The Joint Commission Journal on Quality and Patient Safety 2022; 48:370–375

2021 JOHN M. EISENBERG AWARD FOR INNOVATION IN PATIENT SAFETY AND QUALITY AT THE LOCAL LEVEL

The Kaiser Permanente Northern California Advance Alert Monitor Program: An Automated Early Warning System for Adults at Risk for In-Hospital Clinical Deterioration

Vanessa A. Martinez, DNP, MHA, RN; Robin K. Betts, MBA-HM, RN, CPHQ; Elizabeth A. Scruth, PhD, MPH, RN, CNS, CCRN-K, CCNS, FCCM, FCNS, CPHQ; Jacqueline D. Buckley, MBA, MSN, RN, CCRN-K, CPHQ; Vilma R. Cadiz, MSN, MBA, RN; Linda D. Bertrand, MSN, RN; Shirley S. Paulson, DNP, MPA, RN, NEA-BC; Brian Alex Dummett, MD, CPPS; Stella S. Abhyankar, MD; Vivian M. Reyes, MD; Joeffrey R. Hatton, MBA; Reynaldo Sulit, MSN-NI, RN-BC, CPHIMS, CPHQ; Vincent X. Liu, MD

Background: In-hospital deterioration among ward patients is associated with substantially increased adverse outcome rates. In 2013 Kaiser Permanente Northern California (KPNC) developed and implemented a predictive analytics–driven program, Advance Alert Monitor (AAM), to improve early detection and intervention for in-hospital deterioration. The AAM predictive model is designed to give clinicians 12 hours of lead time before clinical deterioration, permitting early detection and a patient goals–concordant response to prevent worsening.

Design of the AAM Intervention: Across the 21 hospitals of the KPNC integrated health care delivery system, AAM analyzes electronic health record (EHR) data for patients in medical/surgical and telemetry units 24 hours a day, 7 days a week. Patients identified as high risk by the AAM algorithm trigger an alert for a regional team of experienced critical care virtual quality nurse consultants (VQNCs), who then cascade validated, actionable information to rapid response team (RRT) nurses at local hospitals. RRT nurses conduct bedside assessments of at-risk patients and formulate interdisciplinary clinical responses with hospital-based physicians, bedside nurses, and supportive care teams to ensure a well-defined escalation plan that includes clarification of the patients' goals of care.

Success of the Intervention: Since 2019 the AAM program has been implemented at all 21 KPNC hospitals. The use of predictive modeling embedded within the EHR to identify high-risk patients has produced the standardization of monitoring workflows, clinical rescue protocols, and coordination to ensure that care is consistent with patients' individual goals of care. An evaluation of the program, using a staggered deployment sequence over 19 hospitals, demonstrates that the AAM program is associated with statistically significant decreases in mortality (9.8% vs. 14.4%), hospital length of stay, and ICU length of stay. Statistical analyses estimated that more than 500 deaths were prevented each year with the AAM program.

Lessons Learned: Unlocking the potential of predictive modeling in the EHR is the first step toward realizing the promise of artificial intelligence/machine learning (AI/ML) to improve health outcomes. The AAM program leveraged predictive analytics to produce highly reliable care by identifying at-risk patients, preventing deterioration, and reducing adverse outcomes and can be used as a model for how clinical decision support and inpatient population management can effectively improve care.

Acute inpatient deterioration outside of the ICU is associated with significantly higher rates of severe illness and death.[1,2] Failure to identify, communicate, and provide interventions for early clinical indicators of deterioration can lead to delays in care, adverse events, unplanned ICU admissions, and unexpected death.[2] Conclusions derived from studying internal data show that the mortality of ICU transfers from the wards is significantly higher than the mortality of direct admissions to the ICU from the emergency department (ED) (58% vs. 22%), which could be partially attributable to delays in care.[1,3]

Most ICU transfers occur early after admission: more than 50% of ICU up-transfers happen in the first 24 hours and nearly 80% occur in the first 48 hours.[3] Although pa-

1553-7250/$-see front matter

https://doi.org/10.1016/j.jcjq.2022.05.005

tients who up-transfer to the ICU represent only a small proportion of all Kaiser Permanente Northern California (KPNC) hospital admissions (3%–4%), they account for as much as 20% to 25% of hospital deaths and ICU admissions.[4] Most ICU transfers are thought to be avoidable and are often associated with conditions present at the time of admission.[1,4,5]

With this knowledge, KPNC developed and implemented a predictive analytic scoring system called Advance Alert Monitor (AAM).[1,2,6,7] AAM is an early warning system that uses statistical modeling and artificial intelligence/machine learning (AI/ML) and has been shown to have improved prognostic performance over aggregate weighted models.[8] Statistical modeling, including AI/ML approaches, allows for the inclusion of a larger set of clinical predictor variables, which can reduce the degree of unexplained variances in the model.[8]

The AAM program aimed to proactively identify and intervene on inpatients at high risk for clinical deterioration by combining the use of an embedded predictive model, a carefully monitored virtual care program, and multidisciplinary bedside care.[6] The automated system scans the patient electronic health record (EHR) and assigns an AAM score that incorporates diverse clinical data, including composite scores for chronic (Comorbidity Point Score, version 2 [COPS2]) and acute (Laboratory-based Acute Physiology Score, version 2 [LAPS2]) severity of illness.[1,2,7] These two algorithms were validated in cohorts including more than two million hospitalizations: one of the largest contemporary datasets available. A key objective during the development of the AAM algorithm and workflow was to minimize alert fatigue by calibrating the AAM score to a clinically sustainable alert frequency: two new alerts per day per 7,000 annual discharges, translating into a threshold of ≥ 8% risk of deterioration within the next 12 hours).[9]

The goal of minimizing the clinician burden on frontline clinicians also motivated the use of a regional virtual quality nurse consultant (VQNC) initial chart review when the AAM score flagged high-risk patients. Experienced nurses could offer expert clinical assessments of the patient at risk for deterioration, which also allows for screening out of patients in whom appropriate care was already being provided based on standardized, evolving criteria driven by frontline feedback and leadership validation. Similarly, the objective of minimizing the clinical burden of the rapid response team (RRT) nurse included the decision to use clinician-to-clinician communication to trigger local bedside workflows, which significantly enhanced standardization and clinical acceptance. Compliance with the process measures by the frontline RRT nurse has consistently exceeded 90%. In addition, the ongoing communication between the VQNC and the frontline RRT nurse facilitates situational awareness and improves patient safety culture through ongoing exchange of ideas and workflow challenges.

DESIGN OF THE AAM INTERVENTION

The AAM program was developed and implemented for Kaiser Permanente's 21 hospitals in Northern California. Kaiser Permanente is the most extensive not-for-profit integrated health care system in the United States. More than 4.5 million people in Northern California choose to get their care at Kaiser Permanente, and KPNC provides integrated health care through more than 250,000 inpatient visits annually.

The analysis of the program compared outcomes among hospitalized patients whose condition reached the alert threshold where AAM was operational to outcomes of patients at hospitals where AAM was not operational.[1] AAM was a quality improvement project that applied a validated model to predict an individual's likelihood of deterioration and developed a multidisciplinary clinical response pathway that gives clinicians a 12-hour lead time to take action.[1,2] Expert and comprehensive review by the VQNC team minimizes alert fatigue among clinicians, who review the AAM scores hourly, 24/7, for the 21 hospitals.[1,2] The VQNC triages to the RRT nurse, who responds to the alert and collaborates with the hospitalist, bedside RN, and supportive care team to ensure that the patient's goals are clarified and care tailored to the patient's wishes with a defined plan for escalation is in place.[2,6,7,9]

Dissemination Across the System

The AAM program was piloted in two hospitals in 2013–2014, including 453 beds with 17,000 annual discharges.[2] The physician champion, as a part of a patient safety and quality improvement fellowship with wide support from local and regional leadership and frontline staff, used the Institute for Healthcare Improvement (IHI) Plan-Do-Study-Act (PDSA) performance improvement model to conduct dozens of iterations of workflow and documentation standards improvements to integrate, embed, and stress test AAM into the rescue pathways. The pilot's results demonstrated decreased mortality, decreased length of hospital stay, and improved provision of palliative care.[1,2] The results led to deployment of the AAM–based Rapid Response System (RRS) to the remaining 19 hospitals using a staggered schedule. After piloting in two hospitals, the AAM program was implemented in 19 hospitals in a staggered manner between August 1, 2016, and February 28, 2019.[1,2] With the addition of the VQNC team we increased the surveillance to hourly from every six hours, increasing the sensitivity from 25% to 50%, eliminated the frontline need for 24/7 vigilance, and minimized alert fatigue by allowing for interpretation and strategic silencing of alarms based on clinical realities defined and refined by active engagement with frontline feedback. The staggered deployment was based on expected outcomes and operational and geographic criteria where implementation teams

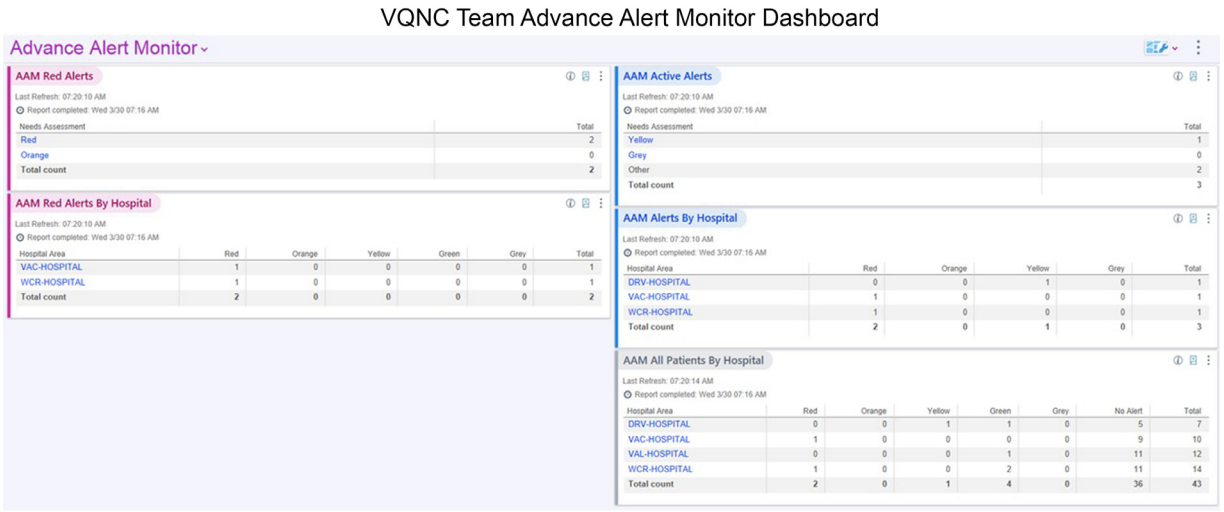

Figure 1: The virtual quality nurse consultant (VQNC) team Advance Alert Monitor (AAM) dashboard shows alerts by hospital. AAM uses 99 distinct variables embedded in the electronic health record to create a score. If the score is above a preset threshold, an alert is generated and electronically notifies a VQNC to review the patient chart for concerning trends. The color-coded alerts signify a different type of alert depending on the patient's status and whether the VQNC team takes action. The Situation, Background, Assessment, Recommendation (SBAR) escalation handoff tool is used to pass information to the local medical center and allows nurses and physicians to use this critical lead time to expand the patient's care. Social work and palliative care clinicians are alerted and, at a minimum, identify the patient's current surrogate and further clarify patient care goals.

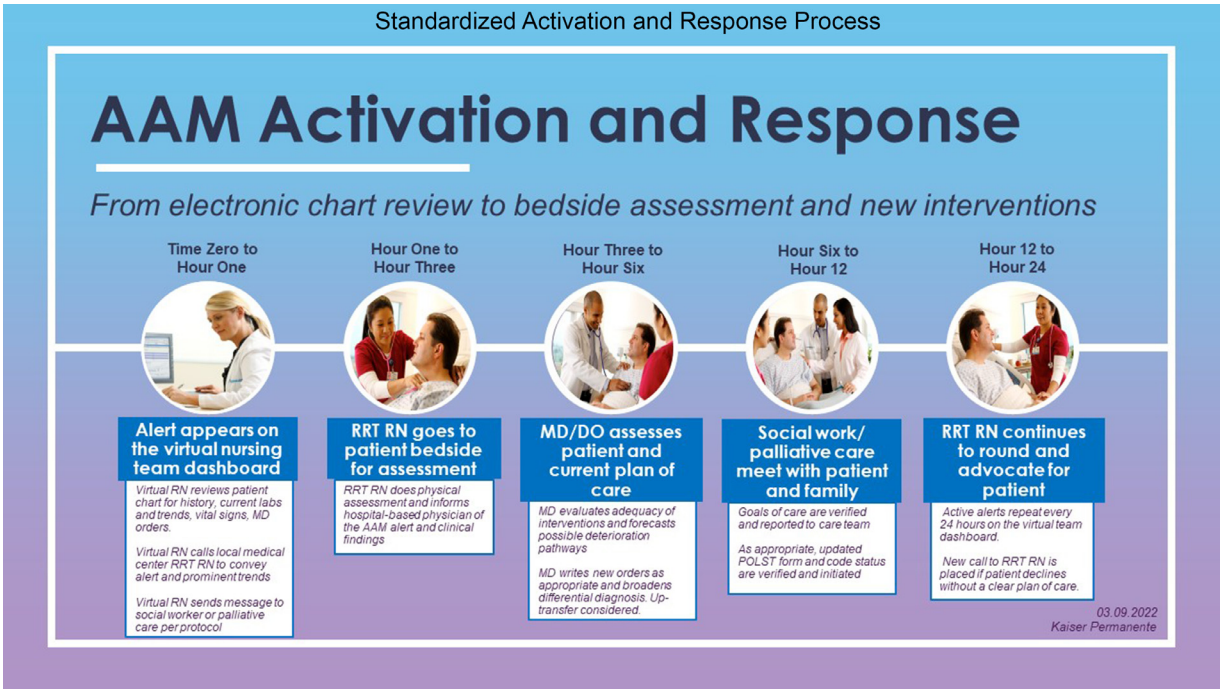

Figure 2: Shown here are the early warning system–required response workflows and performance standards. AAM, Advance Alert Monitor; RRT, rapid response team; POLST, Physician Orders for Life-Sustaining Treatment.

had been well established. The AAM program preparation and implementation schedule required key milestones to be met before, during, and after the AAM process was initiated.[2]

The AAM program's systemwide deployment strategy involved using afferent and efferent arms and a system governance approach.[2] The afferent arm includes the standardization of early detection through remote monitoring.[2] The remote monitoring system provides a real-time 72-hour physiologic score of severity of illness and comorbidity scores.[7] Due to the potentially harmful impact of alert fatigue on RRT nurses, the alert displays only in a dedi-

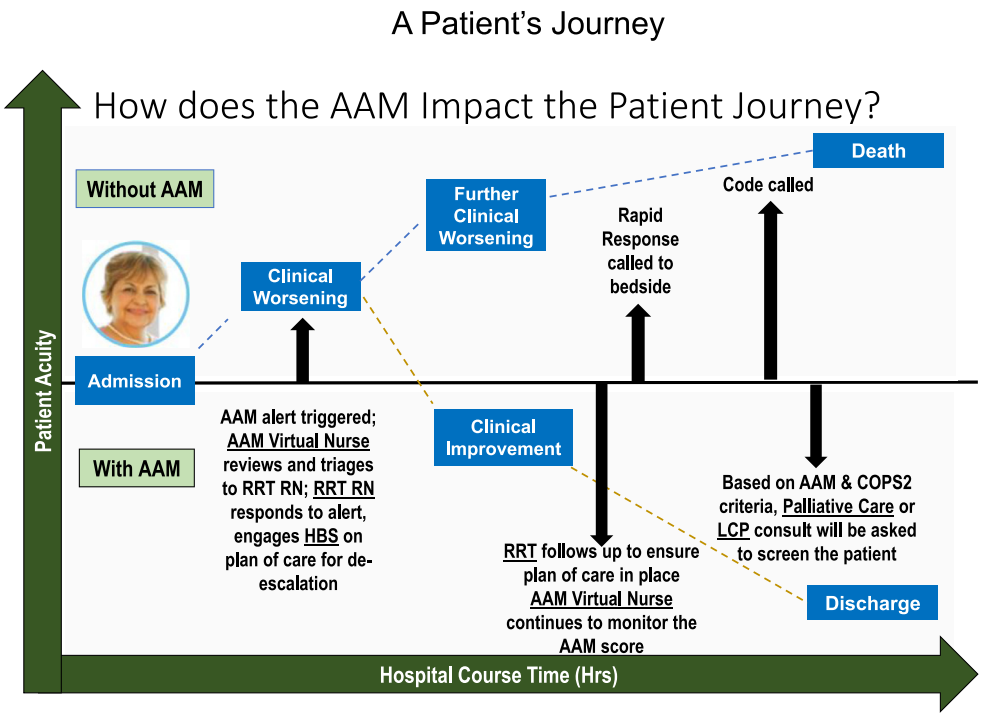

Figure 3: This is an illustration of a patient's journey in their hospital course with and without Advance Alert Monitor (AAM). RRT, rapid response team; HBS, hospital-based specialist; COPS2, Comorbidity Point Score, version 2; LCP, Life Care Planning.

cated EHR dashboard accessible only by the VQNC team (see Figure 1).[1,2,6,7] Alerts are reviewed every hour by the VQNC team.[1,2,6] The elements of the dashboard include both automated and manual processes.[2] The efferent arm consists of standardization of the infrastructure, clinical rescue, and palliative care response—with clear, defined governance structures that manage quality assurance and training.[1,2,6] The governance feedback and direct access supported a regular and efficient approach to incorporating workflow enhancements.

The AAM program represents an innovative approach to patient safety and quality by successfully incorporating information technology, leadership, administration, standard workflows, and training to deploy a coordinated early warning system. By using predictive modeling derived from the EHR, AAM advances patient safety and quality by proactively identifying patients with a high risk of mortality or up-transfer to the ICU. AAM also enhances hospital patient safety and outcomes, including integration of Life Care Planning or Palliative Care, through a standardized activation and response process[9] (see Figure 2).

The AAM alerts are monitored 24 hours a day, 7 days a week, by a VQNC team that communicates significant clinical findings from their chart review of alerted patients with the local RRT nurse via phone. The local RRT nurse responds and acts on the alerts by collaborating with the bedside RN to assess the patient, engaging the hospital-based physician on the plan of care, and intervening as needed. In comparison to the typical hospital course prior to AAM in which a patient's clinical worsening might go undetected and lead to adverse events or delays in care, AAM allows for earlier recognition and response to clinical worsening. When triggered, AAM gives the clinicians 12 hours of lead time before clinical deterioration, permitting early detection, a more nuanced response, and an opportunity to involve social workers and palliative care staff early in the patient's hospital admission to clarify and honor the patient's wishes proactively.

Identifying local site champions and leaders (hospitalists, ICU physicians and nurses, social services, and palliative care) with defined roles and responsibilities for each hospital discipline involved in the workflow, built a shared safety culture and minimized communication gaps. The administrative component includes acquiring formal approval from hospital executive committees of required service agreements (for example, between hospital medicine and ICU). The regional team provided training on standardized communication, clinical response protocols, handoffs, and documentation to the RRT nurses, VQNC, hospitalists, social workers, and palliative care specialists, resulting in a multidisciplinary clinical response pathway to an AAM alert. The team leaders performed daily 15-minute debriefs two weeks before "go live" and at least two weeks post "go live" at each facility where we deliberately engage the frontline RRT nurses and their direct supervisor to troubleshoot and reinforce best practices in real time.[2]

AAM provides a measurable and meaningful impact on improving patient safety and quality. The successful spread

of the AAM program to all 21 KPNC hospitals has resulted in a multidisciplinary and collaborative approach to the standardization of workflows, aligning goals of care, enhancing patient rescue, and engaging patients in their end-of-life planning. At the same time, patients can still participate meaningfully and express their wishes to their surrogate.[9,10]

To illustrate a patient's journey in their hospital course without AAM, upon admission, when a patient starts to exhibit clinical worsening in the early stages, it largely goes undetected (see Figure 3). Only after further deterioration do we see an RRT called at the bedside, which may result in a code or death. AAM provides an earlier response to potential clinical worsening. With AAM, when the patient is identified as at risk upon admission, the AAM VQNC reviews and triages to the RRT nurse, who responds to the alert and engages the hospital-based physicians on the plan of care. The clinical improvement and a proactive follow-up by the RRT nurse ensure that the care plan is in place and that the VQNC monitors patients' AAM score. Based on AAM and COPS2 criteria, the VQNC sends a referral to Palliative Care or Life Care Planning for a consult to screen the patient.

SUCCESS OF THE INTERVENTION

The full results of this initiative have been published previously.[1] We briefly describe the key results and critical findings here. The program quantified the benefit of an automated predictive algorithm model that identified high-risk patients, resulting in lower mortality within 30 days after an alert, reduction of ICU admissions, decreased hospital length of stay, lowered 30-day mortality after admission, and a higher proportion of patients with favorable status (alive, not in the hospital, not rehospitalized) within 30 days after an alert.[1] The analysis incorporated 11,723 cases and 11,723 controls matched to adjust for population differences based on the patient's sex, age, membership status, primary condition, before their ICU stay, and prior code status; 97.7% of cases were matched.[1]

AAM represents a significant advancement in improving patient safety and quality by quantifying the positive outcomes of proactively identifying at-risk patients for clinical deterioration. The evaluation of the program indicates the AAM program is associated with statistically significant decreases in mortality (between 550 and 3,020 over four years), hospital length of stay, and ICU length of stay.[1]

Adjusted Analyses

In the intervention cohort, there was a 3.8% absolute decrease in mortality within 30 days after an event reaching the alert threshold. This difference translated into 3.0 deaths (95% confidence interval [CI] = 1.2–4.8) avoided per 1,000 eligible patients, or 520 deaths avoided (95% CI = 209–831) per year over the 3.5-year study period.[1]

Unadjusted Analyses

The target population was much sicker than medical/surgical patients who did not trigger an alert. Among patients with an alert, patients in the intervention cohort had:

- Lower unadjusted incidence of ICU admission (17.7% vs. 20.9%)
- Shorter hospital length of stay among survivors (6.5 days vs. 7.2 days)
- Lower in-hospital mortality (9.8% vs. 14.4%)
- Lower 30-day mortality after an event reaching the alert threshold (15.8% vs. 20.4%)

LESSONS LEARNED

AAM brought together predictive analytics, virtual clinical monitoring, and in-person care to proactively identify and intervene in high-risk patients with clinical deterioration. To adapt to the global pandemic, special protocols were integrated into AAM to carefully monitor COVID-19 patients. Additional critical measures of success included appropriate triage of high-risk patients and efficient allocation of ICU resources. Safety cultures were shifted from reactive to proactive by using objective data to empower the care team to speak up for the patient. Patients' wishes were clarified and honored, which consequently improved patient satisfaction.

Due to the potentially harmful impact of alert fatigue on RRT nurses, communication channels were established to capture real-time feedback from frontline staff and the VQNC team, while concurrently preserving the program's integrity.[2] As AAM moved to the sustainability phase with more operational ownership, the work to increase leadership visibility and reduce drift continued. Measures to provide strategic regional support were implemented. To improve workflow compliance, consistent local oversight and performance improvement plans were put in place.[2,6] Quality tracking dashboards supported short- and medium-term monitoring of clinician responsiveness and documentation within required time frames.

The regional team monitored the ongoing sustainability by developing a cohesive oversight structure with every hospital.[2,6] Each local facility had an AAM long-term oversight structure comparable to their Critical Care or Code Blue Committees.[2] Weekly and monthly performance dashboards were reported to support ongoing performance improvement and evaluation. Quarterly newsletters, hosting collaborative conference call meetings, and conducting site visits to share best practices were performed to maintain interest in the program and to promote adherence to practice standards.[2]

Providing high-quality health care services is not just about treating illnesses but is also about ensuring that patients' values, needs, and input about their care are con-

sidered. Patient perspectives play a critical role in providing patient-centered care and improving quality outcomes, as demonstrated in a snapshot of this AAM patient (see Figure 3).

The AAM program has provided an additional layer of safety for Kaiser Permanente patients and families regionwide since 2019. The AAM team shared learnings, progress, and barriers in adopting and spreading early warning systems across Kaiser Permanente markets. Currently, the predictive models are being evaluated for inter-regional spread in Hawaii, Southern California, and the Northwest Coast. Moreover, an early warning system was piloted in labor and delivery last year, proactively identifying patients at risk for a catastrophic maternal or neonatal event, subsequently enhancing hospital patient safety and mitigating poor outcomes during a labor and delivery encounter.

The AAM program demonstrated our organization's ability to augment quality and safety by using predictive models and technology. AAM combined predictive analytics, virtual and in-person care; we proactively identified and intervened for high-risk patients with clinical deterioration. While technology, predictive models, and financial resources are essential in sustaining and achieving cultural change, it is vital to have a fully engaged team, governance structure, and standardized workflows that the organization fully supports. The AAM program marked a significant step toward making our hospitals safer for our patients.

Acknowledgments. This work was supported by Kaiser Foundation Hospital and Health Plan, Northern California; The Permanente Medical Group, Inc.; and Division of Research. The authors would like to acknowledge the following individuals for their sponsorship and contributions to the program: Ann Williamson, PhD, RN; and Drs. Gabriel Escobar, Stephen M. Parodi, and Eric Dilda. We wish to thank the entire virtual quality nurse consultant (VQNC) team, local rapid response team, and social work and palliative care teams for supporting the AAM program.
Conflicts of Interest. All authors report no conflicts of interest.

Vanessa A. Martinez, DNP, MHA, RN, is Director, Virtual Nursing Care, Regional Clinical Quality Programs and Data Analytics, Kaiser Foundation Hospital and Health Plan, Northern California. **Robin K. Betts, MBA-HM, RN, CPHQ**, is Vice President, Safety, Quality & Regulatory Services, Kaiser Foundation Hospital and Health Plan, Northern California. **Elizabeth A. Scruth, PhD, MPH, RN, CNS, CCRN-K, CCNS, FCCM, FCNS, CPHQ**, is Regional Director, Clinical Quality Programs, Data Analytics and Tele Critical Care, NCAL Safety, Quality and Regulatory Services, Kaiser Foundation Hospital and Health Plan. **Jacqueline D. Buckley, MBA, MSN, RN, CCRN-K, CPHQ**, is Lead Quality Nurse Consultant, Regional Clinical Quality Programs and Data Analytics, Kaiser Foundation Hospital and Health Plan, Northern California. **Vilma R. Cadiz, MSN, MBA, RN**, is Lead Quality Nurse Consultant, Regional Clinical Quality Programs and Data Analytics, Kaiser Foundation Hospital and Health Plan, Northern California. **Linda D. Bertrand, MSN, RN**, is Lead Quality Nurse Consultant, Regional Clinical Quality Programs and Data Analytics, Kaiser Foundation Hospital and Health Plan, Northern California. **Shirley S. Paulson, DNP, MPA, RN, NEA-BC**, is Director, Regional Adult Patient Care Services, Kaiser Permanente, Northern California. **Brian Alex Dummett, MD, CPPS**, is Associate Program Director, Internal Medicine Residency Program, Permanente Medicine, Mid-Atlantic Permanente Medical Group. **Stella S. Abhyankar, MD**, is Hospital Based Specialist, and Palliative Care, Redwood City, California, and Advance Alert Monitor Clinical Lead, The Permanente Medical Group. **Vivian M. Reyes, MD**, is Regional Medical Director, Hospital Operations, The Permanente Medical Group. **Joeffrey R. Hatton, MBA**, is Regional Director, Hospital Quality and Patient Safety, The Permanente Medical Group. **Reynaldo Sulit, MSN-NI, RN-BC, CPHIMS, CPHQ**, is Lead Quality Nurse Consultant, Regional Clinical Quality Programs and Data Analytics, Kaiser Foundation Hospital and Health Plan, Northern California. **Vincent X. Liu, MD**, is Hospital Based Specialist and Intensive and Pulmonary Care Research Scientist, Division of Research, The Permanente Medical Group. Please address correspondence to Vanessa A. Martinez, vanessa.a.martinez@kp.org.

REFERENCES

1. Escobar GJ, et al. Automated identification of adults at risk for in-hospital clinical deterioration. N Engl J Med. 2020 Nov 12;383:1951–1960.
2. Paulson SS, et al. What do we do after the pilot is done? Implementation of a hospital early warning system at scale. Jt Comm J Qual Patient Saf. 2020;46:207–216.
3. Liu V, et al. Adverse outcomes associated with delayed intensive care unit transfers in an integrated healthcare system. J Hosp Med. 2021;7:224–230.
4. Escobar GJ, et al. Intra-hospital transfers to a higher level of care: contribution to total hospital and intensive care unit (ICU) mortality and length of stay (LOS). J Hosp Med. 2011;6:74–80.
5. Bapoje SR, et al. Unplanned transfers to a medical intensive care unit: cause and relationship to preventable errors in care. J Hosp Med. 2011;6:68–72.
6. Lisk LE, et al. Developing a virtual nursing team to support predictive analytics and gaps in patient care. Clin Nurse Spec. 2020;34:17–22.
7. Dummet BA, et al. Incorporating an early detection system into routine clinical practice in two community hospitals. J Hosp Med. 2016;11 Suppl 1:S25–S31.
8. Linnen DT, et al. Statistical modeling and aggregate-weighted scoring systems in prediction of mortality and ICU transfer: a systematic review. J Hosp Med. 2019;14:161–169.
9. Granich R, et al. Early detection of critical illness outside the intensive care unit: clarifying treatment plans and honoring goals of care using a supportive care team. J Hosp Med. 2016;11 Suppl 1:S40–S47.
10. Kim YS, et al. The natural history of changes in preferences for life-sustaining treatments and implications for inpatient mortality in younger and older hospitalized adults. J Am Geriatr Soc. 2016;64:981–989.