Chapter 50. Patient Care Technology and Safety

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Background

The general public believes that technology will improve health care efficiency, quality, safety, and cost. However, few people consider that these same technologies may also introduce errors and adverse events.[1] Given that nearly 5,000 types of medical devices are used by millions of health care providers around the world, device-related problems are inevitable.[2] While technology holds much promise, the benefits of a specific technology may not be realized due to four common pitfalls: (1) poor technology design that does not adhere to human factors and ergonomic principles,[3] (2) poor technology interface with the patient or environment,[3] (3) inadequate plan for implementing a new technology into practice, and (4) inadequate maintenance plan.[4]

Patient care technology has become increasingly complex, transforming the way nursing care is conceptualized and delivered. Before extensive application of technology, nurses relied heavily on their senses of sight, touch, smell, and hearing to monitor patient status and to detect changes. Over time, the nurses' unaided senses were replaced with technology designed to detect physical changes in patient conditions.[5] Consider the case of pulse oxymetry. Before its widespread use, nurses relied on subtle changes in mental status and skin color to detect early changes in oxygen saturation, and they used arterial blood gasses to confirm their suspicions. Now pulse oxymetry allows nurses to identify decreased oxygenation before clinical symptoms appear, and thus more promptly diagnose and treat underlying causes.

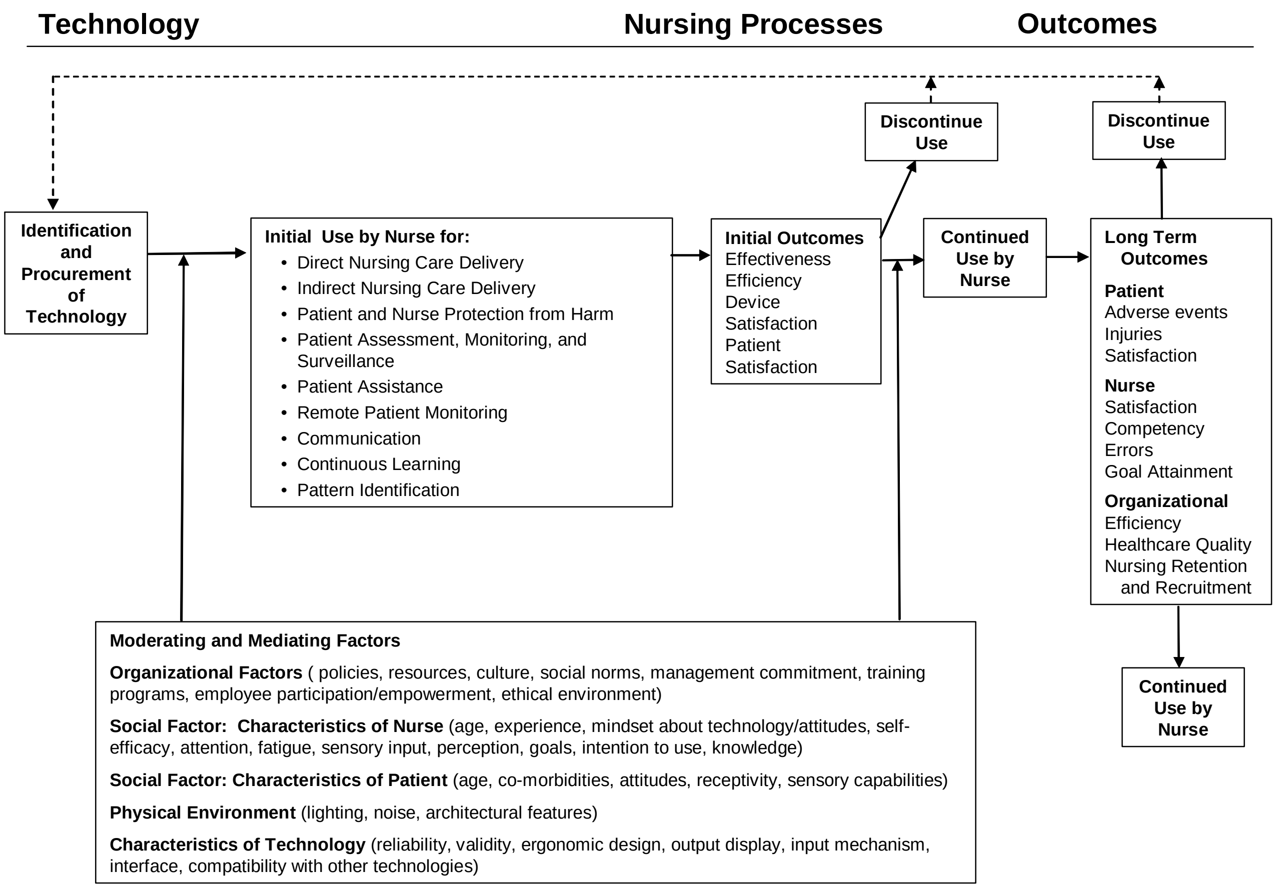
While technology has the potential to improve care, it is not without risks. Technology has been described as both part of the problem and part of the solution for safer health care, and some observers warned of the introduction of yet-to-be errors after the adoption of new technologies.[6] For example, nurses and other health care providers can be so focused on data from monitors that they fail to detect potentially important subtle changes in clinical status. Problems may emerge based on the sheer volume of new devices, the complexity of the devices, the poor interface between multiple technologies at the bedside, and the haphazard introduction of new devices at the bedside. Despite the billions of dollars spent each year on an ever-increasing array of medical devices and equipment, the nursing profession has paid little attention to the implementation of technology and its integration with other aspects of the health care environment.

Patient care technologies of interest to nurses range from relatively simple devices, such as catheters and syringes, to highly complex devices, such as barcode medication administration systems and electronic health records.[7] Technology can be broadly defined to include clinical protocols and other "paper" based tools, but for the purpose of this chapter, we will focus more on equipment and devices that nurses are likely to encounter in delivering direct care to patients. The purpose of this chapter is to provide a conceptual model for technologies that nurses are likely to encounter and to delineate strategies for promoting their effective and safe use.

Conceptual Framework

Based on a review of the literature, a conceptual framework was developed that depicts the relationship among the nurses' use of technologies; moderating and mediating factors that affect use; and the potential nurse, patient, and organizational outcomes (Figure 1). This model was developed independently, but is similar to the work of Fuhrer and colleagues,[8] whose framework of assistive technology device outcomes is patient-centric. We included key nursing processes and outcomes for which technology plays an important role in care delivery and in preventing adverse events.

Figure 1. **Conceptual Model for Technology, Nursing, and Patient Safety**



This conceptual model places the use of technology in the context of nursing practice and offers a framework for examining both the short- and long-term outcomes of technology use on the patient, the nurse, and the organization. Fuhrer's model focused on assistive technologies, that is, a spectrum of interventions—including structural and nonpermanent alterations of the physical environment, equipment attached to the physical environment, devices used by individuals, and behavioral modification—for promoting independence and function with a disability. This model is extended to include a full range of technologies used by nurses in the delivery of nursing care (Table 1). Patient care technologies can be classified in many ways. These technologies are categorized by commonly understood nursing activities: direct nursing care delivery technology, indirect nursing care delivery technology, communication technology, patient and nurse protective devices, nurse protective devices, patient assessment, monitoring and surveillance, patient assistive devices, remote monitoring, continued learning, and pattern identification. Well-designed technology allows nurses to focus on caregiving functions and promoting the health of patients.

Table 1. Technology Commonly Used by Nurses

<table>
<tr><td rowspan="2">Direct Nursing Care Delivery Technology
Barcode medication administration
Intravenous (IV) tubing
IV pumps
Feeding pumps
Nasogastric tubes
Endotrachial tube
Tracheostomy tubes
Syringes
Needles
Urinary catheters and drainage bags
Ostomy appliances
Wound drainage tubes
Chest tubes
Suction equipment
Oxygen and air regulators, tubing, and face masks
Oxygen tanks and regulators
Nebulizers
Dressings (from gauze to specialized materials)
Traction systems
Code carts</td><td>Indirect Nursing Care Delivery Technology
Robotics
Radio frequency identification
Electronic inventory systems
Computerized staffing systems</td><td>Communication With People Distanced by Place and Time
Electronic medical records
Electronic ordering systems
Communication devices (cell phones, PDAs, “Voicera,” paging systems)
Call systems, including emergency call bell</td></tr>
<tr><td>Patient Protective Devices
Floor mats
Beds
Elopement/wandering alarms
Fall alarms
Hip protectors
Specialized mattresses (e.g., low air loss)
Specialized lighting
Hand rails in patient rooms, hallways, and bathrooms
Specialized seating cushions
Limb compression devices</td><td>Patient Assessment, Monitoring, and Surveillance
Telemetry
Bedside monitoring
Ventilators
Video surveillance
Stethoscope
Sphygmomanometer
Thermometer
Otoscope
Ophthalmoscope
Pulse oxymetry</td></tr>
<tr><td rowspan="2">Patient Assistive Devices
Canes
Walkers
Robotics
Stand assist lifts
Trapeze bars
Patient transfer devices ECD
Bed pans
Wheelchair
Prosthetic limbs
Orthotics (braces, shoes)</td><td>Nurse Protective Devices
Face masks
Gloves
Gowns
Hand sanitizer dispensers
Mechanical lifts
Patient transfer devices</td><td>Remote Patient Monitoring
Telemedicine and telehealth</td></tr>
<tr><td>Continuous Learning
Distance learning
Video conferencing
Online training</td><td>Pattern Identification (To learn from errors and systems influences on adverse events)
Electronic medical records
Workload and staffing data systems</td></tr>
</table>

According to Stone and Wiener,[9] workplaces have four dimensions: (1) organizational arrangements, for example, goals, structure, policies, and rewards; (2) social factors, for example, organizational philosophy and values, management style, and interactions with employees and patients; (3) the physical setting/environment, for example, character, physical design, and ergonomics; and (4) technology. In our proposed model, these workplace dimensions affect the nurses’ initial and continued use of technology.

Technology

Technologies used by nurses offer the means for preventing errors and adverse events (e.g., medication errors, miscommunications, delays in treatment, and adverse events—such as failure to rescue, nosocomial infections, pressure ulcers, falls, and complications of immobility). Yet technology also introduces unintended side effects and opportunities for failures.[6] In a chart review, Samore and colleagues[10] found that devices most commonly associated with adverse events were foley catheters (57 percent of adverse events involving devices), arterial catheters (17 percent of such events), central venous catheters (17 percent of such events), and peripherally inserted central catheters (7 percent of such events)—all devices used by nurses in the direct care of patients. At one pediatric hospital, implementation of a computerized provider order entry system intended to reduce handwriting and transcription errors was unexpectedly associated with increased mortality, presumably due to a reduced ability by nursing personnel to anticipate the needs of patients prior to arrival of the patient.[11] Other research showed that although barcoding medication administration was believed by most nursing personnel to decrease medication errors, it was also believed to reduce the ability for physicians to review the accuracy of medication administration and decrease the ability to deviate from routine medication administration sequences.[12] In another example, a few years ago, in an effort to prevent hip fractures from falls from bed, some nursing homes used non-height-adjustable low beds. This solution for preventing hip fractures among residents, however, forced nursing staff to provide care on their knees or bent over, thus increasing staff risk for back and knee injuries. Green[13] noted that all injuries and unintended consequences of technology are impossible to know beforehand, and that they are an unavoidable aspect of technology development. In other words, without technology failures there cannot be progress in technology development.

Nurses may respond to unintended consequences of technology with "work-arounds," or temporary fixes to technology problems or malfunctions. While work-arounds fix an immediate problem at hand, work-arounds can be dangerous, not solving the underlying problem in a system,[14] and thereby increasing opportunities for error over time. For example, in early implementation of barcode administration, scanning devices that were attached to the medication cart with a cord often made it difficult for nurses to scan the patients' identification arm due to infection control restrictions. In response, nurses made duplicate arm bands that they kept at the medication cart. The duplicate bands allowed for ease in scanning, yet doing so bypassed the safety feature that required a positive patient identification (by scanning the band on the arm) before administering a medication and increased the likelihood of "wrong patient" errors. When this work-around was discovered by an independent evaluator, nursing worked with the vendor and infection control experts to use disposable plastic covers to scan infectious patients.[15, 16]

Organizational Factors

Organizational factors that influence the use of technology include policies, resources, culture, social norms, management commitment, training programs, and employee empowerment. It has been noted that the effects of implementing technology—for example, information technology—can vary widely depending on the setting,[17] presumably due to differences in the social-organizational environment such as workflow, work tasks and processes, and the people in the environment. Policy is often looked at as an effective means for implementing change. For example, when implementing safe patient movement and handling programs, it is helpful to have firmly established leadership and management support, equipment, training, and coordination with other departments before mandating mechanical lifting through policy.[18] Policy hastily implemented before consideration of the impact of technology can result in staff averting the policy and risking the consequences or staff appearing to be in compliance with the policy when they are not. Both of these situations can adversely affect staff morale and satisfaction.

Social Factors

Sandelowski[19] noted the complex and often troubled relationship between technology and nursing since the establishment of nursing as a profession in the latter part of the 19th century. Nurses have been both users of technology and facilitators for gaining patient acceptance of technology, but it has sometimes been a struggle for nurses to define the role of technology in their profession. Technology has played out in the debates of caring versus curing and high-touch versus high-tech in explaining the role of nursing in health care. In the 1970s, the mastery of technology often took second place after the mastery of psychosocial skills such as communication and development of a therapeutic relationship. This relatively recent culture of nursing and the culture of health care have in many instances served to work against the systematic incorporation of technology into nursing practice to improve patient outcomes. Using a Heideggerian analysis of technology, Zitzelsberger[20] proposed that the usual ways in which we perceive technology in terms of function, utility, and positive outcomes overshadow other "modes of revealing," so that nurses and other health care personnel are likely to accept technology and incorporate it into practice without critical evaluation of its benefits and problems. For example, why is it that nursing that requires higher levels of technology, as in critical care, is valued more (e.g., paid more) than nursing that requires little technology, as in the personal care of residents in a nursing home?

Certainly, characteristics of nurses will affect the adoption of technology, although little empirical evidence was found to document this phenomenon. Nurses have been found to be willing to embrace safe patient handling and other technologies if they are convenient; easy to use; target a high-risk, high-cost, and high-prevalence problem (such as falls); are consistent with unit and/or organizational goals; and are either compatible with existing work patterns or have the potential for improving efficiency and time spent with patients. It is likely that nurse characteristics that influence the use of technology are specific to the technology in question. For example, in a study of implementation of a nursing documentation information technology system, the investigators found that adoption was influenced by a number of attributes of the nurses, including commitment to nursing care planning and written documentation, acceptance of computers in nursing, computer and typing skills, professional experience, level of motivation, and climate of trust and support within the nursing team.[17]

Physical Environment

The physical environment, particularly in older buildings that were never designed to accommodate newer technologies, is often a constraining factor in the use of many types of equipment used by nurses. For example, research has shown that an ergonomic approach that relies on equipment to promote safe patient handling decreases musculoskeletal injuries in nurses.[21] The environment is critical in the nurses' use of this equipment because if the equipment is not readily accessible, the nurse will be less likely to use it. If the patient handling equipment is located at the end of a hallway in a room behind other equipment, the nurse is less likely to use it than if it is stored in an open alcove in the hallway where it can easily be retrieved.[22]

Mediating and Moderating Factors

Ergonomics and human factors engineering offer useful frameworks for examining many of the mediating and moderating factors (e.g., the user/technology interface) that will affect use of the equipment and outcomes of its use. According to the International Ergonomics Association,[23]

> Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.
>
> Ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people.

According to Gosbee[24] (p. 3), "Human factors engineering is the discipline concerned with understanding human characteristics and how humans interact with the world around them and the application of the knowledge to the design of systems that are safe, efficient and comfortable." Without a complete understanding of human factors, the tendency is to focus on human failures as the major source of error, and to focus attention on automation of tasks to prevent errors. Several problems with this approach are evident: [4]

- By taking away the easy parts of the job, automation can make the difficult aspects of the job more difficult.
- While humans are known to be fallible, we leave staff to cope with tasks the designers could not figure out how to automate, most important, the job of restoring the system to a safe state after a failure.
- Humans are expected to "monitor" the automated processes, even though we know vigilance is not likely when abnormal events are relatively rare.
- Skills need to be practiced continuously to preserve them, yet the occasional system failure denies the staff the opportunity to practice the skills needed in such an emergency.
- Nurses are generally not exposed during educational programs and on the job to engineers, biomedical engineers, industrial designers, and ergonomists, the designers of the equipment they use in providing care.

Because nurses work at the front lines of health care—where nurses, patients, and technologies intersect and where actions are highly visible—there is a tendency to blame these frontline workers for human error associated with technology failures. Reason[4] called these "human operator problems," which can be classified at the individual or systems level. Examples of individual-focused problems include deficient procedures or documentation, lack of knowledge or training, failure to follow procedures, and deficient planning or scheduling. Systems-oriented problems include miscommunication, deficient supervision, and policy problems. Technology failure should be viewed in the broader context of the complex health care system, rather than inappropriately blaming the individual nurse.

Outcomes of Technology Use

As Fuhrer and colleagues[8] noted, a paucity of outcome measures is a significant barrier to the conduct of outcomes research related to technology. The lack of conceptualization of outcomes in the context of the type of technology and its context of use is added. The key initial outcomes of technology are effectiveness, efficiency, and user (i.e., nurse) and patient satisfaction with the device. Verza and colleagues[25] specifically examined "equipment abandonment," that is, the disuse of a previously obtained device, in the context of assistive devices for persons with multiple sclerosis. They found that abandonment could be reduced by an interdisciplinary prescribing approach.

Longer-term objectives reach beyond these immediate ones and include adverse events, injuries, satisfaction, competency, errors, goal attainment, and organizational outcomes such as efficiency, cost (including cost avoidance, return on investment, margins, and working capital),[26] health care quality, and nursing retention and recruitment. Karwowski,[27] in building a model of ergonomics, differentiated positive outcomes (e.g., improved work productivity, shorter performance times, improved product quality, and desirable psychological and behavioral outcomes) from negative outcomes (e.g., loss of productivity, low quality, accidents, injuries, and undesirable physiological and psychological outcomes).

Optimally, technology is designed to minimize errors and buffer the consequences of errors[1] by (1) eliminating errors and adverse events; (2) reducing occurrence of errors/adverse events; (3) detecting errors early, before injury occurs; and (4) mitigating the effects of errors after they occur to minimize injury.[3] In this "ideal" scenario, patient care technology would yield positive nurse, patient, and organizational outcomes. Consider all of the alarms and warning systems used in the delivery of nursing care to detect errors before injury. A partial list includes bed exit alarms, warnings on IV pumps that signal occlusions, patient-initiated call bells, staff-initiated code alarms, wandering and elopement alarms, cardiac monitor alarms, and ventilator alarms. All of these warning systems depend on the ability of the nurse to notice the warning, process the alarm and comprehend what is happening, and finally take the appropriate action to decrease risk to the patient.[28] In one recent study, medical/surgical nurses wanted "smart monitoring devices" that interfaced with the electronic medical record as well as with wireless communication devices.[29] However, this strategy of using automated alarms is challenged by "alarm fatigue" stemming from the sheer number of alarms. Further, alarm fatigue is exacerbated by the well-intentioned, yet misguided decision to deliberately set alarms with a high false alarm rate; the effectiveness of an alerting signal drops precipitously with just a small number of false alarms.[30]

A significant difference in the model presented here from Fuher's[8] is that both nurse and patient outcomes are included. In addition to the potential physical harm from technology, Monk and colleagues[31] proposed that for older adults living with disabilities in their homes, psychological harms are as important as the physical ones. These researchers argued for including three types of physical harm (injury, untreated medical condition, and physical deterioration), four types of psychological and social harm (dependency, loneliness, fear, and debt or poverty), and four generic consequences (distress, loss of confidence in ability to live independently, costly medical treatment, and death) for systematically evaluating technology used to promote independent living.

While patient care technology offers many opportunities to improve nurse productivity and satisfaction, operational efficiency, patient satisfaction, safety, and quality, there is little research evaluating the outcomes of specific patient care technologies. Barcoding, scanning, and robotics have been shown to improve efficiency and decrease costs.[32] The Veterans Health Administration (VHA) has successfully implemented barcode medication administration software. This innovative automated system uses a wireless, point-of-care technology with an integrated barcode scanner. The system can dramatically reduce medication administration errors by letting clinicians verify a patient's identity and validate medications against active orders. After implementation at the Kansas VA hospital, the VHA estimated that the software prevented 549,000 errors while dispensing 8 million doses.[32] In a quality improvement project, Bahlman and colleagues[33] found that implementation of an integrated communication system in an operating room had a positive effect by reducing staff time for phone calls to relay messages; reducing time nurses had to spend hunting pieces of equipment; enabling more timely administration of antibiotics for total joint procedures; improving communication with family members about progress of the patient through preoperative, operative, and postoperative care; and providing a quieter environment due to less overhead paging and the use of vibration modes for wireless telephones.

Moderate evidence is available supporting use of electronic medical records and automated drug-dispensing machines, with reports of increases in nurse satisfaction, retention, and productivity, as well as decreases in errors.[32] Despite the limited research available to support the benefits of technology, a recent Institute of Medicine report identified use of information technologies to automate clinical information as one of the keys to safer, quality health care systems.[34]

Practice Implications

Being informed consumers and users of technology in health care means that nurses be involved in the selection of new equipment, receive the proper training for its use, and monitor equipment safety and the effect of technology on patients and families on an ongoing basis.

Selecting the wrong equipment and technology can be costly and expose the patient to errors.[35] Even when optional equipment/technology is selected, if it is not well integrated into the current delivery system, or it is implemented in a chaotic way, this can result in unexpected costs and increased errors.[35] In choosing the best equipment for the task at hand, we found ergonomic-based and social-marketing approaches extremely beneficial. An ergonomic assessment, focusing on the user/equipment interface, involves asking nurses to test equipment and provide feedback on usability, safety, and patient acceptance. Equipment fairs are one strategy to allow staff the opportunity to evaluate which brand or model of technology would work best in their setting. Manufacturers are usually willing to loan equipment to promote onsite clinical testing. From a social-marketing perspective, all stakeholders potentially affected by a device should be invited to participate in equipment trials.[36] Different user groups will have different perspectives and requirements of the equipment. For example, in evaluating a hospital bed, a patient may focus on comfort, a biomedical engineer may focus on compatibility with other technologies and the ease of maintaining the bed in good working order, and a nurse might focus on the usability of special features such as built-in scales and bed exit alarms. Once a purchasing decision is made, including input from staff nurses, training is critical and may require ongoing competency assessments over time.[35]

The World Health Organization Medical Devices and Equipment team described a life-cycle approach that systematically includes maintenance, training, monitoring, and vigilance reporting on medical devices in use.[37] Through surveillance, nurses play an important role in early identification and correction of latent errors related to technology. Staff who operate equipment and are trained in its use can recognize maintenance problems and request timely maintenance.[38] Similar to the notion of patient surveillance to detect errors early and prevent adverse events[3] (p. 91), equipment surveillance means that nurses conduct purposeful and ongoing data collection to identify malfunctioning and broken equipment, interpret data that indicate equipment problems to determine the source of error, and act based on the interpretation by quickly and directly responding or appropriately reporting and following up.

The Safe Medical Devices Act of 1990, which became effective in 1991, *requires* (italics added) health care facilities to report to the manufacturer and/or the Food and Drug Administration (FDA) all incidents that reasonably suggest that the medical device might have contributed to a death or serious injury or illness. Nurses should be familiar with internal systems of reporting, as well as the FDA medical device reporting (MDR) system (available at http://www.fda.gov/medwatch/how.htm). MDR is the mechanism by which the FDA receives information about medical device adverse events from manufacturers, importers, and user facilities, so any problems with the device can be detected and corrected. ECRI Institute encourages the reporting of device-related incidents and deficiencies to determine whether a report reflects a random failure or one that is likely to recur and cause harm. (Reports can be submitted to ECRI's Web site at http://www.ecri.org/PatientSafety/ReportAProblem/Pages/default.aspx.) Health care failure mode effect analysis[39] and sociotechnical proactive risk modeling[40] offer methods for identifying equipment failures before they happen and strategies for preventing them. Both of the methods have been used in engineering, and both are prospective in that they can be used to identify and prevent product and technology-related problems before they occur. Proponents of proactive risk modeling methods, relatively new to health care,[40] suggest that nurses could play an active role in preventing equipment and technology failures and in responding appropriately to them should they occur.

Risk modeling, an established analytic method in high-risk industries such as aerospace and engineering, is a structured process of determining all the ways a failure can happen to identify likely prevention strategies. Proactive risk modeling has been described as a hybrid between traditional decision support models and process analysis techniques (e.g., root-cause analysis, failure modes, and effects analysis),[41] designed to address rare adverse events associated with high mortality and high costs. For example, after installation of mobile patient lifts into a facility, nurses may anticipate that they would be forced to perform manual lifts, putting themselves at high risk for a lifting injury, if all of the backup battery packs were not fully charged, rendering the electric lifts useless. In naming all of the ways this could happen, a group of nurses would identify processes that, if in place, would avoid the failure of charging batteries, for example, buying extra battery packs or plugging in equipment after each use. Competency checklists could be used to reinforce this process and ensure that everyone is performing it in the same way. Alternatively, the nurses may opt for an alarm system that notifies them when a battery's charge is running low and does not stop alarming until it is plugged into the electrical outlet to charge. Nurses could be proactive in equipment use by discussing "what if" scenarios to determine useful responses in the event of equipment failures. For example, a group of nurses could be asked to discuss what they would do if a patient became stranded in a ceiling lift that would not lower back down to the bed. After such a discussion, nurses would be in a better position to respond if that event were to occur than if they had not anticipated this possibility.

Nurse educators could advance the role of nurses in the use of technology by providing human factors content into nursing curricula and including human factors engineers into newer interdisciplinary approaches to professional education. An engineering perspective views safety as a feature that needs to be "engineered" into technology and that human errors emerge from the human/machine interface. Equipment misuse is viewed as a failure of the designer to tailor the system appropriately to the cognitive strengths and weaknesses of human users.[4] Human factors engineering and good design can help trap failures so the end result is not a bad outcome,[42] and good design can be facilitated by more informed and sophisticated users. Nurses need to operate as though just because a technology is commercially available does not mean it is good. In our experience, manufacturers welcome feedback from nurses because it allows them to make design changes that not only improve patient safety, but also make products more marketable to nurses. Gosbee[42] suggested that nurses can be trained to more easily detect human factor design issues instead of dismissing them as human error or "somebody else's job."

Implementation of new technologies offers nurses yet another avenue for ensuring safe and efficient use of technology (Table 2). In our experience, we have found that staged implementation is often desirable, because it allows for formative evaluation that can be used to improve the implementation process. Staging also minimizes overload associated with training and behavioral changes. From the literature on research translation and our own experiences, clinical champions, local opinion leaders,[43] or "super users" of equipment may greatly facilitate smooth implementation of new equipment. These clinical leaders are most effective when they are respected by coworkers and perceived by coworkers as knowledgeable, clinically competent, and accessible. Clinical leaders can offer on-the-spot training, encouragement, advice, and troubleshooting expertise to other staff as workers are learning to use new equipment.

Table 2. Tips for Nurses To Influence Technology at the Bedside

- Organize equipment fairs to gain input from key users and stakeholders before purchases.
- Examine performance of technology on challenging scenarios in a simulated setting with a small number (three to five) of untrained, representative users.[44]
- Mentor and oversee temporary (agency) nurses and other personnel (e.g., resident physicians) during first-time use of sophisticated technology.
- Develop cogent arguments to administration to justify purchase of new equipment and technologies, balancing the cost of equipment (costs of purchase, training, and maintenance) against costs saved if equipment was not purchased.
- Become critical users of technology by identifying problems early and communicating them to vendors and in-house biomedical engineering staff.
- Report adverse events associated with medical devices to the Food and Drug Administration MAUDE reporting system and/or ECRI's Problem Reporting System.[45]
- Serve as a resource person on your unit for new technologies by getting training early, communicating with vendors, training others on your unit, and offering to field questions as new technology is implemented.

Research Implications

As previously described, there are a number of moderating and mediating factors for how useful technology is in practice. Appropriately addressing these factors will require collaboration across a number of disciplines. Clinical experts are needed to provide critical input into the design and application of technologies in health care. Direct patient care nurses need to be actively involved in the design and testing of technology. Human factors experts aid in integrating technology into existing workflow and in making interfaces easy to learn and use under stressful conditions.

It has been suggested that some of the mismatches between device design and health care settings might stem from a more fundamental disagreement about the nature of work.[46] An area for further study is whether the implicit theories of work by designers and managers are oversimplified in relation to the actual work setting, and whether these oversimplifications doom technologies to fail regardless of how usable the interface is or how many clinical experts have provided input during the design, procurement, implementation, and maintenance phases.

A major barrier to widespread use of technology is cost. Further research is needed to build a business case for use of technology, including return on investment and cost-benefit analyses.[35] Proactive assessment of key stakeholder perceptions of the technology is also essential, including end-users (nurses and others directly involved) as well as patients and their families.[35]

Chaotic implementation of new technologies appears to be the norm in health care. More research is needed to more effectively introduce new technologies, minimizing risk to the patient, and reducing stress on nursing staff. Likewise, once technology is integrated into nursing care delivery systems, adequate maintenance programs are needed.

Specific research priorities include the following:

1. There is a paucity of research evaluating the outcomes of specific patient care technologies. Further research is needed to evaluate the immediate and long-term outcomes associated with specific technologies used in nursing practice. Research should include nursing, patient, and organizational outcomes.
2. Nursing practices and care delivery systems vary across sites. Further research is needed to evaluate the effects of various nurse processes and environmental conditions on the use, effectiveness, and efficiency of specific technologies used in nursing practice.
3. There are a number of moderating and mediating factors affecting technology use in health care (e.g., organizational factors, social factors, physical environment, and characteristics of technology). Further research is needed to examine these mediating and moderating factors and how they affect both the use of technology and outcomes.
4. Variations in how technologies are implemented exist across organizations and practice settings. Research is needed to improve the processes for introducing technology into the workplace to optimize outcomes.
5. Given that a major barrier to widespread use of technology is cost, further research is needed to build a business case for use of specific technologies, including return on investment and cost-benefit analyses.
6. Because learning from errors and near misses is critical for building an effective culture of safety, research should be conducted to identify effective ways to learn from equipment-related adverse events across practice sites.
7. Research and development needs to focus on how to best integrate multiple technologies into patient care to maximize outcomes and decrease burdens on nurses.
8. Recognizing the inordinate amount of time nurses spend in performing indirect or nonnursing care, research is needed to evaluate the effect of technologies designed to reduce the time spent on nonnursing tasks (such as hunting and gathering supplies) and in indirect nursing care activities (such as documentation) to maximize the time nurses can spend in providing direct patient care.

Other considerations are:

1. What are the most critical challenges to successfully implementing new technologies into health care environments and nursing practice?

2. How do nurses serve as the last line of defense in protecting the patient from harm associated with technology?
3. What are the opportunities for nurses at the bedside to become involved in technology design and testing?

Conclusions

Research on the quality of care reveals a health care system that frequently falls short in its ability to apply new technology safely and appropriately.[34] Workplaces, instruments, and equipment can be developed according to human factors design criteria,[47] but as an end-user, nurses can maximize safety through the selection process, ongoing surveillance of equipment, and proactive risk-assessment methods.

The approach offered for nurses is consistent with the following four-pronged strategy developed by the World Health Organization Medical Devices and Equipment team:[37]

- **Policy:** Nurses providing direct patient care should be involved in setting and evaluating institutional, organizational, and public policy related to technologies.
- **Quality and Safety:** Nurses providing direct patient care can ensure that the technologies they use meet international quality and safety standards and technical specifications needed to perform in the clinical environment in which they are used.
- **Access:** Nurses providing direct patient care can ensure that institutional decisions are made with their input and the input of other critical stakeholders.
- **Use:** Nurses providing direct patient care should be involved in their intuitional policies and processes related to maintenance, training, monitoring, and reporting adverse events related to technology.

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