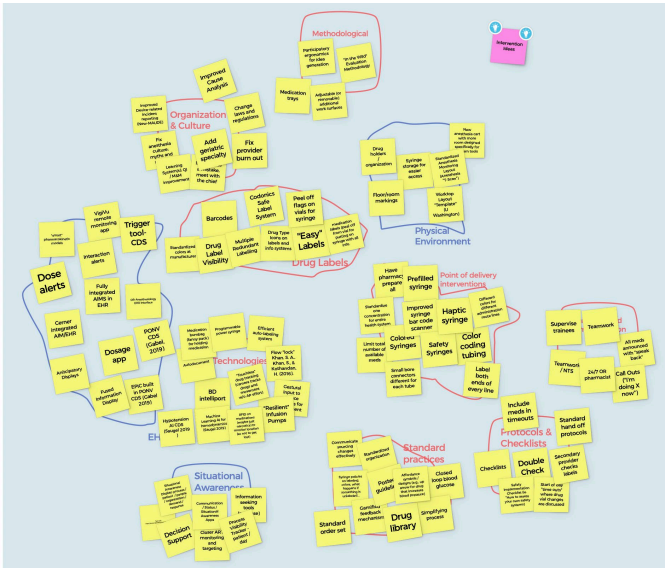
Successful anesthesia medication management remains reliant on individual provider expertise, vigilance, and careful adaptation, but many other systems components affect performance, often in indirect or non-linear ways. The potential variability in working environment, organization, or context means that, though some standardization might reduce unnecessary variability, over-standardization, especially of some human actions, would highly undesirable. Patient-centered care requires adaptation to a range of patient, surgical, team, and organizational contexts.

Adapting to multiple factors and outcomes means that some interventions come at the expense of other factors and outcomes, often in the form of shortcuts. For example, although barcode scanning might lead to safer intravenous drug administration, it can increase interactions with devices or other tasks, increasing workload, eventually leading to shortcuts that create new paths for adverse events. Additionally, although some standardization (of devices, processes, workspaces) could be advantageous, there is also no "one right way" that fits every anesthesia medication delivery scenario. Standard color-coded syringe labels or icons that distinguish between classes of drugs have been suggested to potentially lead to an increase in syringe swaps between drug classes due to newly developed shortcuts. Common teamwork and communication interventions, such as closed-loop communication, double checks, or formalized communication channels, would benefit from a broader range of stakeholders, including patients, families, and supporting roles. Because communication with other team members and coordination of people, tasks, and technologies attempt to standardize behaviors that are required for the necessary adaptation, they may be rejected or lead to undesirable outcomes on other dimensions (e.g., increasing costs or professional dissatisfaction).

This demonstrates not only the importance of considering personal, professional, regulatory, financial, and other organizational requirements in medication safety but also provides methods for understanding their influences on individual behaviors.

Idea Generation

We hosted workshops at which individuals experienced in clinical work, systems engineering, and human-centered approaches to solutions used data from our systems models to generate a list of more than 100 potential solutions. Solutions and approaches generated from the workshops were categorized and ranked based on the themes suggested by resilience engineering: 1) improve expectation, 2) improve response, 3) improve monitoring, and 4) improve learning.

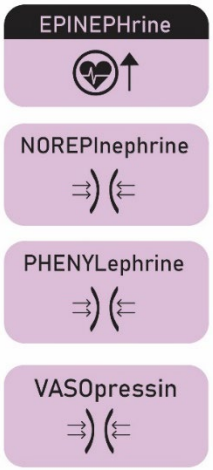


Engineering principles include visibility and simplicity (Can anyone see what the system is doing right now?), adaptability (Can this fit a range of different contexts?), interacting interventions (not "one best way," but multiple integrated approaches at different levels within the system), adoption and implementation (How likely is the intervention to be used?), and explicit tradeoffs (understanding that everyday work requires people to make safety/cost/throughput decisions that vary with context).

Development

DECISION MAKING: Medication Icons

Icons are used widely in everyday life. They aim to provide instant recognition, emphasize differences in information presented, improve instructions, and increase understanding, providing easy-to-understand "knowledge in the world." Addition of icons to medication labels in an OR setting could allow for improved discrimination, better visibility, and more easily processed information that might reduce the opportunities of medication administration failures.

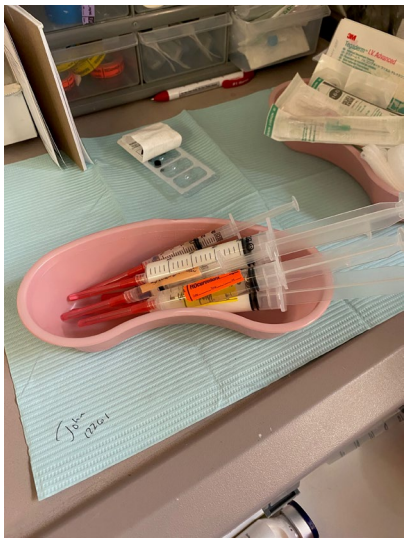


Initiated by a local clinical incident, a set of icons was designed for use on intravenous (IV) bags through an iterative process that included anesthesiologists, designers, pharmacists, certified registered nurse anesthetists (CRNAs), and human factors (HF) engineers. A user-centered design approach was utilized to design the icons, involving identifying each icon's meaning and potential value to the clinicians. The design team conducted focus groups with anesthesia providers multiple times to obtain their feedback on icon design and label design. The icon designs were iteratively designed with the use of color, different font styles and sizes, and information about concentration.

The focus groups discussed the difference between pediatric and adult concentrations and how these can be a source of error in anesthesia medication delivery. Icons were designed for concentration, and a few design iterations were tested with text. The focus groups were centered around understanding the role of vasoactive medications and coming up with graphical means to represent those through icons. After multiple design iterations, the researchers designed secondary labels for all vasoactive medications, which incorporated each medication's newly created icon, and an icon for typical concentration used for pediatric and adult patients. The labels also contained the designated color and medication name in Tallman lettering based on the guidelines in the Statement on Labeling of Pharmaceuticals for Use in Anesthesiology by the American Society of Anesthesiologists.

Before deployment, we sought to test the value of the icons to improve discrimination between different IV medications in an OR. Our study found that the addition of carefully designed set of icons to standard pharmacy labels improved discrimination and confidence of IV medication identification in a simulated OR setting. The presence of icons significantly increased the distance at which IV medications could be identified, albeit only by a small margin. When icons were present, participants were also significantly more likely to be more confident in medication selection. These preliminary results were encouraging for the value of medication icons as an alternative, or an addition to, color coding and Tallman lettering for improving identification. This study is one of the first to provide evidence to support the use of medication icons as a way to improve medication identification and thus reduce medication harm.

DELIVERY: Syringe Hub



The current organizational method in many institutions is to make do with what is convenient. For many, this is a single compartment kidney bean trays, which are quick, cheap and portable. The makeshift solutions, such single compartment kidney bean trays, have been linked to potential or actual harm.

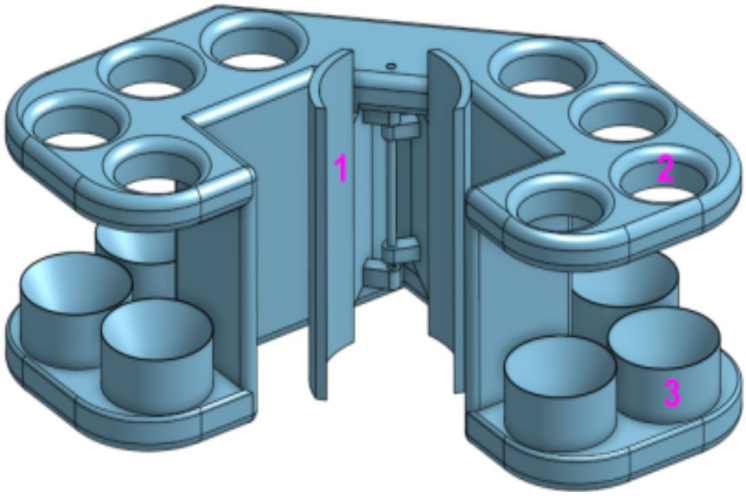
The development of the syringe organizational hub was based on observations of anesthesia medication delivery and contextual interviews, inspired by past designs and developed based on focus groups, interviews with providers, a survey, and in situ testing. We identified several design criteria necessary to encompass a sufficiently wide range of use cases to address the issue of scalability and widespread adoption:

- Able to hold at least seven syringes
- All holes can hold syringes ranging from 1 mL to 20 mL in size
- Able to be easily held in one hand
- Attachable to the IV pole so the syringes can be in a more centralized location
- Able to rest on a flat surface without falling
- Able to be easily cleanable to reduce contamination
- Clamp can attach to poles ranging from .5 in to 2 in in size
- Clamp can be operated with one hand
- Able to securely hold syringes so as not to fall while remaining easily removable

We then used a 3D printer to manufacture several prototypes. As each prototype was designed, it was shown to providers for feedback, and an in-depth interview was conducted. Each iteration was modified based on provider feedback and OR SMART data. Seven prototypes were developed iteratively.

The three primary modifications made concerned the clipping mechanism, the syringe containment mechanism, and the shape. The final iteration is depicted here.

Final CAD model of the syringe organizational hub featuring a spring-loaded clip to facilitate attachment to an IV pole (1); holes (2) with tapered wells (3) to allow for easy syringe insertion and removal while maintaining the ability to safely hold syringes; and a hexagonal shape that is tight to the IV pole to ensure stability while at the same time offering plenty of space for the eight syringe holes, each capable of holding standard syringes ranging from 1 mL to 20 mL.

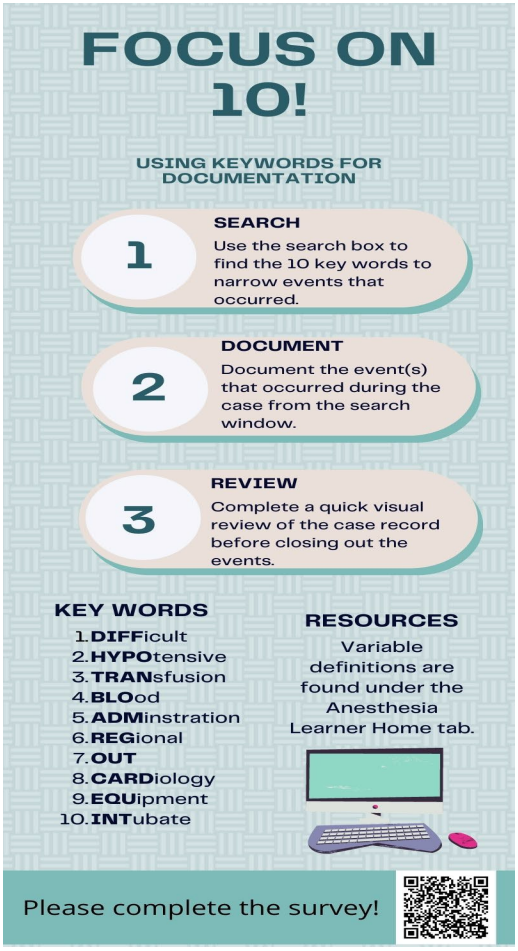


CONTEXT: Improving Reporting of Complications Through Academic Detailing

Investigation of the low reporting of the National Anesthesia Clinical Outcomes Registry (NACOR) perioperative complications revealed that staff did not understand why the module was added and lacked knowledge of the origin and definition of events. A needs assessment was completed to develop an evidence-based intervention. Eight anesthesia providers were interviewed: three resident physicians, two faculty anesthesiologists, and three CRNAs; they were asked six open-ended questions.

Conclusions from the interviews were that major barriers included education, time, and lack of feedback from previous projects. Staff felt they lacked adequate knowledge, time, and resources to properly complete the module in the EHR. They also believed a disconnect exists between what is viewed as the right thing to do, be transparent with adverse events, and what will happen if you do the right thing, make the provider feel vulnerable, have a perception of personal failure, and have fear of disciplinary action.

Academic Detailing (AD) is an interactive educational program for healthcare professionals with over three decades of research backing its effectiveness to promote behavioral change among clinicians. Successful AD programs use strategies that include defining a specific behavioral and educational objective, enlisting the involvement of clinician opinion leaders in the design and implementation of the educational interventions, and using direct professional connection with 1:1 peer interaction. An Academic Detailing program includes seven key elements: introduction to establish credibility, baseline needs assessment and motivational factors, key messages with features and benefits, understanding barriers and enablers, identifying and handling objectives, summary with repetition of key messages, and closing with the opportunity for follow up. Using Academic Detailing to increase reporting of NACOR perioperative complications was seen as appropriate.



CONTEXT: Workspace Design Guidelines

Current standard anesthesia workspace layouts result in anesthesia providers performing their tasks in dispersed locations, which can lead to increased head and body rotation and movements. These movements can cause disruptions, fatigue, and musculoskeletal and safety issues (Guy et al., 2011). Because anesthesia work surfaces are often cluttered, which may lead to contamination and errors, it is necessary to ensure that clinicians have an organized area in which to perform their tasks. Moreover, due to suboptimal positioning and equipment accessibility, many anesthesia providers are also challenged by personnel moving into and through their workspace, causing distractions and contamination. The observations and literature findings were supported by vetting process and channeled into eight evidence-based design guidelines, which categorize the problems and direct the development of potential design solutions while considering tradeoffs between different recommendations. Guidance included why it was important and how to achieve the aims:

- Locate critical tasks within a primary field of vision. The anesthesia workspace should facilitate the need to cover a wide angle of viewing, working at multiple locations and task switching, enabling anesthesia providers to optimize task performance and overall situational awareness during all phases of surgical procedures.
- Eliminate travel into and through the anesthesia zone (for other staff). The design of the anesthesia workstation should eliminate unnecessary staff travel into and through the anesthesia zone to eliminate safety risks, disruptions, and accidental disconnections and improve circulation and flow in the operating room.
- Identify and demarcate a distinct anesthesia zone with adequate space for the anesthesia provider. The anesthesia workspace should be located in a demarcated and distinct anesthesia zone with adequate space and the required equipment and storage to perform tasks effectively without requiring unnecessary movement in the OR.
- Optimize the ability to reposition/reconfigure the anesthesia workspace. The design of the anesthesia workspace should facilitate the optimal repositioning/reconfiguring of the anesthesia workspace to facilitate workflow, improve ergonomics, and accommodate the changing needs in the OR over time and to reduce the risk of environmental hazards.
- Minimize clutter from equipment. The anesthesia workstation should have minimal clutter from equipment to reduce environmental hazards and disruptions and minimize contamination in the anesthesia workplace.
- Provide adequate and appropriately positioned surfaces for medication preparation and administration
- Provide adequate space for critical tasks, such as medication preparation and administration. These tasks can be performed safely without disruption or contamination while at the same time allowing the anesthesia provider to maintain a visual connection to the patient.
- Optimize task and surface lighting. The medication preparation areas, whether on the top of the anesthesia workstation or the medication drawer, should have sufficient task and surface lighting to improve the visibility necessary for medication-related activities.

RESULTS

DECISION MAKING: Medication Icons Implementation

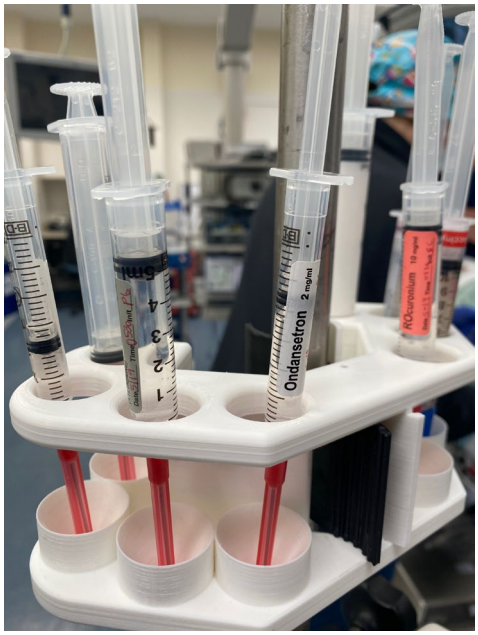
Four medication labels were previously developed for the following commonly used LASA drugs: epinephrine, norepinephrine, phenylephrine, and vasopressin, incorporating Tallman lettering, color coding, and iconography. This study sought to (i) explore their usefulness and appeal with clinical staff through surveys and (ii) audit the active in-surgery use of labels in MUSC OR suites. The survey, administered 2 weeks after the start of the study, contained 16 questions, including questions related to role demographics; perceived usefulness, visibility, and awareness of medication delivery; etc.

Four comment sections allowed for written feedback. Observational data was collected by sampling on 3 days in a 2-week period across three sites. In total, 49 survey responses were received through REDCap, including responses from CRNAs (n=24), attendings (n=13), a fellow (n=1), residents (n=4), anesthesia techs (n=0), pharmacists (n=5), and pharmacy techs (n=2) from various sites. Responses differed by role on care team. The labels were well received by pharmacists and OR staff but were viewed with indifference by anesthesia providers. Tallman lettering was reported as being utilized most for medication identification. Usefulness of color coding was rated high. Audits showed high compliance of usage during the implementation study. Observational concerns were raised during audits. Added workflow of additional labels and the possibility of erroneous label application could be mitigated by applying a single label at the compounding pharmacy (i.e., the anesthetic supplier) to remove one step and minimize risk of error. Other medications that were identified with the potential to benefit from icon labels included Precedex, insulin, and remifentanil. This work has contributed to a larger project proposal that seeks to extend the development of icons to dose, route, and action while extending to intensive care unit work and studying implementation more broadly.

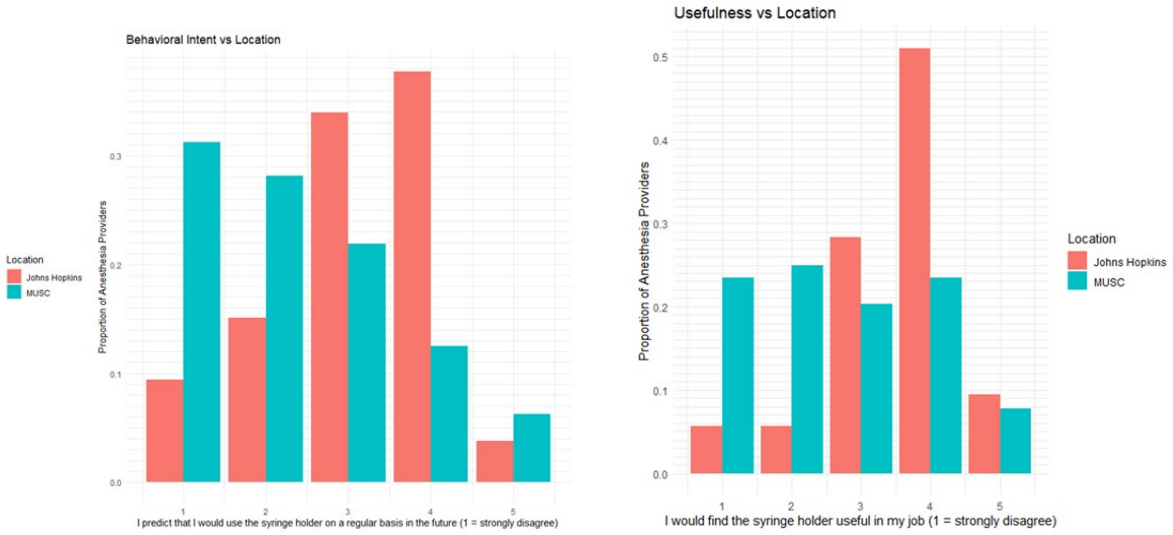
DELIVERY: Syringe Hub Implementation

The perceived acceptance of the device was explored utilizing the Technology Acceptance Model, completed in REDCap after watching the video. Four linear regression models (one for each TAM construct) were used to assess whether demographic variables such as anesthesia role, hospital system, or years of experience significantly influenced the TAM constructs. In total, 120 anesthesia providers responded, of which three had incomplete responses and were excluded for analysis.

Of the remaining 117 respondents, 36.8% were CRNAs (n=43), 33.3% were attendings (n=39), 25.6% were residents (n=30), and the remaining 4.3% were anesthesia technicians (n=2) or fellows (n=3). Most respondents had fewer than 5 years of experience (n=43) or between 6 and 10 years of experience (n=26). The responses were evenly split between the two hospitals surveyed. Anesthesia provider perceptions of the Likert scale (1-5) TAM constructs are reported as follows: On average, respondents had high (>3) Ease of Use ratings but moderate to low (≤3) Usefulness, Attitude, and Behavioral Intent ratings. Results of the linear regression models revealed that participants at the Southeastern hospital system had significantly lower Usefulness ratings (P<.001), Attitude ratings (P<.001), and Behavioral Intent ratings (P<.05). No predictor significantly influenced Ease of Use ratings. Neither anesthesia provider type nor having more than 10 years of experience significantly influenced the ratings of any TAM construct.



Of the 117 respondents, 53 (45.3%) chose to give qualitative feedback. The qualitative analysis found that the five most frequently noted concerns were cleanliness (n=17) (i.e., the syringe holder would be difficult to clean), the use of the device would require process deviation (n=17) (i.e., the addition of this syringe holder would not fit into how the anesthesia providers does their job or would add an unnecessary step to their job), the device would create inefficiency (n=9) (i.e., the syringe holder would act as an impediment or slow down the administration of medications), it would create increase IV pole clutter (n=8) (i.e., the syringe holder would interfere with the IV lines), and concerns about stability (n=7) (i.e., syringes would fall out of the syringe holder). Anesthesia providers at the Southeastern hospital system reported many more of these concerns than providers at the mid-Atlantic hospital system. In addition, CRNAs had many more process deviation concerns than other roles, and attendings had fewer inefficiency concerns than other roles.



We found that the acceptance of the device was significantly lower at non-native institutions despite the device's objective: improvement of syringe organization. Though we were able to identify workflow integration as a large barrier to acceptance, we could not identify the smaller, more specific, barriers to acceptance. We found that an effective device is not enough when seeking adoption at non-native institutions, but it is necessary to address the small barriers to acceptance if widespread adoption is what you desire. This can only be done by incorporating non-native institutions into the design process while trying to identify and address the smaller barriers to acceptance.

Syringe Hub effectiveness

To assess the impact of the syringe organizational hub on the work practice, we performed in-situ observations of anesthesiology residents using the device during cardiac surgery cases at a large academic hospital in the mid-Atlantic United States. We observed a total of 31 cases through convenience sampling (18 of which utilized the syringe organizational hub and 13 of which used the traditional standard, kidney, basin). A logistic regression model was used to predict the number of syringe movements as well as predict the use of the hub.

There were significant differences in the quantity and quality of syringe movements between the two systems. Cases in which a syringe hub was used had significantly less syringe movements per hour (M=11.5, SD=4.8) than cases in which a kidney basin was used (M=16.7, SD=6.00) ($p<.05$). The figure above compares the origin of a syringe prior to delivery with (A) the locations mapped on the work area and (B) the percentage of syringes of medication delivered from those locations. When the hub was used, most medication deliveries originated with the hub.

Linear regression predicts that the percentage of medications delivered from the syringe holder (M=.399, SD=.261) was significantly higher than the percentage of medications delivered from the kidney basin (M=.112, .227) ($p<.01$).

The results of this in-situ observation study suggest that a provider's use of the syringe organizational hub significantly reduced syringe motion. Not only were there fewer syringe movements, but, when medications were delivered to the patient, there was less variation in the locations from where the syringes came, greatly reducing deliveries from the patient's bed and the work surface. These results suggest that the device was successful in reducing syringe movements and consolidating the location of drug delivery which may assist in reducing overall complexity of the syringe storage. This shows that a simple device can have a significant impact on the operating room workflow.

CONTEXT: Improving Reporting of Complications through Academic Detailing

There was a statistically significant increase in the number of reported events, from 55 in 2021, before intervention, to 134 in 2022, post intervention. Of the 36 CRNAs who participated in the intervention, 18 had a positive change in reporting behaviors. Twenty-nine REDCap surveys (83.3%) were completed by the CRNAs who reviewed the intervention. The results indicated that participants generally were very satisfied with the AD program intervention, as they most frequently selected the most positive scale response. Staff members expressed concerns regarding the amount of dedicated time needed to enter the "10 key words" provided to them as a guide for quicker and easier identification of the perioperative complications. Also, the time required to meet with the academic detailer may have contributed to lower scores reported for those two questions. The use of Tallman lettering in the key words provided more visual cues to facilitate noticing, recalling, and complying with documentation by staff. These visual cues facilitated reporting through the ability to quickly identify complications and increased the speed of visual search performance as well as made providers aware of the 90 NACOR perioperative complications.

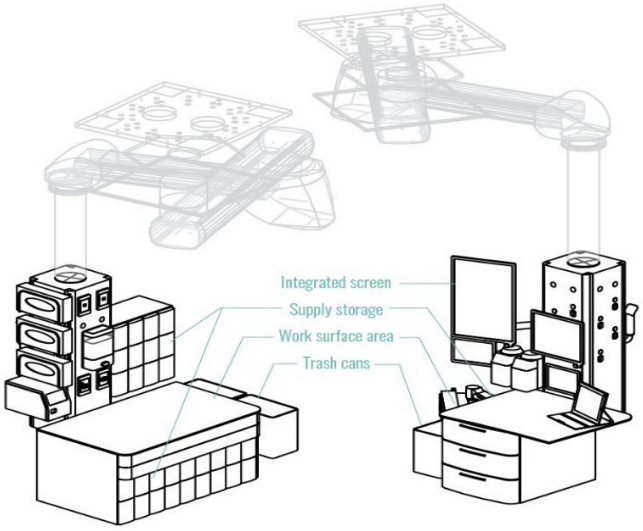
Staff expressed concerns regarding the malpractice and legal ramifications of reporting adverse events after the recent prosecution of RaDonda Vaught. No medication errors were reported during the data collection period, which may be reflective of the proximity of the case to the intervention. Staff also expressed reluctance to document any event that was not readily apparent by vital signs or flowsheet data in EPIC. Legal and malpractice concerns were addressed during the AD sessions and by reinforcement of proper documentation of events in the intraoperative record. Staff was assured that the documentation of perioperative events was reviewed and approved by hospital compliance and legal staff. This appears to have made an impact, as staff reported more events across more variables.

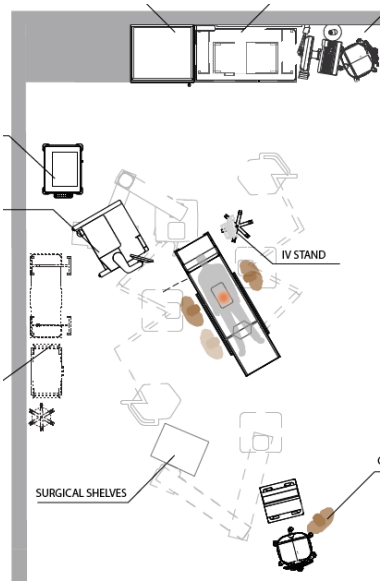
Virtual Reality Workspace and System Evaluation

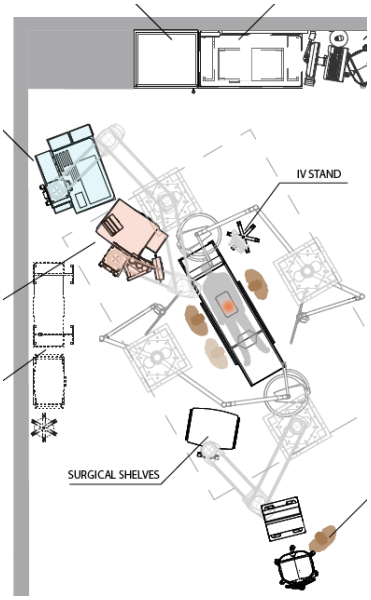
In our final evaluation, we built a Virtual Reality OR environment to:

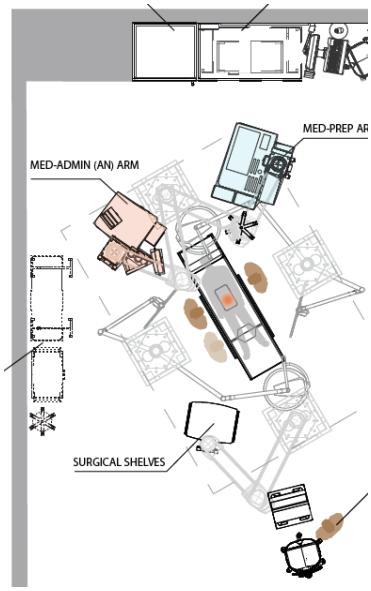
- Evaluate different OR configurations ("Traditional" vs two "Boom" configurations)
- Identify interactions between OR configuration and other work system interventions

Eighteen participants from two sites were guided through a 30-minute experiment that presented three different OR configurations and collected both quantitative and qualitative data. The quantitative data asked participants to answer, on a scale of 1-10 (in which 10 is highest), how well does this layout (i) support your overall situational awareness in the OR? (ii) allow you to visually monitor the patient at all times? (iii) allow you to adapt and reconfigure your workspace to your needs? (iv) support ease and efficiency of movement as you perform your tasks? and (v) provide adequate horizontal workspace for performing tasks? Significant differences ($p<0.05$) were found between the 'standard' layout and the other two configurations for questions 1, 2 and 5, and approaching significance ($0.09<p>0.05$) for Q3 and Q4. No significant differences were found between the other two configurations.









Standard Configuration **New Configuration 1** **New Configuration 2**

This suggested, subjectively at least, that more than a traditional OR layout, these two OR designs:

- Supported situational awareness.
- Allowed visual monitoring of the patient at all times
- Provided adequate horizontal workspace for tasks.

It may also have allowed reconfiguration and movement efficiency, though these results were less clear, as they were not testable with the VR.

IMPLICATIONS FOR MEDICATION DELIVERY AND HARM REDUCTION

- A high variability in information seeking and decision making often makes an "error" difficult to determine, and the standardization of any one approach difficult.
- Device reliability and display design is rarely factored into the analysis of medication harm.
- Formal systems analysis methods reveal needs for adaptations, trade offs, teamwork, and the need to balance patient, personal, professional, organizational, and regulatory outcomes.
- There are clear opportunities to enhance awareness and decision making in the OR through better labeling, syringe management, and workspace designs and improved reporting of complications
- These interventions had demonstrated subjective improvements in situational awareness, visual monitoring, and workspace availability.
- Many more opportunities remain to improve anesthesia medication delivery through the application of sociotechnical systems engineering and the application of human factors principles.

CONCLUSIONS

The focus on medication "errors" rather than harms can be misleading and can result in a focus on changing human intent or behaviors directly rather than seeing them as a result of a complex sociotechnical system. Applying human factors engineering and systems thinking to the medication process generates a wealth of new ways to improve safety the efficiency of medication delivery. This Learning Laboratory identified interactions between the system factors that impact the anesthesia medication management and how these interactions impact work practices. We developed several different interventions (labels, syringe holders, workspace design configurations) that accounted for these complex interactions between the environment, tasks, tools, people, the work as done, and a variety of outcomes. These were evaluated with clinicians, in virtual reality, interviews/focus groups, or within actual clinical practice, with demonstrated benefits in terms of visibility, monitoring, and efficiency of medication delivery. The application of systems safety science within healthcare has often been limited, with the complexity, variations, and interactions between the systems elements rarely recognized or evaluated in anesthesia with respect to medication harm. Our studies have demonstrated methods for exploring these interactions and how this can lead to the design and implementation of innovative interventions with measured substantive benefits. Both these general approaches, and the specific innovations studied here, can be used to enhance patient safety outcomes and improve the work environment for anesthesia providers in the future.

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