Evaluation of Automated Video Monitoring to Decrease the Risk of Unattended Bed Exits in Small Rural Hospitals

Katherine J. Jones, PT, PhD,* Gleb Haynatzki, PhD,† and Lucas Sabalka, PhD‡

**Objectives:** This study aimed to evaluate the effectiveness of using 1 to 4 mobile or fixed automated video monitoring systems (AVMs) to decrease the risk of unattended bed exits (UBEs) as antecedents to unassisted falls among patients at high risk for falls and fall-related injuries in 15 small rural hospitals.

**Methods:** We compared UBE rates and fall rates during baseline (5 months in which patient movement was recorded but nurses did not receive alerts) and intervention phases (2 months in which nurses received alerts). We determined lead time (seconds elapsed from the first alert because of patient movement until 3 seconds after an UBE) during baseline and positive predictive value and sensitivity during intervention.

**Results:** Age and fall risk were negatively associated with the baseline patient rate of UBEs/day. From baseline to intervention: in 9 hospitals primarily using mobile systems, UBEs/day decreased from 0.84 to 0.09 (89%); in 5 hospitals primarily using fixed systems, UBEs/day increased from 0.43 to 3.18 (649%) in patients at low risk for falls were observed safely exiting the bed; and among 13 hospitals with complete data, total falls/1000 admissions decreased from 8.83 to 5.53 (37%), and injurious falls/1000 admissions decreased from 2.52 to 0.55 (78%). The median lead time of the AVM was 28.5 seconds, positive predictive value was nearly 60%, and sensitivity was 97.4%.

**Conclusions:** Use of relatively few AVMs may allow nurses to adaptively manage UBEs as antecedents to unassisted falls and fall-related injuries in small rural hospitals. Additional research is needed in larger hospitals to better understand the effectiveness of AVMs.

**Key Words:** falls, automated video monitoring, artificial intelligence, critical access hospitals, patient safety

*J Patient Saf* 2021;17: e716–e726

From the †Department of Health Services Research and Administration, College of Public Health, University of Nebraska Medical Center and Jones Health Services Consulting; ‡Department of Biostatistics, College of Public Health, University of Nebraska Medical Center, Omaha, and Ocuvera, LLC, Lincoln, Nebraska.

Correspondence: Katherine J. Jones, PT, PhD, Department of Health Services Research and Administration, College of Public Health, University of Nebraska Medical Center and Jones Health Services Consulting, 13506 Burt St, Omaha, NE 68154 (e-mail: kjones57@gmail.com).

This project was supported by the U.S. Department of Agriculture National Institute of Food and Agriculture Small Business Innovation Research Phase I (project 1012701), the Nebraska Department of Economic Development, and Ocuvera LLC, Lincoln, Nebraska. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute of Food and Agriculture, U.S. Department of Agriculture.

K.I. was an associate professor in the College of Allied Health Professions at the University of Nebraska Medical Center until June 2018, when she retired. She completed this article as an independent contractor. L.S. is employed by Ocuvera, LLC, and has an ownership interest in the company; he did not participate in data analysis. G.H. has no conflicts of interest to declare.

Copyright © 2020 The Author(s). Published by Wolters Kluwer Health, Inc. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.
cost of equipment and monitoring technicians,38,40,44 potential for human error by monitoring technicians,40 response delays due to hand-offs between monitoring technicians and nurses,39,40 and privacy concerns of patients and staff.42

Automated video monitoring systems (AVMSs) use video streams to find the floor and bed and machine learning to detect body segments and then predict the likelihood that a patient will exit the bed.45 At a threshold expectation of an UBE, the AVMS sends a predictive alert (i.e., before an UBE) and real-time video to nursing staff via a mobile device or central monitor.45 The goal is to provide a nurse the time and information needed to assess a patient’s behavior in clinical and environmental context (i.e., adaptively manage fall risk), respond to meet the patient’s needs, and prevent an UBE.

An AVMS may mitigate limitations associated with CVM. First, an AVMS eliminates monitoring technicians, their associated costs, delayed response, and their potential for human error, misinterpretation of behavior, and miscommunication. Second, an AVMS may use 3-dimensional (3D) images that appear as grayed-out shapes (Fig. 1) rather than photographic images to mitigate privacy concerns. To our knowledge, the evidence needed to transfer AVM technology from pilot testing to standard of care does not exist. The purpose of this study was to evaluate the feasibility and effectiveness of using a prototypical AVMS from Ocuvera, LLC (Lincoln, Nebraska)45 to decrease the risk of UBEs as antecedents to unassisted falls among patients at high risk for falls and fall-related injuries in small rural hospitals (SRHs). These hospitals may have higher fall rates than larger, urban hospitals26,46 due to limited resources and a higher prevalence of older adults who are at high risk for falls and fall-related injuries.26 This study was approved by the institutional review board of the University of Nebraska Medical Center.

**METHODS**

**Setting, Design, Participants, and Procedures**

From April 2017 to May 2018, we recruited 15 hospitals in a Midwestern state to participate in this no-cost study. We used a 1-group pretest-posttest design to compare patient and hospital rates of UBEs during baseline and intervention phases, which lasted approximately 5 and 2 months, respectively, within each hospital. To determine baseline rates of UBEs, the AVMS recorded patient movement during baseline but did not send predictive alerts to nurses. During intervention, nurses received alerts on mobile devices and a central monitor. Of the 15 hospitals, 13 were critical access hospitals licensed for 25 beds or less (Table 1). Patients admitted for acute care, skilled rehabilitation, observation, or hospice and deemed to be at high risk for falls or fall-related injuries were eligible to participate.

**TABLE 1. Hospital Characteristics and Study Enrollment**

| Hospital | Bed Size | Camera No. and Type | Admissions During Baseline (n = 4680), n (%) | Admissions During Intervention (n = 3771), n (%) | Baseline Patients (n = 221), n (%) | Intervention Patients (n = 151), n (%) |
|----------|----------|---------------------|------------------------------------------|------------------------------------------|--------------------------------|
| A        | 100–200  | 4 fixed             | 1318 (28.2)                              | 2440 (64.7)                              | 21 (9.5)                       | 15 (9.9)                         |
| B        | ≤25      | 1 mobile            | 171 (3.7)                                | 126 (3.3)                               | 8 (3.6)                        | 8 (5.3)                         |
| C        | ≤25      | 1–2 mobile*         | 151 (3.2)                                | 32 (0.8)                                | 12 (5.4)                       | 5 (3.3)                         |
| D        | 26–99    | 4 fixed             | --                                      | --                                      | 17 (7.7)                       | 13 (8.6)                        |
| E        | ≤25      | 1–2 mobile*         | 185 (4.0)                                | 45 (1.2)                                | 3 (1.4)                        | 7 (4.6)                         |
| F        | ≤25      | 1–2 mobile*         | 714 (15.3)                               | 153 (4.1)                               | 11 (5.0)                       | 8 (5.3)                         |
| G        | ≤25      | 1–2 mobile*         | 472 (10.1)                               | 86 (2.3)                                | 13 (5.9)                       | 5 (3.3)                         |
| H        | ≤25      | 1–2 mobile*         | 473 (10.1)                               | 89 (2.4)                                | 4 (1.8)                        | 0 (0.0)                         |
| I        | ≤25      | 4 fixed             | 282 (6.0)                                | 222 (5.9)                               | 28 (12.7)                      | 50 (33.1)                       |
| J        | ≤25      | 4 fixed             | 214 (4.6)                                | 220 (5.8)                               | 22 (10.0)                      | 16 (10.6)                       |
| K        | ≤25      | 2 mobile            | 158 (3.4)                                | 131 (3.5)                               | 13 (5.9)                       | 4 (2.6)                         |
| L        | ≤25      | 1 mobile            | 100 (2.1)                                | 42 (1.1)                                | 18 (8.1)                       | 4 (2.6)                         |
| M        | ≤25      | 4 fixed             | 312 (6.7)                                | 71 (1.9)                                | 21 (9.5)                       | 8 (5.3)                         |
| N        | ≤25      | 2 mobile            | 97 (2.1)                                 | 96 (2.5)                                | 16 (7.2)                       | 5 (3.3)                         |
| O        | ≤25      | 1 mobile            | 33 (0.7)                                 | 18 (0.5)                                | 14 (6.3)                       | 3 (2.0)                         |

*These hospitals received 1 mobile camera during baseline and 2 mobile cameras during intervention.*

© 2020 The Author(s). Published by Wolters Kluwer Health, Inc. www.journalpatientsafety.com | 717
Procedures included installing the AVMS, training nurses to consent patients and use the system, and collecting and analyzing patient demographic data, fall event data, and video data. We requested that hospitals report fall event data during the study using a secure online system developed for previous studies. The AVMS consisted of a room sensor, mobile devices for nursing staff, and a central monitor at the nurse’s station (Fig. 2). The room sensor included a Microsoft Kinect (Microsoft Corporation, Redmond, WA) for Xbox One depth camera (field of view, 70.6 degrees wide by 60 degrees tall), a touchscreen, and an internal computer to analyze patient movement and send predictive alerts when movement exceeded the threshold expectation of an UBE. The camera used an infrared signal for night vision and provided 3D images of grayed-out shapes (Fig. 1) by measuring the depth for each pixel as its distance to the camera’s imaging plane. Cameras were installed as mobile units on a cart or fixed units on a wall to accommodate the needs/environment of each hospital. Cameras were 3 to 6 ft from the foot of the bed and 6.5 to 7 ft above the floor. We provided onsite training for nurses with supporting documentation about the AVMS, starting/stopping patients, and consenting patients. We emphasized 2 topics:

• Point the camera at the foot of the bed to improve accuracy of predictive algorithms.
• Press the “Privacy Mode” button during sensitive patient care to stop the camera for 15-minute increments.

We regularly exchanged a hard drive within each room sensor, transported it to our office, downloaded system performance data and video to a restricted-access hard drive, and converted the video into numeric data for analysis. We manually identified UBEs in the video by viewing every sixth frame at high speed and then determining whether there was an associated alert for each identified UBE. To adjust for errors associated with this manual process, we randomly sampled for missed UBEs. To account for UBEs found by random sampling, we weighted the number of manually found UBEs using the ratio: (total time for given patient not within 7 minutes before and 2 minutes after a manually found UBE)/(total time not within 7 minutes before and 2 minutes after

FIGURE 2. Ocuvera AVMS.
a randomly found UBE). The average weight for a randomly found UBE was approximately 50.

**Measures and Analyses**

Measures included hospital characteristics (Table 1), patient demographics (Table 2), hospital admissions and fall event information, hours of video recorded, UBEs per patient, and lead time for baseline UBEs. We calculated 2 UBE rates:

+ patient rate of UBEs per day = (total number of UBEs per patient/total hours of video per patient) \times (24 hours per day) and
+ hospital rate of UBEs per day = (total number of UBEs per hospital/total hours of video per hospital) \times (24 hours per day).

To determine the potential prospective advantage of the AVMS, we measured the lead time for UBEs that occurred during baseline when nurses did not receive alerts. Lead time was the number of seconds that elapsed from the first alert generated by the system due to patient movement until 3 seconds after the UBE. If the system did not generate an alert until after the UBE, then lead time was negative. We calculated lead time if the patient movement that precipitated the alert began when the patient was lying in bed and was alone from the time movement began until 3 seconds after the UBE. We used descriptive statistics and hypothesis tests appropriate for the distribution and sample size of the measure to compare differences between baseline and intervention values. We attempted a mixed linear model to predict median lead time using patient as a random effect, but this model did not converge because of limited sample size. We report the specific tests used in the notes section of our tables and within figure titles. We considered $P$ values less than 0.05 to be statistically significant and those less than 0.10 to be marginally significant (of interest) given our sample size of 15 hospitals and the value of identifying potentially promising evidence.52,53 We used IBM SPSS Statistics version 25 to conduct all analyses (IBM, Armonk, New York).

We determined the positive predictive value (PPV) and sensitivity of alerts received by nurses during intervention. To determine PPV, 1 or 2 nurses from hospitals not participating in the study independently reviewed video of patient movement that led to alerts during intervention. Nurses classified an alert as "true positive" if they judged that patient behavior in the video warranted assessment or "false positive" if they believed that patient behavior did not warrant assessment. Disagreements were resolved by consensus when possible. To determine the sensitivity of the alerts, we calculated the proportion of UBEs during intervention that were preceded by an alert.

**RESULTS**

During the 13 months of the study, 408 patients consented to participate. We analyzed video from 372 (91%) patients (Table 1). Video was not analyzed when a camera was improperly positioned such that the bed was not fully visible for more than half of the admission, which typically occurred with mobile cameras during baseline. Five hospitals used fixed cameras, and 10 used mobile cameras. Approximately 4% of hospital admissions participated in the study.

**Patient Demographics**

The characteristics of patients did not vary significantly from baseline to intervention (Table 2). More than 90% of patients were...

| Demographics | Aggregate | Baseline | Intervention | $P^*$ |
|--------------|-----------|----------|--------------|------|
| Age category | n = 358, n (%) | n = 216, n (%) | n = 142, n (%) | 0.687 |
| <65          | 29 (8.1)   | 17 (7.9) | 12 (8.5)     |      |
| 65–84        | 150 (41.9) | 87 (40.3) | 63 (44.4)    |      |
| 85+          | 179 (50.0) | 112 (51.9) | 67 (47.2)    |      |
| Sex          | n = 350, n (%) | n = 211, n (%) | n = 139, n (%) | 0.826 |
| Female       | 195 (55.7) | 119 (56.4) | 76 (54.7)    |      |
| Male         | 155 (44.3) | 92 (43.6)  | 63 (45.3)    |      |
| Diagnoses†   | n = 354, n (%) | n = 217, n (%) | n = 137, n (%) | 0.549 |
| Cardiovascular | 47 (13.3) | 32 (14.7) | 15 (10.9)    |      |
| Fall history  | 24 (6.8)   | 14 (6.5)  | 10 (7.3)     |      |
| Gastrointestinal | 19 (5.4)   | 12 (5.5)  | 7 (5.1)      |      |
| Infection    | 31 (8.8)   | 16 (7.4)  | 15 (10.9)    |      |
| Mental status change | 22 (6.2) | 9 (4.1) | 13 (9.5) | |
| Neurological | 23 (6.5)   | 13 (6.0)  | 10 (7.3)     |      |
| Orthopedic   | 47 (13.3)  | 29 (13.4) | 18 (13.1)    |      |
| Renal/Urinary | 22 (6.2)   | 16 (7.4)  | 6 (4.4)      |      |
| Respiratory  | 59 (16.7)  | 37 (17.1) | 22 (16.1)    |      |
| Weak         | 19 (5.4)   | 14 (6.5)  | 5 (3.6)      |      |
| Other        | 41 (11.6)  | 25 (11.5) | 16 (11.7)    |      |
| Fall risk category‡ | n = 326, n (%) | n = 196, n (%) | n = 130, n (%) | 0.459 |
| Low          | 23 (7.1)   | 13 (6.6)  | 10 (7.7)     |      |
| High         | 116 (35.6) | 75 (38.3) | 41 (31.5)    |      |
| Very high    | 187 (57.4) | 108 (55.1) | 79 (60.8)    |      |

*Differences between baseline and intervention phases calculated using the Pearson $\chi^2$ test or Fisher exact test.
†Admitting diagnoses were sorted into categories consistent with those used by Morse et al.47
‡Fall risk scores from the assessment used by each hospital were categorized as low, high, or very high consistent with published studies.48–51
65 years and older, and half were 85 years and older. Most were female; respiratory, cardiovascular, and orthopedic conditions were the most prevalent diagnoses. Approximately 93% of patients were at high or very high risk for falls.

### Unattended Bed Exits

Of 221 patients in the baseline phase, 71 (32%) exited the bed unattended 507 times (mean, 7.14; median, 3.00; range, 1–66). Of 151 patients in the intervention phase, 47 (31%) exited the bed unattended 815 times (mean, 17.35; median, 6.00; range, 1–203). Weights were applied to the UBE count for 1 baseline patient (79-year-old man at high risk for falls whose UBE count increased from 22 to 66) and 1 intervention patient (79-year-old woman at low risk for falls, whose UBE count increased from 52 to 203). Age and fall risk were significantly associated with the rate of UBEs/day during baseline (Table 3). Specifically, patients younger than 65 years and those at low risk for falls had significantly greater median rates of UBEs/day than did older patients and those at high/very high risk for falls. Only age was significantly associated with the rate of UBEs/day during intervention; patients younger than 65 years had greater rates of UBEs/day than did older patients.

The hospital rate of UBEs/day ranged from 0 to 1.68 during baseline and from 0 to 5.16 during intervention (Table 4). Thus, it seemed that hospitals used the system for 2 different purposes during intervention: to intervene and prevent UBEs or to monitor patients as they exited the bed unattended.

### Table 3. Patient Rate of UBEs/Day During Baseline and Intervention by Patient Demographics

| Category (n Baseline, n Intervention) | Patient Rate of UBEs/Day in Baseline, Median (Range) | \(P^a\) | Patient Rate of UBEs/Day in Intervention, Median (Range) | \(P^a\) |
|---------------------------------------|-----------------------------------------------------|------|------------------------------------------------------|------|
| Sex                                   |                                                     |      |                                                      |      |
| Female                                | 0.00 (0.00–16.75)                                   | 0.932 | 0.00 (0.00–73.06)                                   | 0.267 |
| Male                                  | 0.00 (0.00–40.39)                                   |      | 0.00 (0.00–17.94)                                   |      |
| Age                                   |                                                     | 0.001 |                                                      |      |
| <65 y (17, 12)                        | 0.78 (0.00–16.75)                                   |      | 2.14 (0.00–17.18)                                   |      |
| 65–84 y (87, 63)                      | 0.00 (0.00–40.39)                                   |      | 0.00 (0.00–73.06)                                   |      |
| 85+ y (112, 67)                       | 0.00 (0.00–4.26)                                    |      | 0.00 (0.00–13.42)                                   |      |
| Fall risk                             |                                                     | 0.015 |                                                      | 0.130 |
| Low (13, 10)                          | 3.41 (0.00–15.75)                                   |      | 0.80 (0.00–73.06)                                   |      |
| High (75, 41)                         | 0.00 (0.00–22.74)                                   |      | 0.00 (0.00–17.94)                                   |      |
| Very high (108, 79)                   | 0.00 (0.00–40.39)                                   |      | 0.00 (0.00–17.18)                                   |      |

*Nonparametric independent-samples median test.

### Table 4. Hospital Use of AVM System During Intervention and Comparison of Rate of UBEs Per Day by Study Phase

| Hospital (Intervention Cameras) | Hospital Admissions* in Intervention, % | Patients at High/Very High Risk for Falls in Intervention, % | Baseline, n | Intervention, n | Difference | \(P^\dagger\) |
|---------------------------------|----------------------------------------|-------------------------------------------------------------|--------------|----------------|------------|------------|
| Aggregate monitoring            | 3.11                                   | 89.0                                                         | 0.43         | 3.18           | 2.75       | 0.043      |
| A (4 fixed)                     | 0.6                                    | 60.0                                                         | 1.29         | 5.16           | 3.87       |            |
| D (4 fixed)                     | —                                      | 91.7                                                         | 0.15         | 0.18           | 0.03       |            |
| L (1 mobile)                    | 22.5                                   | 97.3                                                         | 0.40         | 3.60           | 3.20       |            |
| N (2 mobile)                    | 9.5                                    | 100.0                                                        | 0.03         | 1.14           | 1.11       |            |
| Aggregate intervening          | 6.59                                   | 96.5                                                         | 0.84         | 0.09           | –0.75      | 0.018      |
| C (2 mobile)                    | 6.3                                    | 100.0                                                        | 0.49         | 0.00           | –0.49      |            |
| E (2 mobile)                    | 15.6                                   | 100.0                                                        | 0.00         | 0.00           | 0.00       |            |
| F (2 mobile)                    | 15.6                                   | 71.4                                                         | 0.00         | 0.00           | 0.00       |            |
| G (2 mobile)                    | 5.2                                    | 100.0                                                        | 0.77         | 0.36           | –0.41      |            |
| H (2 mobile)                    | 0.0                                    | —                                                            | 0.00         | —              | 0.00       |            |
| J (4 fixed)                     | 0.7                                    | 100.0                                                        | 0.66         | 0.02           | –0.64      |            |
| K (2 mobile)                    | 3.1                                    | —                                                            | 0.98         | 0.04           | –0.94      |            |
| M (2 mobile)                    | 11.3                                   | 100.0                                                        | 1.68         | 0.28           | –1.40      |            |
| O (1 mobile)                    | 16.7                                   | 100.0                                                        | 0.62         | 0.00           | –0.62      |            |

*Fourteen hospitals reported admissions by month during the study for all patients admitted to acute, skilled rehabilitation, observation, or hospice beds.

\(\dagger\)Differences between baseline and intervention phases calculated using the related-samples Wilcoxon signed ranks test.

\(\dagger\)Hospital D did not report admissions data.

\(\dagger\)Hospital H did not contribute any patients to the intervention phase of the study.
UBE\text{e}s/day increased from baseline to intervention in 5 hospitals, and it remained 0 or decreased from baseline to intervention in 9 hospitals. (One hospital did not participate in the intervention). Among the 5 monitoring hospitals, the aggregate rate of UBE\text{es}/day increased significantly from 0.43 during baseline to 3.18 (649\%) during intervention; 3 of these 5 had fixed cameras. Nurses reported that when census was high, patients at low risk for falls were often admitted to rooms with fixed cameras and were not moved because of the cost of cleaning rooms. Conversely, among the 9 intervening hospitals, the aggregate rate of UBE\text{es}/day decreased significantly from 0.84 during baseline to 0.09 (89\%) during intervention; 8 of these 9 had mobile cameras.

Among the 9 intervening hospitals during baseline, age was significantly and negatively associated with the rate of UBE\text{es}/day. Among 118 patients (Fig. 3A),

- 71 (60\%) had “0” UBE\text{es}/day and
- 47 (40\%) had a median rate of 1.31 UBE\text{es}/day (range, 0.04–22.74 UBE\text{es}/day).

Among these 9 during intervention, age was not significantly associated with the rate of UBE\text{es}/day. Among 61 patients (Fig. 3B),

- 54 (89\%) had “0” UBE\text{es}/day and

![Figure 3A](image1.png)

**FIGURE 3.** A, Baseline: age is significantly associated with rate of UBE\text{es} per day for 9 sites that used AVM system to intervene and prevent UBE\text{es} (Spearman $\rho = -0.333$, $P < 0.001$). B, Intervention: age is not associated with rate of UBE\text{es} per day for 9 sites that used AVM system to intervene and prevent UBE\text{es} (Spearman $\rho = -0.075$, $P = 0.567$).
• 7 (11%) had a median rate of 0.54 UBEs/day (range, 0.054–13.42 UBEs/day).

Among the 5 monitoring hospitals during baseline, age was significantly and negatively associated with the rate of UBEs/day. Among 98 patients (Fig. 4A),

• 77 (79%) had “0” UBEs/day and
• 21 (21%) had a median rate of 1.11 UBEs/day (range, 0.07–40.39 UBEs/day).

Among these 5 during intervention, age was significantly and negatively associated with the rate of UBEs/day. Among 81 patients (Fig. 4B),

• 44 (54%) had “0” UBEs/day and
• 37 (46%) had a median rate of 3.72 UBEs/day (range, 0.06–73.06 UBEs/day).

**Lead Time**

We calculated the median lead time in seconds for the 318 UBEs associated with 64 of the 71 patients who exited the bed during baseline. The distribution of these medians was right-skewed (mean [SD], 53.61 [71.05]; median, 28.00; range, 0–396). To summarize these skewed data, we identified the 95% central range of the 64 medians54 (mean [SD], 50.58 [56.99]; median, 28.50; range, 1–248). Among the latter 60 observations in the 95% central range, age
was positively and significantly associated with median lead time (Fig. 5). Sex and fall-risk category were not significantly associated with median lead time.

PPV and Sensitivity

The denominator for calculating the PPV of the AVMS was the 4190 alerts associated with patient movement generated during intervention. Because 2 nurses reviewing alerts were not consistently available to independently review and concurrently resolve disagreements, we calculated a conservative and an optimistic estimate of PPV. The numerator for the conservative estimate was the 2362 alerts that 2 nurses agreed were true positives, or if there was only one review, it was also true positive. The numerator for the optimistic estimate was the 2487 alerts that 2 nurses agreed were true positives, and if there was a disagreement, at least one nurse identified the alert as true positive, or if there was only one review, it was also true positive. Thus, the conservative PPV was 56.4% and the optimistic PPV was 59.4%. Forty-seven patients exited the bed unattended 815 times during intervention. Of these 815 UBEs, 794 were preceded by an alert. Thus, the sensitivity of the AVMS to detect UBEs was 97.4%.

Fall Events

From baseline to intervention among the 13 hospitals with complete admissions and fall event data, total falls/1000 admissions decreased from 8.83 to 5.53 (37%), and injurious falls/1000 admissions decreased significantly from 2.52 to 0.55 (78%; Table 5). Approximately 41% of patient falls during the study occurred at bedside. From baseline to intervention among the 5 monitoring hospitals, no study patients fell at the bedside, and the proportions of:

• assisted falls increased significantly from 0% to 44%,
• injurious falls decreased marginally from 33% to 6%, and
• patients requiring increased postfall observation decreased marginally from 33% to 6%.

From baseline to intervention among the 9 intervening hospitals:

• the proportion of falls that occurred at the bedside decreased from 41% to 0%,
• total falls/1000 admissions decreased significantly from 13.37 to 3.67 (72.6%), and
• injurious falls/1000 admissions decreased marginally from 2.77 to 1.22 (56%).

Although not statistically significant, the proportions of patients requiring postfall observation and imaging decreased among all hospitals.

DISCUSSION

We sought to evaluate the feasibility and effectiveness of using a prototypical AVMS to decrease the risk of UBEs as antecedents to unassisted falls among patients at high risk for falls and fall-related injuries in SRHs. Our results demonstrate that the high sensitivity and median lead time of 28 seconds make it feasible to significantly decrease the median rate of UBEs/day in SRHs by 89% with 1 to 2 mobile cameras (Table 4, Fig. 3). Surprisingly, we found that the effectiveness of the AVMS to decrease rates of UBEs may be associated with camera type and hospital usage (Table 4, Fig. 4). Specifically, when census is high, hospitals using few fixed cameras may admit patients at low risk for falls to rooms with the AVMS and then use it to observe these patients as they exit the bed. Regardless of camera type and hospital usage, when evaluated using the intention-to-treat principle,55 the AVMS may have been effective in preventing bedside falls and decreasing total falls/1000 admissions by 37% and injurious falls by 78% (Table 5). In contrast, CVM decreased total fall rates by 20% to 29%.38,40,43 Thus, nurses may use the sensitivity, lead time, and information generated by the AVMS to adaptively manage fall risk (e.g., apply and use a gait belt and assistive device) and decrease the risk of UBEs as antecedents to unassisted falls and fall-related injuries and not to limit safe mobility. This interpretation is consistent with a PPV value of nearly 60% and is in contrast to the alarm fatigue associated with bed pressure-sensor alarms.36,37

This may be the first study to report the incidence of UBEs among hospitalized patients and to report that age and fall risk are associated with a patient’s rate of UBEs/day. Specifically, younger adults and those at low risk for falls may exit the bed unattended more frequently than older adults and those at high risk for falls (Table 3). However, the older a patient, the longer is the lead time provided by an alert so that older patients, who are at highest risk for fall-related injuries,6,54 also have the greatest lead time before an UBE (Fig. 5). These findings are consistent with normative studies that have documented the negative correlation between age and physical function.57–59

FIGURE 5. Baseline: age is significantly associated with median lead time (Spearman ρ = 0.359, P = 0.006).
TABLE 5. Fall Event Characteristics and Falls Per 1000 Admissions

| Fall Event Characteristics | All Falls During Study | Hospital Used AVM to Monitor | Hospital Used AVM to Intervene |
|----------------------------|------------------------|-----------------------------|-------------------------------|
|                            | Baseline | Intervention | $P^*$                      | Baseline | Intervention | $P^*$ |
| Fall location, n = 66, n (%) |          |              |                           |          |              |       |
| Bedside                    | 27 (40.9) | 6 (40.0)    | 0.729                      | 12 (41.4) | 0 (0.00)     | 0.271 |
| Not bedside                | 39 (59.1) | 9 (60.0)    |                           | 17 (58.6) | 4 (100.0)    |       |
| Bathroom                   | 24 (36.4) | 8 (44.4)    |                           | 9 (31.0)  | 1 (25.0)     |       |
| Chairside                  | 13 (19.7) | 1 (5.6)     |                           | 6 (20.7)  | 2 (50.0)     |       |
| Hallway                    | 1 (1.5)   | 0 (0.00)    |                           | 1 (3.4)   | 0 (0.00)     |       |
| Room                       | 1 (1.5)   | 0 (0.00)    |                           | 1 (3.4)   | 0 (0.00)     |       |
| Fall assistance, n = 65, n (%) |          |              |                           |          |              |       |
| Unassisted                 | 47 (72.3) | 14 (100.0)  | 0.004                      | 20 (69.0) | 3 (75.0)     | 1.00  |
| Assisted                   | 18 (27.7) | 0 (0.00)    |                           | 9 (31.0)  | 1 (25.0)     |       |
| Extent of harm, n = 66, n (%) |          |              |                           |          |              |       |
| No harm                    | 52 (78.8) | 10 (66.7)   | 0.070                      | 23 (79.3) | 2 (50.0)     | 0.241 |
| Harm                       | 14 (21.2) | 5 (33.3)    |                           | 6 (20.7)  | 2 (50.0)     |       |
| Actions taken due to fall, n = 66, n (%) |          |              |                           |          |              |       |
| Increased observation      | 11 (16.7) | 5 (33.3)    | 0.070                      | 4 (13.8)  | 1 (25.0)     | 0.500 |
| Imaging                    | 9 (13.6)  | 3 (20.0)    |                           | 4 (13.8)  | 0 (0.00)     | 1.00  |
| Medication change          | 3 (4.5)   | 0 (0.00)    |                           | 3 (10.3)  | 0 (0.00)     | 1.00  |
| Surgical procedure         | 1 (1.5)   | 0 (0.00)    |                           | 1 (3.4)   | 0 (0.00)     | 1.00  |

$^*$ Differences between baseline and intervention phases calculated using the Fisher exact test.

$^†$ None of these bedside falls occurred among study patients.

$^‡$ Two hospitals either did not report admissions or did not report fall event data and were removed from this analysis.

$^§$ Differences between baseline and intervention phases calculated using the related-samples Wilcoxon signed rank test.

Limitations and Future Research

Limitations to this study include missing data that decreased sample size, some of which were fixed. Nurses failed to submit complete demographics for nearly 10% of patients, and we could not calculate fall rates for 2 of 15 hospitals because of missing admissions and fall event data. Using few cameras per hospital led to collecting admissions rather than patient days because we anticipated the need to explain the lack of an impact on fall rates of an intervention applied to 4% of admissions. Using few cameras may have led to “rationing” of the AVMS to patients at highest risk for falls, and using fixed cameras may have led nurses to use the AVMS for some patients at low risk for falls and to not use it for some at high risk for falls and fall-related injuries. As rare events, the rate of falls may vary considerably over a few months.60 Thus, changes in falls/1000 admissions from baseline to intervention should be interpreted as indicating potential promising evidence rather than proof of causation. Finally, this study took place in SRHs in which half of patients were 85 years and older and should not be generalized to larger hospitals. Additional research is needed to better understand the effect of the AVMS on fall rates and the costs of postfall assessment and treatment. These studies should be conducted in larger hospitals in which every patient at high risk for falls within a unit has access to an AVMS. These studies should compare fall rates and postfall costs between study and control units for up to 1 year before and after intervention.

CONCLUSIONS

Nurses used the high sensitivity and lead time provided by this prototypical AVMS to adaptively manage UBEs as antecedents to unassisted falls and fall-related injuries. Because of the low census in SRHs, just 1 to 2 mobile cameras may improve patient safety in these hospitals with limited resources and high proportions of older adults who are at high risk for falls and fall-related injuries. Additional research is needed to better understand the effect of an AVMS on fall rates and the costs of postfall assessment and treatment.

REFERENCES

1. Oliver D, Healey F, Haines TP. Preventing falls and fall-related injuries in hospitals. Clin Geriatr Med. 2010;26:645–692.
2. Weiss AJ, Elixhauser A, eds. Overview of Hospital Stays in the United States, 2012. Rockville, MD: Agency for Healthcare Research and Quality; October 2014 HCUP Statistical Brief; No. 180. Available at: http://www.hcup-us.ahrq.gov/reports/statbriefs/sb180-Hospitalizations-United-States-2012.pdf. Accessed February 26, 2020.
3. Morello RT, Barker AL, Watts JJ, et al. The extra resource burden of in-hospital falls: a cost of falls study. Med J Austr. 2015;203:367.
4. Rubenstein LZ, Josephson KR. The epidemiology of falls and syncope. Clin Geriatr Med. 2002;18:141–158.
5. Bouldin EL, Andreason EM, Dunton NE, et al. Falls among adult patients hospitalized in the United States: prevalence and trends. *J Patient Saf*. 2013;9:13–17.

6. Venema DM, Skinner AM, Nailon R, et al. Patient and system factors associated with unassisted and injurious falls in hospitals: an observational study. *BMC Geriatr*. 2019;19:348.

7. NORC at the University of Chicago. Estimating the additional hospital inpatient cost and mortality associated with selected hospital-acquired conditions. Agency for Healthcare Research and Quality Web site. Available at: https://www.ahrq.gov/hai/pf/haccost2017.html. Published November 2017. Updated 2017. Accessed February 29, 2020.

8. Wong CA, Recktenwald AJ, Jones ML, et al. The cost of serious fall-related injuries at three midwestern hospitals. *Jt Comm J Qual Patient Saf*. 2011;37:81–87.

9. Fields J, Alturkistani T, Kumar N, et al. Prevalence and cost of imaging in inpatient falls: the rising cost of falling. *Clinicoecon Outcomes Res*. 2015;7:281–286.

10. Deshpande N, Metter EJ, Lauretani F, et al. Activity restriction induced by fear of falling and objective and subjective measures of physical function: a prospective cohort study. *J Am Geriatr Soc*. 2008;56:615–620.

11. Staggs VS, Dunton N. Associations between rates of unassisted inpatient falls and levels of registered and non-registered nurse staffing. *Int J Qual Health Care*. 2014;26:87–92.

12. Agency for Healthcare Research and Quality. Supporting documents—common formats—hospital version 1.2. Available at: https://www.psonpe.org/psonpe_web/publicpages/supportingDocsV1.2. Accessed June 13, 2018.

13. Staggs VS, Mion LC, Shorr RI. Assisted and unassisted falls: different events, different outcomes, different implications for quality of hospital care. *Jt Comm J Qual Patient Saf*. 2014;40:358–364.

14. Jones KJ, Skinner A, Venema D, et al. Evaluating the use of multiteam systems to manage the complexity of inpatient falls in rural hospitals. *Health Serv Res*. 2019;54:994–1006.

15. Drolet A, DeJulio P, Harkless S, et al. Move to improve: the feasibility of using an early mobility protocol to increase ambulation in the intensive and intermediate care settings. *Phys Ther*. 2013;93:197–207.

16. Centers for Medicare and Medicaid Services. Hospital-acquired conditions. CMS.gov Web site. Available at: https://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/HospitalAcqCond/Hospital-Acquired-Conditions.html. Updated 2020. Accessed March 28, 2020.

17. Agency for Healthcare Research and Quality. AHRQ national scorecard on hospital-acquired conditions updated baseline rates and preliminary results 2014–2017. AHRQ National Scorecard on Hospital-Acquired Conditions Web site. Available at: https://www.ahrq.gov/sites/default/files/wysiwyg/professionals/quality-patient-safety/pfi/hacscore-report2019.pdf. Published January 2019. Updated 2019. Accessed February 26, 2020.

18. Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. *J Am Geriatr Soc*. 2001;49:664–672.

19. Evans D, Hodgkinson B, Lambert L, et al. Fall risk factors in the hospital setting: a systematic review. *JNPN*. 2001;7:38–45.

20. Oliver D, Daly F, Martin FC, et al. Risk factors and risk assessment tools for falls in hospital in-patients: a systematic review. *Age Ageing*. 2004;33:122–130.

21. Tzeng HM, Yin CY. The extrinsic risk factors for inpatient falls in hospital patient rooms. *J Nurs Care Qual*. 2008;23:233–241.

22. Brewer BB, Carley KM, Benham-Hutchins M, et al. Nursing unit design, nursing staff communication networks, and patient falls: are they related? *HERD*. 2018;11:82–94.

23. Real K, Bardach SH, Bardach DR. The role of the built environment: how decentralized nurse stations shape communication, patient care processes, and patient outcomes. *Health Commun*. 2017;32:1557–1570.
48. Morse JM, Tylko SJ, Dixon HA. The patient who falls—and falls again: defining the aged at risk. *J Gerontol Nurs.* 1985;11:15–18.

49. Schmid NA. 1989 Federal Nursing Service Award Winner. Reducing patient falls: a research-based comprehensive fall prevention program. *Mil Med.* 1990;155:202–207.

50. Victoria Department of Human Services Metropolitan Health and Aged Care Division. *Minimising the Risk of Falls and Fall-Related Injuries: Guidelines for Acute, Sub-acute and Residential Care Settings.* Melbourne, Australia: Victorian Government Department of Human Services; 2004.

51. Poe SS, Cvach M, Dawson PB, et al. The Johns Hopkins fall risk assessment tool: postimplementation evaluation. *J Nurs Care Qual.* 2007;22:293–298.

52. Berwick DM. The science of improvement. *JAMA.* 2008;299:1182–1184.

53. Kirk RE. Practical significance: a concept whose time has come. *Educ Psychol Meas.* 1996;56:746–759.

54. Altman DG. *Practical Statistics for Medical Research.* London: Chapman & Hall; 1999.

55. Detry MA, Lewis RJ. The intention-to-treat principle: how to assess the true effect of choosing a medical treatment. *JAMA.* 2014;312:85–86.

56. Anderson C, Dolansky M, Damato EG, et al. Predictors of serious fall injury in hospitalized patients. *Clin Nurs Res.* 2015;24:269–283.

57. Jones CJ, Rikli RE, Beam WC. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Res Q Exerc Sport.* 1999;70:113–119.

58. Chen HT, Lin CH, Yu LH. Normative physical fitness scores for community-dwelling older adults. *J Nurs Res.* 2009;17:30–41.

59. Rikli RE, Jones CJ. Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. *Gerontologist.* 2013;53:255–267.

60. He J, Dunton N, Staggs V. Unit-level time trends in inpatient fall rates of US hospitals. *Med Care.* 2012;50:801–807.