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Evaluation of Sensor Technology to Detect Fall Risk and Prevent Falls in Acute Care

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Background: Sensor technology that dynamically identifies hospitalized patients' fall risk and detects and alerts nurses of high-risk patients' early exits out of bed has potential for reducing fall rates and preventing patient harm. During Phase 1 (August 2014–January 2015) of a previously reported performance improvement project, an innovative depth sensor was evaluated on two inpatient medical units to study fall characteristics. In Phase 2 (April 2015–January 2016), a combined depth and bed sensor system designed to assign patient fall probability, detect patient bed exits, and subsequently prevent falls was evaluated.

Methods: Fall detection depth sensors remained in place on two medicine units; bed sensors used to detect patient bed exits were added on only one of the medicine units. Fall rates and fall with injury rates were evaluated on both units.

Results: During Phase 2, the designated evaluation unit had 14 falls, for a fall rate of 2.22 per 1,000 patient-days—a 54.1% reduction compared with the Phase 1 fall rate. The difference in rates from Phase 1 to Phase 2 was statistically significant ($z = 2.20$; $p = 0.0297$). The comparison medicine unit had 30 falls—a fall rate of 4.69 per 1,000 patient-days, representing a 57.9% increase as compared with Phase 1.

Conclusion: A fall detection sensor system affords a level of surveillance that standard fall alert systems do not have. Fall prevention remains a complex issue, but sensor technology is a viable fall prevention option.

Patient falls within acute care hospitals remain a significant and persistent health problem, despite years of intensive efforts to prevent them. The Institute for Healthcare Improvement reported in 2012 that falls within hospitals were the most frequent adverse event and that injuries from falls—which are not reimbursed by Medicare—can be associated with significant morbidity and mortality.[1] Inpatient falls pose significant financial costs for hospitals, including the expenses incurred to prevent falls, the treatment costs associated with injuries due to a fall, and the expenses associated with lawsuits.[2] Efforts at preventing falls in hospital settings have largely involved implementation of multicomponent programs, which have reduced falls by as much as 30%.[3] However, no specific intervention has been shown to be most effective, except for the need to individualize fall prevention strategies on the basis of a patient's unique risk factors. Reliable implementation (for example, persistent managerial oversight and clinical staff fall prevention protocol adherence) is also needed for specific at-risk and vulnerable subpopulations, such as the frail elderly and those at risk for injury (for example, patients with osteoporosis or low platelet counts).[1] Finding the "silver bullet" for fall prevention has been elusive. As Goldsack and colleagues have noted, preliminary evidence for multifactorial fall prevention program is promising, but the impact of any individual fall prevention component remains unclear.[4]

As hospitals strive to reduce fall rates, one standard practice involves the assessment of each patient's fall risk category using a valid fall risk assessment tool. Joint Commission Provision of Care, Treatment, and Services (PC) Standard PC.01.02.08 addresses the hospital's assessment of a patient's risk for falls and implementation of interventions to reduce falls on the basis of his or her assessed risk.[5] Thus, it is imperative to find a tool that predicts which patients are more likely to fall in the hospital setting.[6]

One study that evaluated three instruments used to assess the risk of falls in acute hospitalized patients found that their sensitivity and specificity vary considerably, depending on the population and the environment in which the instruments are used.[7] Evidence for the validity of another widely used fall risk assessment tool, the Johns Hopkins Fall Risk Assessment (JHFRAT), is scant.[8] A problem with the use of fall risk assessment tools is that a patient's risk can vary, depending on a variety of frequently changeable risk factors—at the level of a patient's condition (for example, comorbidities, confusion, visual problems, impaired gait or balance, weakness) or behavior (fear of falling or impulsiveness), transient risk factors (polypharmacy, postural hypotension, and changing location, such as while walking or moving from a bed or chair), and the physical environment (poor lighting, high bed position, items out of reach, and using equipment on wheels for support).[7,9] Patients often

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do not recognize or accept their own fall risk and thus fail to take basic precautions, such as asking for assistance from their caregivers or using an assistive device to ambulate.[10,11] A patient's fall risk can change in minutes, and acute care staff generally do not have the time to conduct multiple risk assessments during the course of a shift. Research findings indicate that hospitals should use a comprehensive fall risk assessment tool to identify modifiable and nonmodifiable risk factors and then implement evidence-based fall prevention interventions for the patients who are determined to be high risk.[12] However, patients at moderate and even low risk also fall, and as patient risk changes, as noted, certain interventions may become unnecessary, thus wasting resources. It is estimated that 80% to 90% of the falls that occur in hospitals are not witnessed, with 50% to 70% occurring around the bed, bedside chair, or while transferring (for example, to a chair or bedside commode).[7,10] Sensor technology with motion detection holds promise as a way to identify patient fall-risk behaviors (such as walking [gait speed]) and actual falls, and to then automatically alert health care staff. In a study involving community-dwelling older adults, researchers examined the efficacy of combining standard clinical fall risk factors with a fall risk assessment algorithm based on inertial sensor data and the Timed Up and Go (TUG) test.[13] The combined clinical and sensor-based approach yielded a classification accuracy of 76.0%, compared to 73.6% for sensor-based assessment alone or 68.8% for clinical risk factors alone.[13] However, research involving the use of sensor technology for fall prevention has largely focused on the home, assisted living, nursing homes, or other community-based settings.[9,14] In a literature review, Kosse et al. concluded that although current sensor technologies (for example, wearable sensors, nonwearable sensor mats, infrared detection, bed/chair alarms) were associated with up to a 77% reduction in fall-related injuries, with a relatively low (16%) average rate of false alarms, the data are inconsistent as to whether current sensor technologies are effective in reducing the number of falls in institutionalized geriatric patients.[14]

Evaluating innovative sensor technology in the real clinical world is invaluable not only to determine efficacy of technology in reducing fall occurrence but also to understand the impact of such a system on patient care staff performance. In a previous performance improvement (PI) project conducted by this project team, a unique fall sensor system, which used a depth-image sensor to capture actual falls (on a video rewind function) provided valuable data for analysis of actual fall events.[10] The depth sensors captured a total of 13 patients who fell on two medicine units, involving 16 detected falls in patient rooms. On the basis of the hospital's serious event management system (SEMS) reports, a total of 31 falls were reported for the same time frame. Twelve of the 16 detected falls were matched with the SEMS reports. A total of 19 falls occurred outside sensor range. The discrepancy was due to the fact that the depth sensors captured only falls occurring around patients' bedsides and not in bathrooms or hallways. Four falls captured by the sensor system were missed or unidentified by staff. The complete fall detection sensor system, including depth sensor and bed sensor, is based on research initially developed at the University of Missouri involving patients in long term care facilities.[15] In this article, we report on the first application of the complete fall detection sensor system for use in preventing falls in an acute care setting.

METHODS

Setting

Barnes-Jewish Hospital (St. Louis) is a 1,158-bed academic medical center with 48 inpatient units (including critical care).

PI Team

The PI team, consisting of researchers, nurse clinicians, physical therapists, and professional practice staff, conducted the two-phase project on two of the hospital's inpatient medical units, for a total of 53 beds. The team obtained a grant from the Foundation for Barnes-Jewish Hospital to lease and install the fall detection sensor system, including previously used depth sensors and the addition of bed sensors. The system, developed by Foresite Healthcare, LLC (St. Louis), was installed for monitoring patients for the detection of early bed exits and falls. During the 12 months prior to Phase 1, the fall rate for all medicine floors (excluding ICUs) within the hospital was 4.29 falls per 1,000 patient-days. During the same time frame, the two medicine units chosen had two of the highest fall rates among all non-ICU units: 4.78 (evaluation unit) and 4.38 (comparison rate). Both units have a comparable acute medical patient population and are managed by the same nurse manager. This project was reviewed by the Human Research Protection Office of the affiliated university and deemed exempt.

Fall Detection Sensor System

A unique fall detection sensor system using the Kinect depth sensor computes patient fall risk probability, sends text alerts when patients exit beds, captures actual falls (on a video rewind function), and sends text alerts to patient care staff when falls do occur, providing valuable data for performance improvement analysis after fall events.[15,16] The system captures an unidentifiable 3-D image of a patient walking (Figure 1) within his or her hospital room—specifically the stride-to-stride gait speed—and applies algorithms to compute a TUG score each time a patient walks. The algorithms use decision trees to detect falls. Based on the data prior to a fall, the system learns what pattern of data leads to a fall, which is primarily based on TUG estimates, which are in turn based on monitoring walking speed and gait analysis.[17] However, the algorithms also take into account use of assistive devices, time in bed, bed exits, and sit to stand time. There is a continuously updated baseline, which is adjusted as more

Depth Sensor Image of a Patient in a Room

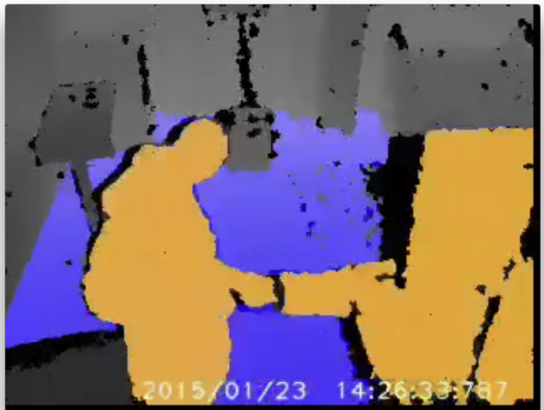

Figure 1: The fall detection sensor system captures an unidentifiable 3-D image of a patient (shown in orange) walking within his or her hospital room.

data are accessed by the system.[17] The TUG score is used to create fall probability categories (high, moderate, and low), which change over time as a patient's gait speed changes. The system also uses computer algorithms to analyze motion data and distinguish between fall and non-fall events.[18] The text-alert message is sent directly to a specific IP (Internet Protocol) address and port on the hospital's phone system and submits an ASCII string directly to nursing staff members' dedicated work phones. The text reports a confidence level along with a message that a fall has occurred in a patient room.[18]

The Foresite Healthcare system also provides a database for evaluation of the fall detection sensor system. The system offers a website for project team members and staff nurses to review the frequency of which individual patients are at a high fall probability; videos of patient walks that correspond to low, moderate, and high fall probability; videos of actual falls; and video rewind clips of activities 10 minutes before and after falls.

Bed Sensor Technology

A hydraulic bed sensor, a device that is placed in a patient bed underneath the mattress (Figure 2), has pressure-sensitive hydraulic tubes, which are used to build a ballistocardiogram (BCG) of a person lying on a mattress.[17,19] The BCG is similar to an electrocardiogram (EKG) but shows the mechanical effect of the blood pumping through the veins instead of the electrical effect of the heart beating. The bed sensor is so sensitive that it can accurately detect the BCG underneath standard hospital mattresses; the exceptions are specialty beds with integrated mattresses and bed frames. The bed sensor monitors bed occupancy and the exit of patients from their beds. Combining this information with the fall probability categorical information from the depth sensor, the fall detection system alerts patient care staff via text messages when patients who are determined to be at a high fall probability start to exit their beds[18] to enable nurses to intervene and possibly prevent falls from occurring. The system can also capture video images if a fall occurs, in addition to video rewind of the nurse rescue.

Project Phases

The project consisted of two separate phases. In Phase 1 (August 2014–January 2015), the depth sensors alone were used on the two medicine units to capture video images of any actual falls occurring in patient rooms during the pilot period and to examine characteristics of those falls.[10] In Phase 2 (April 2015–January 2016), the depth sensors remained in place on the same two medicine units, with one designated as the comparison unit and the other as the evaluation inpatient unit. Bed sensors were added to the system for only the designated evaluation unit. This allowed the PI team to continue to capture any actual falls in patient rooms on both comparable units during the pilot and to also determine if the depth and bed sensor combined aided in reducing falls and falls with injuries on the evaluation unit. The bed sensors were not used for patients requiring specialty beds due to the inability to place sensors under mattresses. Signs had been posted in each patient room during Phase 1

Bed Sensor

Figure 2: The hydraulic bed sensor is placed in a patient bed underneath the mattress.

and remained throughout Phase 2 to inform patients and families of the presence of the sensors. The hospital's legal department approved the wording of the signs. Patients and families were not given access to view any videos of fall events.

Staff Orientation and Involvement

Before implementation of Phase 2, staff meetings were conducted to orient all nurses who were involved in patient care from both units. Staff from the evaluation unit often floated to the other medical unit and vice versa. Nurses were shown examples of fall images and were presented findings from Phase 1 of the project. To prepare for Phase 2, staff also received detailed descriptions of how the depth and bed sensors combined to send both high-fall-probability bed exits and actual fall-alert text messages. Nursing staff were instructed on the methods required to remove and place the bed sensors on patient beds and how to disinfect and store the sensors. Housekeeping staff received instruction on methods for proper cleansing and disinfection of the sensor mats at the time of patient discharge and transfer.

The PI team encouraged ongoing input from nursing staff on the project methodology. A decision was made to only send text alerts of bed exits for patients at high fall probability. Staff perceived that sending out text alerts for patients at low or moderate risk of falls would be excessive and cause alarm fatigue. During Phase 2, the unit manager and clinical nurse specialist (CNS) on the project team queried staff frequently about their perceived responsiveness to the text alerts, whether they found the alerts reliable, and their perceptions of factors that affected their ability to respond when alerts were received.

Data Sources

Data for the review of actual falls, frequency of high-risk-fall-probability patient-bed exits and text alerts were made available on the Foresite Healthcare website. In instances when a fall did occur, involved nursing staff reviewed the fall and rewind functions to huddle and discuss the event. The reports from the hospital's SEMS and electronic health record were accessed to review any factors reported by staff to be associated with the fall (for example, mental status, fall risk assessment score) and the interventions taken after the fall. The SEMS fall report system was also accessed to collect data on fall occurrences and falls with injuries for the evaluation and comparison medicine units and the aggregate of the six other comparable medicine units. Data regarding staff perceptions of the sensor system and staff responses to fall huddles were gathered through group discussions during planned staff meetings.

RESULTS

Patient Fall Rate

The falls that were captured on video by the sensor system occurred only in patient rooms. It was not appropriate to place sensors in patient bathrooms, and the system cannot discern gait data to detect individual patients if sensors are placed in hallways.[19] From April 1, 2015, through January 30, 2016, the evaluation unit had a total of 14 falls, for a fall rate of 2.22 per 1,000 patient-days, according to hospital SEMS reports. Table 1 shows the comparison of fall rates for the evaluation and comparison units in addition to the six other medicine units (excludes critical care units) in the hospital that continued ongoing fall prevention practices. The six comparable units are within the same acute medicine service as the chosen two project units and thus are not systematically different. Fall rates were calculated for three time frames, as follows:

- Baseline: 12 months prior to the Phase 1 project
- Phase 1 project (5 months)
- Phase 2 project (10 months)

The decline in the fall rate on the evaluation unit during Phase 2 represented a 54.1% reduction in the fall rate when compared with Phase 1, when only the depth sensors were in place. The 2.22 fall rate represented a 53.7% reduction when compared with the baseline rate. To determine if the decrease in fall rates from Phase 1 to Phase 2 was statistically significant, we compared the rates using the z distribution, which assesses whether the observed rate of change is significantly greater than zero. The difference in rates from Phase 1 (4.83/1,000 patient-days; 95% confidence interval [CI]: 2.39–7.27/1,000 patient-days) to Phase 2 (2.22/1,000 patient-days; 95% CI: 1.05–3.35/1,000 patient-days) was statistically significant ($z = 2.20$; $p = 0.0297$).

Table 1. Fall Rates, Baseline (August 2013–July 2014), Phase 1 (August 2014–January 2015), and Phase 2 (April 2015–January 2016)

	Baseline Fall Rate*: 12 Months Prior to Phase 1	Fall Rate: Phase 1—Depth Sensors Only	Fall Rate: Phase 2— Bed and Depth Sensors	% Change: Phase 2 vs. Baseline	% Change: Phase 2 vs. Phase 1
Evaluation Unit (depth and bed sensor)	4.78	4.83	2.22	–53.7	–54.1†
Comparison Medicine Unit (depth sensor only)	4.38	2.97	4.69	7.0	57.9
Six other Medicine Units (no sensors)	3.93	3.79	3.32	–15.4	–12.3

*Fall rate equals number of falls/1,000 patient-days.

†The difference in rates from Phase 1 (4.83/1,000 patient-days; 95% confidence interval [CI]: 2.39–7.27/1,000 patient-days) to Phase 2 (2.22/1,000 patient-days; 95% CI: 1.05–3.35/1,000 patient-days) was statistically significant ($z = 2.20$; $p = 0.0297$).

Table 2. Fall with Injury Rates, Baseline (August 2013–July 2014), Phase 1 (August 2014–January 2015), and Phase 2 (April 2015–January 2016)

	Baseline Fall with Injury: 12 Months Prior to Phase 1	Fall with Injury: Phase 1—Depth Sensors Only	Fall with Injury: Phase 2—Bed and Depth Sensors	% Change: Phase 2 vs. Baseline	% Change: Phase 2 vs. Phase 1
Evaluation Unit (depth and bed sensor)	0.55	0.32	0.48	–13.1	47.6
Comparison Medicine Unit (depth sensor only)	1.16	0.89	0.78	–32.6	–12.3
Six other Medicine Units (no sensors)	0.70	0.68	0.62	–11.2	–9.1

During the Phase 2 project, the comparison medicine unit had a total of 30 falls, for a fall rate of 4.69 per 1,000 patient-days, according to hospital SEMS reports. This was a 57.9% increase in fall rate compared with Phase 1. The increase occurred without an intervention and represented a return to a level similar to the baseline. The 4.69 fall rate represented a slight increase (7.0%) when compared with the baseline rate. The six other acute medicine units in the hospital showed a gradual drop in fall rate over the three time periods. Ongoing fall prevention initiatives occurred for all hospital units during those periods.

The fall detection sensor system captured a full view of 3 (21.4%) of the 14 falls. A full view included capturing the patient's entire body descending to the floor. The system captured 1 fall that was not reported in SEMS. The remaining 11 falls were captured by the system on video, but fall alerts were not sent due to the actual fall being blocked from depth sensor sighting. Patients either pulled curtains in front of the depth sensor just prior to falling, or fell at an angle behind a portion of the bed, blocking view of the descent to the floor.

Both medicine units had a history of relatively few injuries from patient falls. During the Phase 2 pilot period the evaluation unit had a fall with injury rate of just 0.48 per 1,000 patient-days (see Table 2), which still represented a 47.6% increase compared with Phase 1, when only depth sensors were in place, but a 13.1% decline in comparison with the baseline results.

Of the falls that did occur and were captured on the detection system videos, 2 were high risk, 6 low risk, and 6 with level of risk unknown. The Foresite system assigns an unknown probability when a patient walk has not been captured within the last 48 hours or if no walk has occurred, implying bed rest. In comparing the JHFRAT scores for the same falls, 2 were low, 5 moderate, 6 high, and 1 auto high (automatic when a patient has a previous fall history).

Bed Exits and Text Alerts

During Phase 2, 1,889 patients were admitted to the evaluation floor. Among those patients, 270 were a high-fall-probability risk (14.3%). There were 16,882 bed exits detected for all patients, with 4,026 (23.8%) involving high-fall-probability patients. This averaged to 13.10 high-fall-probability exits per day, with a range of 3.81 to 26.45. There were 47 patients at high fall probability who had no exits reported, as a result of being on bed rest or who were transferred off the medicine unit before becoming ambulatory. A total of 1,466 high-fall-probability text alerts were sent, averaging 4.79 per day. The text alerts for high-fall-probability patient exits are configurable. Because hospital staff enter a patient room to attend to the patient after a text alert is sent, and because there may be several ensuing bed exits as staff help the patient, the system configuration is set to not send out another text alert for a high-fall-probability bed exit for 30 minutes for that patient—hence the discrepancy between high-risk exits and text alerts.

Staff Response

The responses of nursing staff to the fall detection sensor system were important factors in understanding the system's full impact on staff work activities and because their input affected implementation of the project. Initially, there were compliance issues related to the consistent placing of sensor mats on beds and removal of mats prior to a bed leaving the medicine unit (for example, during an ICU transfer). There were also difficulties with tracking the location of sensor mats when left on beds that had been moved to ICUs. The unit secretaries were then designated to help with tracking, which proved successful. Sensor mat tracking and placement were not always priorities on this busy medicine unit, compared with the critical needs of the patients. When new, better designed, and more durable mats were obtained during the last three months of the pilot study, compliance with placement and usage improved. However, the new mats were harder to place on the beds, necessitating more education and time for staff to use them.

The fall detection sensor system relies on nursing staff to respond to the text alerts that indicate falls or out-of-bed exits. By responding in a timely manner to the text alerts and implementing individualized interventions, falls can be prevented. The system does not capture nurse response time to the alerts. Each nurse assigned to patients during a course of a shift, the unit secretaries, and the lead charge nurses received text alerts. Staff perceived alarm fatigue, particularly in those instances when there were multiple high-fall-probability patients on the unit. Staff reported the usual difficulties: being able to respond to any alarm (text) quickly (for example, being occupied with another patient or wearing an isolation gown) and being unable to reach the phone. The text alerts had no audible features to improve recognition that a fall-related alert was received. Audible differentiation of text alerts is being considered for the system in the future. Overall, most staff saw the benefit of the alarms and indicated that it created a quieter environment compared to the use of the louder standard hospitalwide bed alarm system.

Fall Huddles

After a fall event, the nursing staff and lead charge nurses conducted a fall huddle to discuss the fall, analyze characteristics of the fall, and identify strategies for preventing falls from occurring in the future. During a huddle, factors preceding a fall (for example, reaching for items on a table, difficulty with a long fitting gown, needing to toilet) were identified so that appropriate interventions could be tailored for the affected patient. Fall huddles influenced nursing staff to appreciate the physical intensity of certain falls. The nursing staff and managers on the evaluation unit perceived that the fall prevention sensor system clearly created a change in the unit's fall culture. Viewing of an actual fall video leaves a very vivid impression of the severity of any fall. Another benefit from the huddle involved being able to assess the nature of the actual fall and determine if extensive diagnostic tests were needed. There were two cases in which head CT (computed tomography) exams were avoided because videos showed that the patients who fell did not strike their heads against a surface. The existence of the system also influenced staff nurses' recognition of high-risk fall factors (for example, unsteady gait, difficulty rising to sitting position to exit a bed) and likely led to interventions that could not be identified using standard PI methodology.

DISCUSSION

The findings from this PI project suggest that the fall detection sensor system was an influential factor in the reduction of falls on the evaluation unit. The system is dynamic, constantly updating a patient's fall risk probability whenever a walk occurs, a feature that cannot be achieved by using standard fall risk assessment tools. However, in the small sample of 14 actual falls, the JHFRAT score (taken prior to the fall either at admission or on a daily update) rated 50% of the patients at high risk for falling. During the pilot study, the evaluation and comparison unit remained comparable with regard to the type of patients. Nursing staff floated between the two units, and there was turnover; however, there was no significant difference in turnover between the two units.

In a recent study involving patients in long term care, also involving the depth and bed sensor system used in the current project, Phillips et al. reported that a cumulative change in gait speed over time was significantly associated with probability of a fall ($p < 0.0001$).[19] However, the current PI project involved acute-stay patients, whose length of stay is considerably shorter than that of long term care patients. The ability of the system to predict fall probability in any setting depends on the volume of data captured. The system "learns" in two different levels: (a) The volume of data coming in from all sensor systems affects the ability of the algorithm to accurately predict falls, and (b) the data from each particular patient fine-tune the algorithm for that patient. For example, the more walks captured from a particular patient, the more accurately the system can classify the patient's fall probability.[17] This has implications for placing the sensor system on patient care units where patients have lengthier stays. In addition, the longer the system is used the more accurate will be probability estimates.

The sensor system has beneficial clinical implications, including reductions in fall rates and prevention of harm. By being able to alert nurses of high-risk patients starting to exit their beds, staff have time to enter patient rooms and prevent falls. In contrast to the standard bed alarm system used by the hospital, the Foresite sensor system alerts staff early when patients become restless and begin to exit their beds. The standard system does not alarm until a complete bed exit occurs. Previously, depth sensors have been shown in other studies to have an advantage over wearable devices by offering an unobtrusive way of sourcing information and creating a means of monitoring patients to verify whether or not they have fallen.[20] The Foresite system takes fall prevention further by detecting bed exits. When a fall occurs involving a high-fall-probability patient, the Foresite system immediately alerts staff, who then become able to rescue the patient quickly to prevent any further harm. The Foresite system provides an important benefit in being able to review actual fall and rewind videos. Staff and management personnel learn what factors or conditions precipitate bed exits and what environmental and pathophysiological factors contribute to the falls. Knowing the causes for a particular fall allows for implementation of individualized interventions, which is potentially more effective than using bundles of standard interventions.

Showing the fall videos to the nursing staff and educating them about sensor mat application and how to respond to the fall text alerts were of great benefit in creating a fall prevention consciousness and awareness of the need to implement all necessary fall prevention measures. When falls did occur, staff perceived that they became more responsive and were more likely to respond to subsequent out-of-bed alerts.

The majority of the actual falls (85.7%) involved patients who were low or had an unknown fall probability, based on the Foresite sensor system probability ratings. It is important to recognize that the JHFRAT scores (50% high) represented admission assessment scores and are basically static, unless nurses reassess patients. In contrast, the Foresite system is dynamic, offering an alert system that enables staff to respond when high-fall-probability-risk patients exit their beds. The findings suggest that the fall detection system was effective in alerting nurses to high-fall-probability patients exiting beds. Because of concerns about alarm fatigue, the text alerts have not been implemented for patients at low or moderate risk for falls.

Limitations

There are limitations to the fall prevention sensor system due to the nature of patient activity and system features. Formal fall text alerts were sent for only 21.4% of actual falls because 11 falls occurred out of range of the depth sensor. Two patients closed their room curtains and then fell behind the curtains. A patient in a semiprivate room exited a bed and walked over to the other bed before falling. If a patient rolls intentionally out of bed onto the floor slowly, the system will not register the event as a fall and therefore will not send out an alert. There were also instances of patients falling at the foot of their bed with bed sensors installed at the head, thus blocking view of the fall as the patient hit the floor. Also, if the patient has been on bed rest and has not walked in the room, the system will not assign a fall probability for the patient. Foresite Healthcare has since created a newer depth sensor to capture a broader view in a patient room and is developing an algorithm to assign fall probability to patients on extensive bed rest.

System Upgrades

During the pilot, multiple upgrades to the fall prevention sensor system were made by Foresite Healthcare. With the hospital being the first to test the system on a large scale, the upgrades were made in response to adapting the system to the acute care environment, including type of bed sensor mat, materials used for the mat, color and design of electrical cords used to connect the sensor to the computer interface, and features of the informational array on the Foresite Healthcare website. The upgrade work shows the importance of testing innovative systems in actual clinical settings before committing to full implementation. Frequently new technology = receives only cursory review before hospitals commit to use.

Another upgrade added to the sensor system is the ability of clinical staff to change the fall risk probability for a patient for up to 24 hours. The medicine unit frequently has patients with encephalopathy, dementia, and other forms of confusion that do not necessarily alter a patient's gait speed but could contribute to falls. For example, none of the patients who fell used call lights to request assistance by staff. When staff dispute a patient's fall risk probability, the nursing staff can now override the fall probability by raising it for 24 hours, based on fall criteria selected by the CNS and staff.

Finally, because 6 (42.9%) of the 14 falls were classified by the system as "unknown," and because of the concern by the PI project team that patients who have been confined to bed and have not walked are at risk for postural hypotension, the system required a change. System upgrade now assigns a high fall probability if there is 16 hours of accumulated on-bed time without a walk being captured.

SUMMARY

This PI project confirmed what Aranda-Galladro et al. argued—that it is important to assess real compliance by health care personnel with procedures related to fall prevention.[7] Kosse et al. agree that it is important to include users' opinions and demands in developing and introducing sensor systems into patient care settings.[14] Time and space are also needed to practice and get used to a sensor system and to use it correctly. Overall, the manager and staff of the evaluation unit acknowledged that the sensor system created a better fall prevention consciousness. Despite operational challenges and occasional alarm fatigue that staff experienced during the pilot, the fall prevention sensor system afforded a level of monitoring and surveillance that has yet to be reported in the literature. There is a clear need for a large-scale evaluation of the sensor system to be conducted within the acute care setting. Fall prevention remains a complex issue, but sensor technology is a viable and important fall prevention option to consider.

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REFERENCES

1. Boushon B, et al. How-to Guide: Reducing Patient Injuries from Falls. Cambridge, MA: Institute for Healthcare Improvement, 2012. Accessed May 17, 2017. http://www.ihi.org/resources/Pages/Tools/TCABHowToGuideReducingPatientInjuriesfromFalls.aspx.
2. Spetz J, Brown DS, Aydin C. The economics of preventing hospital falls. J Nurs Adm. 2015;45:50–57.
3. Miake-Lye IM, et al. Inpatient fall prevention programs as a patient safety strategy: a systematic review. Ann Intern Med. 2013 Mar 5;158:390–396.
4. Goldsack J, et al. Hourly rounding and patient falls: what factors boost success? Nursing. 2015;45:25–30.
5. The Joint Commission. 2017 Comprehensive Accreditation Manual for Hospitals (E-dition). Oak Brook, IL: Joint Commission Resources, 2016.
6. Spoelstra SL, Given BA, Given CW. Fall prevention in hospitals: an integrative review. Clin Nurs Res. 2012;21:92–112.

7. Aranda-Gallardo M, et al. Instruments for assessing the risk of falls in acute hospitalized patients: a systematic review and meta-analysis. BMC Health Serv Res. 2013 Apr 2;13: 122.
8. Klinkenberg WD, Potter P. Validity of the Johns Hopkins Fall Risk Assessment Tool for predicting falls on inpatient medicine services. J Nurs Care Qual. 2017;32:108–113.
9. Kenny RA, Scanaill CN, McGrath MM. Falls Prevention in the Home: Challenges for New Technologies. Santa Monica, CA: Rand Corporation, 2012. Accessed May 17, 2017. http://www.rand.org/content/dam/rand/www/external/labor/aging/rsi/rsi_papers/2012/kenny2.pdf.
10. Potter P, et al. Anatomy of inpatient falls: examining fall events captured by depth-sensor technology. Jt Comm J Qual Patient Saf. 2016;42:225–231.
11. Hitcho EB, et al. Characteristics and circumstances of falls in a hospital setting: a prospective analysis. J Gen Intern Med. 2004;19:732–739.
12. Oliver D. Preventing falls and falls-injuries in hospitals and long-term care facilities. Rev Clin Gerontol. 2007;17:75–91.
13. Greene BR, Redmond SJ, Caulfield B. Fall risk assessment through automatic combination of clinical fall risk factors and body-worn sensor data. IEEE J Biomed Health Inform. 2016;doi:10.1109/JBHI.2016.2539098. Epub 2016 Mar 7.
14. Kosse NM, et al. Sensor technologies aiming at fall prevention in institutionalized old adults: a synthesis of current knowledge. Int J Med Inform. 2013;82:743–752.
15. Rantz MJ, et al. Automated fall detection with quality improvement “rewind” to reduce falls in hospital rooms. J Gerontol Nurs. 2014;40:13–17.
16. Banerjee T, et al. Monitoring patients in hospital beds using unobtrusive depth sensors. Conf Proc IEEE Eng Med Biol Soc. 2014;2014:5904–5907.
17. Personal communication between author [P.P.] and George Chronis, CEO and Chief Technology Officer, Foresite Healthcare, St. Louis, Mar 21, 2016, Oct 17, 2016.
18. Rantz MJ, et al. Sensor technology to support Aging in Place. J Am Med Dir Assoc. 2013;14:386–391.
19. Phillips LJ, et al. Using embedded sensors in independent living to predict gait changes and falls. West J Nurs Res. Epub 2016 Jul 27.
20. Hamm J, et al. Fall prevention intervention technologies: a conceptual framework and survey of the state of the art. J Biomed Inform. 2016;59:319–345.