11-2019

Implications of Vital Sign Monitor and Electronic Medical Record Integration on Identification of Patients in Deteriorating Condition

Brandon Buxton
Western Michigan University, brandon.a.buxton@wmich.edu

Jefton Knight
Bronson Healthcare Group, Kalamazoo, MI, knighje@bronsonhg.org

Utkarsh Shrivastava
Western Michigan University, utkarsh.shrivastava@wmich.edu

Implications of Vital Sign Monitor and Electronic Medical Record Integration on Identification of Patients in Deteriorating Condition

Brandon Buxton
Western Michigan University, Bronson Healthcare Group
6901 Portage Road
Kalamazoo, MI 49008
Brandon.a.buxton@wmich.edu
269.532.3401

Jefton Knight
Bronson Healthcare Group
6901 Portage Road
Kalamazoo, MI 49002
knighje@bronsonhg.org
269.552.4173

Utkarsh Shrivastava
Western Michigan University
Department of Business Information Systems
1903 W Michigan Avenue
Kalamazoo, MI 49008
utkarsh.shrivastava@wmich.edu
269.387.5410

Abstract: The manual transcription of patients' vital signs often delays entry of critical information to Electronic Medical Record (EMR) systems. This documentation delay within inpatient settings results in a lack of recent information on patient condition, decreased ability for providers to make clinical decisions, and an increased risk of data error. To alleviate these concerns, hospitals are adopting device interface systems which digitally integrate medical devices and EMRs. Prior studies have found that this type of system integration can potentially reduce the time spent on manual entry of information in the EMR and support other value-added activities in the hospital. However, these studies suffered from intervention bias from direct monitoring of clinicians using time-motion methodologies, which are resource restrictive and can affect patient care. In this study, we utilize a natural experiment setting to understand how the implementation of a device interface system between vitals monitors used on medical/surgical units and the EMR has impacted hospital workflows and patient care in a regional hospital. Our investigation focuses on two areas. First, we examine if the new system influenced documentation delays, and whether the impact was similar for different employee roles. Since vitals on medical/surgical units are typically taken by Patient Care Assistants (PCA's) or other ancillary staff, we hypothesize that a greater average decrease in documentation delay will be found in their role. Second, we study the effect of interface system implementation on downstream patient care activities, such as models designed to identify patients in deteriorating condition. We analyze data on documentation delays across more than 5,000 patients and 330,000 documentation events for one week before and after system implementation. Additionally, we intend to utilize hierarchical models to distinguish the impact of systems for various roles (including PCA's and nurses) across the hospital. Preliminary findings suggest that the interface system results in a statistically significant decrease in time between when vital signs are taken and documented, as well as The findings from this research would inform hospitals of the benefits and the requirements for a successful integration of medical devices and EMR systems, as well as the impact on activities dependent on accurate and timely vital signs documentation.

INTRODUCTION

Vital signs are routinely obtained measurements of a patient's hemodynamic status in both ambulatory and inpatient settings. The ability to closely monitor vital signs has been identified as an advantageous practice for recognizing both deteriorating patients and those that may no longer require acute care (Ludikhuize, Smorenburg, de Rooij, & de Jonge,

2012). Despite this, significant issues have been discovered in analysis of the workflow for obtaining and documenting patient vital signs on medical-surgical floors where continuous monitoring systems are not commonly employed (Weenk et al., 2018). Clinicians have been found to regularly enter data incorrectly into the electronic medical record (EMR), delay entry of data until long after it has been obtained from the patient, and even omit entries until shift-end (Fieler, Jaglowski, & Richards, 2013). This has encouraged the adoption of both fixed and mobile EMR-integrated vital signs documentation devices which are designed to reduce error in data entry, increase value-added patient care time, and shorten documentation delay. Implications of such systems have been studied, and dramatic decreases in both error and delay have been noted. However, the effects of a vital sign integration system on scoring models which identify patients in declining condition, and are commonly calculated automatically by the EMR, have not been studied.

This research examines the effects of integration of a vital sign capture device and EMR on both the delay of documentation of vital signs by staff and the timeliness of warnings that allow patients who are exhibiting unstable vital signs to be recognized, and intervention to be taken, sooner. We particularly examine the effect of the implementation on the timeliness of warnings based on the Modified Early Warning Score (MEWS), a widely used algorithm for identifying patients in need of immediate assessment or intervention. We find that the implementation of such a system will significantly impact the timeliness of warnings created by the EMR, providing a substantial benefit to both the hospital and hemodynamically unstable patients affected.

The positive clinical applications of EMR usage have been well documented. EMR's have been noted to reduce errors as compared to paper charting (Hogan & Wagner, 1997). EMR usage has been strongly encouraged through the HITECH Act of 2009, which provided incentives for EMR adoption and penalties if hospitals failed to implement them. However, the time efficiency of EMR documentation has been questioned. Anecdotal experience from the authors reveals that nurses and clinical staff frequently comment that EMR documentation detracts from time spent on direct-patient care activities. Despite the anecdotal comments of clinicians, literature has identified that EMR utilization does not affect documentation time vs. paper charting (Hakes & Whittington, 2008). Due to the current ubiquity of adoption of EMR's, research has shifted from implementation to optimization. Utilization of systems that optimize workflow inefficiencies, especially those related to patient complexity, has been suggested as a "next step" in developing more effective EMR's at both the vendor and hospital level.

Reduction in the amount of times a clinician is required to document in an EMR during a shift offers the opportunity to reduce both frequency of data error entry and the outright time spent documenting. One of the most obvious targets for such an intervention is the documentation of vital signs, which reflect a patient's hemodynamic status. Typically obtained using a machine, these values must then be transferred to the EMR, creating an opportunity for error and delay, particularly when paper "workarounds" like notes are used (Stevenson, Israelsson, Nilsson, Petersson, & Bath, 2018). Previous literature has noted the effects of poor data quality on predictive acuity scoring models, including the Modified Early Warning Score (MEWS) (Keene, Kong, Clarke, & Brysiewicz, 2017). Communicating this data from the machine to the EMR eliminates the risk of human error in documentation, as well as greatly reducing delay (Meccariello, Perkins, Quigley, & Rock, 2010; Smith, Banner, Olney, Friedman, & Eng, 2009).

The effect of the implementation of such a system on nursing workflows has been examined; however, it has mainly consisted of time-motion studies with direct observation of employees by researchers (Fieler et al., 2013). These studies are possibly subject to both the Hawthorne effect and observation bias, which could skew findings (Eckmanns et al., 2006). They additionally require extensive workhours to directly observe employees while timing workflows. We conduct this study using an entirely retrospective method, utilizing EMR documentation from before and after the intervention to evaluate efficiency improvements on thousands of patients.

Most critically, the impact of automatic documentation of vital signs on predictive scoring models, such as MEWS, has not been examined in non-critical care settings. We predict that implementation of the vital signs interface system has a significant effect on timeliness of warning alerts, which can expedite patient assessment and intervention, thereby reducing the detrimental effects of further patient decline.

BACKGROUND

Preparation

Information Technology staff at a 404-bed regional hospital were approached regarding the possibility of implementing a vital sign interface system by Operations staff at the institution. Following examination of multiple vendors, a third-party integrated EMR interface and device vendor was selected for implementation. This system offered compatibility with the EMR used by the hospital.

Workflow for documentation of patient vital signs prior to system implementation was frequently prolonged due to clinicians delaying entry of data until after all vital signs sets for assigned patients had been obtained. This was especially frequent when clinicians (particularly Patient Care Assistants, the main non-nursing ancillary staff at the hospital) had a sequence of patients with vital signs documentation required at the same time. Workflow analysis revealed that they frequently documented vital signs on paper notes carried on their person, then inputting the data later. This time difference between the time vital signs were taken, "Time Taken" and the time vital signs were documented, "Time Recorded", is obtainable from the EMR, and was the main variable of interest in this study. The vital signs monitors sought to reduce this delay by automatically uploading data to the EMR following measurement acquisition by the machine.

To accomplish this, the system utilizes three main parts. First, the monitor used to obtain patient vital signs was enabled, via radio card installation, to speak to the interface. Since the model of device selected was already in use at the hospital prior to the interface system installation, some devices required hardware upgrades to accomplish this. The device then had to be appropriately configured via files provided by the vendor to create messages that are understood by the interface. Next, the data obtained by the device was transmitted over an internal wireless connection to the Connex interface. This interface, installed on a hospital server, both converts and stores data received from the devices into a Health Level 7 (HL7) message that can be interpreted by the EMR. Data from the interface is then transmitted to the EMR, where it is read and recorded within Documentation Flowsheets, the location vital signs data is stored. The entire process takes about thirty seconds from the time the clinician selects "Send" on the device to when the data is visible within the chart.

From a clinician's perspective, the workflow for utilizing the integrated monitor adds few new tasks. First, the clinician scans their ID badge. The clinician's badge is linked to the system, allowing for identification of the clinician on the device and within the EMR. They then scan the patient's wristband, which links an encounter-specific identifier in the EMR and the device. Following visual verification of both identifiers, the clinician proceeds to take vital measurements. These measurements typically consist of blood pressure, heart rate, temperature, pulse oximetry, and respiratory rate. However, the devices were also configured to offer the ability to document weight, scale used, oxygen flow type, and oxygen flow rate. These options are present on a different screen and are used much less frequently by clinicians. Once the data has been obtained, the clinician presses "Send", initializing the aforementioned data flow between the device to the EMR. Logs of the messages sent are kept on the device, the server, and within the EMR. Clinicians can validate the transmission of data by looking at the sent messages on the device, as well as validating within the EMR. Clinicians were advised to validate data regularly to ensure they are consistently crossing over throughout the shift.

Implementation

Implementation took place over a four-month period in 2019. Input was needed from Server, Interface, Clinical Documentation, Nursing, and Biomedical Technologies teams. Two hospital units were originally selected as pilot groups for the go-live; however, this was later changed to all non-ICU medical surgical units at the hospital. The project was not planned to replace all devices in use at the hospital. Instead, 71 devices were either upgraded or purchased to enable connectivity. Clinicians were expected to continue to manually document vital signs if an integrated device is not available.

Integrated testing took place two weeks prior to go-live. All known problems were resolved to the satisfaction of users prior to go-live. Go-live took place over a two-day window in late June, with 13 medical/surgical units receiving integrated devices. Intensive care units were purposefully excluded from implementation, since all ICU's had fixed

hemodynamic monitoring systems that obtain readings at more frequent intervals. A technical and clinical specialist from the vendor came on site and trained end-users at all units which received devices. An issue involving clinician identification within the EMR was identified on the second day, but was able to be quickly resolved through the intervention of IT leadership. No other potential safety issues were noted during go-live, potentially due to prior clinician experience with the device. Since the device had been used for manual data entry prior to integration, clinicians were familiar with the device design.

Evaluation

Following implementation, the IT team primarily responsible for the system was requested by IT and Operations leadership to determine the efficacy of the intervention. This request, in line with the "Check" stage of the Plan-Do-Check-Act model, provided an opportunity to evaluate the system and clinicians' opinions of it. Anecdotal and informal surveys were conducted by Clinical Informatics Nurses who regularly round on inpatient units to identify and help resolve documentation questions posed by clinicians. Feedback from clinical staff was positive, with most remarking about the time savings the new system brought to their workflow.

One unexpected comment from a nurse involved downstream patient care activities seemingly unrelated to the device integration. Nurses are advised in hospital policy to have recent vital signs recorded before administering a high-risk medication. This leads to delays when vital signs have already been taken by ancillary care staff but have not been documented in the EMR. It is inadvisable from a patient satisfaction perspective to repeatedly take vital signs in a short period for non-acuity related reasons, so nursing staff would then try to reach the PCA or other ancillary staff that obtained the measurements prior to administering the medication. Depending on the workload and availability of staff, this could delay medication administration. This comment led to the consideration of other downstream patient care activities that utilize hemodynamic status data and the impact of the integration on those workflows.

The first, and primary, downstream activity identified was the Modified Early Warning Score (MEWS) model, which utilizes six data points (Table 1) to identify patients who may require immediate evaluation and intervention. The model is automatically scored by the EMR based on the values input by clinicians. When the patient's score exceeds a threshold of five points, a warning banner appears when opening the patient's chart, alerting the clinician and advising them to contact the provider or rapid response team to evaluate and intervene to avoid further decline. Since the model is dependent on accurate vital signs to identify declining patients, it was identified as something that could be affected by the system implementation. More important was the evaluation of the impact of improved documentation timeliness on when the alert occurs relative to the most recently taken vital signs. Reduction in this time allows for clinicians to intervene sooner, especially when they are unaware that the patient has declined from a previous state and still may appear to have otherwise acceptable vital signs (Keene et al., 2017).

Table 1: MEWS Criteria

MEWS Criteria							
Variable	**Points contributed to MEWS**						
	3	**2**	**1**	**0**	**1**	**2**	**3**
Respiration Rate	< 4	<= 7	<= 9	$9 < x < 17$	>= 17	>= 21	>= 30
Heart Rate	< 30	<= 40	<= 50	$50 < x < 100$	>= 101	>= 111	> 129
Systolic Blood Pressure	<= 70	<= 80	<= 100	$100 < x < 161$	>= 161	> 200	-
Oxygen Saturation %	<= 88%	-	-	> 88%	-	-	-
Temperature	<= 94	<= 95	<= 96.9	$96.9 < x < 100.6$	>= 100.6	>= 101.6	>= 105.1
Level of Consciousness	Lethargic, Comatose, Obtunded	Sedated	Drowsy	Alert	-	-	-

METHODOLOGY

Cohort Identification

The first task in evaluating efficacy of the intervention was to identify patients who should be considered in the data set. While previous studies had closely examined one to two units (Fuller, Fox, Lake, & Crawford, 2018), we decided to evaluate all patients admitted to the hospital that may have been affected by the change. This large sample base both preserves patient anonymity and helps protect against unrelated, unit-specific factors that may influence results. Patients within non-interfaced departments were also excluded from the analysis when they could be identified. This primarily was accomplished by excluding data taken via fixed devices, typically utilized in ICU, ED, and surgical departments.

To obtain the relevant vital signs data, one week before and after the intervention was queried from the EMR. All of the documentation of interest is completed within Documentation Flowsheets, a spreadsheet-style functionality for recording data that changes over time. All Flowsheet documentation for one patient is stored within the same record for a 24 hour period, necessitating the extraction of all Flowsheet documentation, including that unrelated to the study, in patients that met criteria. This resulted in daily extracts of approximately 200,000 rows.

Prior to extracting Flowsheet documentation, identification of employees of an employee cohort was required. To accomplish this, the employee user file was queried for nine employee types. These nine employee types includes: registered nurse, licensed practical nurse, medical assistant, patient care assistant, patient care technician, vascular access specialist nurse, medical assistant intern, certified nurse assistant, and nursing student. This provided ~10,000 employees who were associated with one of the nine employee types, including all such employees since the EMR had been implemented. Employees were further refined to include only those that had a last login department of one of the interfaced units. This served to limit employees to those who conceivably could have taken vital signs on a patient within the cohort. Since float staff are instructed to log into the department of the unit where they are currently working, their exclusion was not a concern. This resulted in a set of approximately ~3,000 employees, which was acceptable for the large granularity filtering desired.

Once employees who may have taken vital signs on a cohort patient were identified, the record containing Flowsheet data was queried for documentation that met all of the following criteria in Table 2. For pre-intervention data, this resulted in a cohort of 2576 inpatient encounters. For post intervention data, this resulted in a cohort of 2462 inpatient encounters.

Table 2: Flowsheet Data Criteria

Flowsheet Data Criteria	
Criteria	***Purpose***
User who took the vital signs (or any flowsheet row that day) is contained within the previously established employee cohort	Limiting the patient population to those who were treated by employees working in the interfaced units
Documentation is limited to one 24-hour period from 0000 to 2359	Provided timeframe for data; changed each day.
Flowsheet documentation contains at least one blood pressure recording that day	Excluding patients for which no documentation was generated

Alert Identification

Following establishment of patient cohorts, alerts based on vital signs were then identified. Alerts due to a MEWS score of five or greater from the weeks evaluated were extracted and linked with Flowsheet data. To establish a relevant link between the alert and the time vital signs were recorded, the criteria in Table 4 were established.

Table 3: Alert Criteria

Alert Criteria	
Criteria	***Purpose***
Vital signs taken and alert occurred with identical patients.	Ensures patient is the same in both instances
Flowsheet row matches rows used in MEWS model.	Limits data to that which can affect MEWS
The vital sign/MEWS row time taken and time recorded pre-date the alert instant	Excludes data that is generated after the alert
Time recorded is the greatest time recorded prior to the alert instant	Selects the latest value that is recorded prior to the alert
Only one row per alert is selected	Even when multiple rows are documented at the same time, only one is selected

RESULTS

Table 4 below describes pre and post intervention variables. We analyzed the time to enter vital signs into the EMR for 2576 patients before and 2462 patients after the implementation of the integrated system. During the post-intervention period there is a sharp increase in the total vital signs documented. About 36% of the documentation during the post-intervention period was done using the integrated device. We conduct one tail and two tailed t-test to test to discern if the mean time taken between when vital signs were obtained to the firing of MEWS alert is the same for both pre and post intervention scenarios or not. In this study, the intervention is the implementation of the device integration in the hospital. However, it should be noted that post intervention about 36.885% of the vital signs documentation events utilized the integrated system.

Table 4: Descriptive Statistics

Variable	**Pre- Intervention**	**Post-Intervention**
Patients in cohort	2,576	2,462
Total vital sign documented	160,207	179,150
% Taken by RN/PCA	80.61%	81.74%
% Recorded by integrated device	0%	36.88%
Total MEWS documented	83,478	83,727

Table 5 below shows the outcome of three two sample t-tests. In the first test we investigate if there is a significant difference in the time taken to fire MEWS when the vitals were entered using integrated device versus not using the integrated device. During our two week observation period there were only 303 instance when the patient's vitals were so critical that the warning based on the MEWS was triggered. However, during only 45 of those warning was the integrated system used to record the vitals data to the EMR system by the hospital employee. The results show that the time taken to fire the warning was significantly smaller (by ~30 minutes) when the integrated system was used. This significant improvement can prove to be life saving for the patients who arrive at the hospital in a critical condition or decline while admitted.

Next, we conduct the test of difference in mean for time taken to enter vitals by the hospital employees with or without the integrated device for all vitals entry observations (including in the pre and post intervention period). Again, we find that vitals entry using the integrated device is significantly faster (by 17.1 minutes). Another, t-test (Test 3 in table 5) only considers observations during the post intervention period, when about 38.88 % to the overall vitals were entered using the integrated device. This test also shows that the average time to enter vitals is significantly reduced from 19.5 mins to 1.382 mins when the integrated device is used.

Table 5: Two Sample T-Test

	Test 1		**Test 2**		**Test 3**	
Statistic	Time taken to receive MEWS (Overall)		Time taken to record vitals (Overall)		Time taken to record vitals (Post Integration)	
	Not Using Integrated Device	*Using Integrated Device*	*Not Using Integrated Device*	*Using Integrated Device*	*Not Using Integrated Device*	*Using Integrated Device*
Mean	46.9003	16.9948	18.4873	1.3828	19.5768	1.3828
Variance	6038.8861	508.5038	5860.1429	261.7041	3821.365	261.7041
Observations	258	45	273293	66064	113086	66064
Hypothesized Mean Difference	0		0		0	
t-Statistic	5.0762		107.3140		93.63759	
P(T<=t) one-tail	3.8708E-07		0		0	
t Critical one-tail	1.6512		1.6448		1.644865	
P(T<=t) two-tail	7.7416E-07		0		0	
t Critical two-tail	1.9699		1.9599		1.9599	
Alpha value	0.05		0.05		0.05	

DISCUSSION & CONCLUSION

The implementation of the integration system had a significant impact on both the documentation delay for all vital signs taken and on the delay between vital signs being taken and the alert regarding the declining hemodynamic status of the patient. The clinical implications of such an improvement are notable. Delay in rapid response team activation results in a significantly higher risk of mortality and longer hospitalizations (Gupta et al., 2017). Though not all rapid response team activations are predicated by warnings within the EMR, such warnings provide the ability to alert clinicians that may not be aware of a patient's deterioration. In cases where rapid response activation is due to a decision-support system-based warning, presentation of the warning as soon as the patient's decline is recognizable is paramount. Delay in entry of vital sign documentation due to clinician workload, fatigue, or other factors is suspected to be significantly improved due to this intervention. Faster response once a patient is declining may result in lower morbidity and mortality.

Two-sample T Tests assuming unequal variances found a statistically significant difference in the time between when vital signs are taken and when they are recorded when an integrated device was used and the time between when vital signs are taken and the instant of the MEWS Alert. Further research to be completed in this study includes the analysis of documentation and alert delay due to vital sign entry for various departments and employee types in the hospital. We would also like to account for the heterogeneity the response to integrated system for different types of employees, vital types and hospital units. Additional relevant outcomes may be established by looking at the time between when vital signs are taken and rapid response team arrival at the bedside, in cases where activations were preceded by an alert.

Limitations of this study are evident in the implementation of the integration system. Since device integration was not implemented for all vital sign measurement devices in the hospital, many vital sign documentation events were not completed using the integrated devices. This reduces the effect of the intervention and dilutes data. This is partially avoided through the identification of vital sign documentation events that utilize the integrated system. Additional factors include the training of employees using the device. Initially, only Nurses and Patient Care Assistants were trained to use the integration system. Other users (such as respiratory or physical therapists) had to learn from another user who had been trained to use the device or learn via trial and error. In future study we plan to account for this endogeneity arising due to selection bias.

Since data analyzed in this study were entirely based on user-entered values, there exists a possibility for inaccuracy. The primary variable analyzed, documentation delay, is reliant on users accurately reporting when they actually

obtained the vital signs from the patient. It is expected that users may frequently round to the nearest easily rememberable time (such as five or ten minute intervals) or may fail to record the actual time they obtained the vital signs, instead documenting the time vital signs were taken as the time that they entered them in the EMR. The assumption of the study is that clinicians accurately and consistently record the time that vital signs were obtained from the patient.

Finally, one variable used in calculation of MEWS, Level of Consciousness, was not interfaced using the device. Alerts that were prompted due to a change in that value would not be affected by the integration. However, since that variable alone does not possess a point-value great enough to trigger an alert, an integrated device would have some effect on the time between when vital signs are obtained from the patient and the alert.

This study highlights how hospitals can reap the benefits of a meticulously integrated system. Though the costs of such an integration are significant, the subsequent reduction in documentation delay and expedition of care for critically ill patients may offset the cost of the investment. Future studies can further investigate the monetary incentives of such an integration strategy. The findings of this study may encourage the adoption of such a system for institutions which are considering cost-reduction strategies through technological investment. Additional opportunities for further commercial development include other technologies focused on reducing clinician documentation time, optimizing hospital workflows, and minimizing the opportunity for human error.

REFERENCES

Chen, Y., Xie, W., Gunter, C. A., & Liebovitz, D. (2015). Inferring Clinical Workflow Efficiency via Electronic Medical Record Utilization. *AMIA Annual Symposium Proceedings*, 416–425.

Eckmanns, T., Bessert, J., Behnke, M., Eckmanns, T., Bessert, J., Behnke, M., … Ru, H. (2006). *Compliance With Antiseptic Hand Rub Use in Intensive Care Units : The Hawthorne Effect*. *27*(9), 931–934.

Fieler, V. K., Jaglowski, T., & Richards, K. (2013). Eliminating errors in vital signs documentation. *CIN - Computers Informatics Nursing*, *31*(9), 422–427. https://doi.org/10.1097/01.NCN.0000432125.61526.27

Fuller, T., Fox, B., Lake, D., & Crawford, K. (2018). Improving real-time vital sign documentation. *Nursing Management*, *49*(1).

Gupta, S., Green, C., Subramaniam, A., Lim, D. Z., Low, E., & Tiruvoipati, R. (2017). The impact of delay in rapid response activation on patient outcomes at a metropolitan hospital. *Australian Critical Care*, *30*(2), 117. https://doi.org/10.1016/j.aucc.2017.02.022

Hakes, B., & Whittington, J. (2008). Assessing the Impact of an Electronic Medical Record on Nurse Documentation Time. *CIN - Computers Informatics NursingComputers, Informatics, Nursing*, *26*(4), 234–241.

Hogan, W., & Wagner, M. (1997). Accuracy of Data in Computer-based Patient Records. *Journal of the American Medical Informatics Association*, *4*(5), 342–355. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-0031230270&partnerID=40&md5=604b24625519757cfa08a6a88331d150

Keene, C. M., Kong, V. Y., Clarke, D. L., & Brysiewicz, P. (2017). The effect of the quality of vital sign recording on clinical decision making in a regional acute care trauma ward. *Chinese Journal of Traumatology - English Edition*, *20*(5), 283–287. https://doi.org/10.1016/j.cjtee.2016.11.008

Ludikhuize, J., Smorenburg, S. M., de Rooij, S. E., & de Jonge, E. (2012). Identification of deteriorating patients on general wards; measurement of vital parameters and potential effectiveness of the Modified Early Warning Score. *Journal of Critical Care*, *27*(4), 424.e7-424.e13. https://doi.org/10.1016/j.jcrc.2012.01.003

Meccariello, B. M., Perkins, D., Quigley, L. G., & Rock, A. (2010). Vital Time Savings. *Journal of Healthcare Information Management*, *24*(4).

Smith, L. B., Banner, L., Olney, C. M., Friedman, B., & Eng, D. (2009). *Connected Care: Reducing Errors Through Automated Vital Signs Data Upload*. *27*(5), 318–323.

Stevenson, J. E., Israelsson, J., Nilsson, G., Petersson, G., & Bath, P. A. (2018). Vital sign documentation in electronic records: The development of workarounds. *Health Informatics Journal*, *24*(2). https://doi.org/10.1177/1460458216663024

Weenk, M., Van Goor, H., Van Acht, M., Engelen, L. J. L. P. G., Van De Belt, T. H., & Bredie, S. J. H. (2018). A smart all-in-one device to measure vital signs in admitted patients. *PLoS ONE*, *13*(2), 1–12. https://doi.org/10.1371/journal.pone.0190138