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# Use of a real-time, algorithm-driven, publicly displayed, automated signal to improve insulin prescribing practices

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ABSTRACT

*Aim:* The clinical andon board (CAB) is a novel electronic surveillance and communication system, which alerts providers to and prompts treatment of dysglycemia. This investigation was designed to determine the CAB's effectiveness in supporting adherence to standardized evidence-based protocols, as well as improving glycemic control.

*Methods:* This study was a retrospective pre/post analysis of insulin orders and blood glucose values. We used a Student's *t*-test for continuous variables and $Chi^2$ for all other variables. This study included patients 18 years or older admitted to the hospital medical service as an inpatient with a length of stay greater than 24 h and less than 90 days. We used Pearson's correlation coefficient to evaluate the relationship between CAB and blood glucose.

*Results:* The rate of compliance in prescribing basal insulin for patient with diabetes increased from 56% to 77% ($p < 0.001$). Similarly, compliance rates for prescribing correctional insulin in patients without diabetes increased from 15% to 37% ($p < 0.001$). Performance on the CAB was linearly related to blood glucose ($p = 0.004$), and there was a small statistically (not clinically) significant improvement in mean blood glucose values.

*Conclusion:* This approach is effective in alerting and engaging providers to prescribe insulin in a standardized manner with potential to improve glycemic control.



## 1. Introduction

Hyperglycemia and diabetes are prevalent conditions in the hospital, affecting up to 46% of critically ill patients and 32% of patients outside of critical care [1]. Studies have shown an association between hyperglycemia and significant untoward clinical consequences, such as a longer length of stay (LOS), increased readmissions, infectious complications in surgical patients and in-hospital death rates [2]. Insulin is the only recommended therapy for treatment of diabetes in

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the hospital [3]. However, safe and effective prescribing of insulin in the hospital is challenging for a number of reasons, physiologic and otherwise [4]. Similar to hyperglycemia, hypoglycemia has been linked to negative clinical outcomes [5].

Given these challenges, hospital systems have developed different approaches to glycemic control including education, standardized order sets, data reporting as well as inpatient glycemic management teams [6]. With respect to educational efforts, clinical decision support and order sets, evidence for improved glycemic control is mixed, and the impact on physician prescribing behavior is even less clear [7,8]. These elements appear to be necessary, but not sufficient elements of a successful glycemic control improvement effort [9]. Diabetes management teams can be effective with sustained results, even with variable infrastructure and operators [10]. A recent article by Rushakoff et al demonstrated similar benefits using a virtual, informal diabetes specialty consultation [11].

At our institution, previous quality improvement efforts have focused on education and standardized order sets under the auspices of a glycemic control steering committee. With these components in place, we implemented a novel electronic surveillance and communication system, called the clinical andon board (CAB). The intent of the CAB was to increase the visibility of each patient's glycemic control and to provide treatment recommendations in real-time, so that the entire care team could then collaborate with the primary provider, within his/her work flow, to optimize glycemic control. The purpose of this investigation was to determine the effectiveness of the CAB in supporting better adherence to standardized protocols, as well as improving glycemic control.

## 2. Materials and methods

### 2.1. Study design, setting and population

We performed a single center pre/post retrospective analysis at Virginia Mason Medical Center in Seattle, Washington, USA. Virginia Mason is an urban tertiary referral acute care hospital licensed for 336 beds with approximately 500 physicians, five accredited residency programs and 10,974 inpatient admissions in 2017. The hospital employs 42 hospitalists as 36 full time equivalents to provide 165 encounters daily. The institution is well-known for its early adoption, continued use and study of Lean management principles [12].

The study population included patients aged 18 years or older admitted to the hospital medical service as an inpatient with a length of stay greater than 24 h and less than 90 days. Patients who had surgery during the stay were excluded. The visit type and diagnosis was extracted from billing data. The attending physician of record and blood glucose values were extracted from the electronic health record (EHR). Blood glucose values included both point of care testing and serum levels. Insulin orders were also extracted from the EHR; only "SUB-Q" route of administration orders were included except in the case of insulin pumps. The included insulin orders were categorized by insulin analog and fixed or variable dosages. Basal insulin was defined as long acting (with a fixed dose). Correctional insulin was defined as short-acting insulin analogs with a variable dose. Andon signal color for each patient was saved every 24 h at midnight and downloaded for analysis. The study period was from January 1, 2012 through December 31, 2017 with an implementation period between July 1, 2014 and January 31, 2016. This investigation was performed as part of a quality assurance project and a waiver was granted from the Institutional Review Board.

### 2.2. Intervention

In 2012 and a multidisciplinary glycemic control steering committee was identified. The committee performed a literature review and held a series of meetings to develop consensus among all stakeholders on a hospital-wide protocol. The protocol was based on the basal-bolus insulin regimen for insulin naïve patients with type 2 diabetes, as described in the RABBIT-2 trial. [13] Our protocol is conservative with a higher threshold to initiate basal-bolus therapy (blood glucose >180 mg/dL (10 mmol/mol)) and a lower total daily dose (0.3 units/kg). The algorithm does not distinguish between insulin insufficiency and insulin resistance physiology. Regarding stress-induced hyperglycemia and glucose intolerance, we developed an institution-wide consensus based on clinical judgement and experience. Recommendations were to start correctional insulin at the threshold blood glucose >180 mg/dL (10 mmol/mol), and to initiate an evaluation for diabetes.

With the protocol in place, other work during the pre-intervention period included development of standardized order sets and institution-wide education. Subsequently, there was a small pilot of pharmacy surveillance using an EHR generated list of patients with a diagnosis of diabetes. Using this list, our pharmacists were reviewing a large number of charts without recommendations (66%) and the process was labor intensive (median, 9:52 min per chart). Furthermore, patients with other hyperglycemic conditions were not captured by the diagnosis driven list. During the pilot, we observed lower rates of hyperglycemia and a stable rate of hypoglycemia. This demonstrated a need to rapidly triage all patients, decrease the burden of work and increase the therapeutic yield. Thus, work began on development of the CAB.

An andon is a way of notifying a worker of real-time operational conditions [14]. Our glycemic andon displayed alerts within the EHR about a patient's current glycemic status (outcome metric) as well as insulin order status (process metric). If a patient's blood glucose value is at goal (100–180 mg/dL (5.6–10 mmol/mol)), a green andon is displayed for that patient. When blood glucose is outside of the goal range, insulin orders are examined relative to our algorithm. In this scenario, if the insulin regimen is consistent with our protocol, a yellow andon is displayed. However, if a patient is hyperglycemic (>180 mg/dL (10 mmol/mol)) and one or more components of basal-bolus therapy are absent, a red andon is displayed with instructions indicating what type of insulin to add. If a patient is hypoglycemic <70 mg/dL

(3.9 mmol/mol), a red hypoglycemia alert will appear. The signal is updated for every hospital patient every sixty seconds.

Initially, the glycemic andon was visible only in individual patients' charts; it was quickly recognized that this could be a powerful tool to promote multidisciplinary collaboration with the pharmacists. In a small pilot of the CAB, time-motion studies showed clear benefit with dramatic improvements in both therapeutic yield (80% of patients reviewed with recommendations) and time required (4:25 min per chart). In an effort to educate and engage providers, two improvement workshops were held resulting in mutually agreed upon roles and operations for responding to red andons in the clinical setting. After providers knew how to respond accordingly, the andons for all patients were displayed on a large wall mounted monitor in their respective units, visible to care teams as well as patients, families and visitors. This wall mounted display is known as the CAB. The public posting of the CAB was designed to enhance group situational awareness of glycemic status, as a further aid to improve glycemic control. Installation was complete in February 2016.

### 2.3. *Statistical analysis*

We used a Student's *t*-test for continuous variables and $Chi^2$ for all other variables in Tables 1 and 2. In Fig. 1, we developed a statistical process control chart for the proportion of red andons. In Fig. 2, the relationship between proportion of green andons and rates of hyperglycemia is reported as Pearson's correlation coefficient.

## 3. Results

There were 23,331 admissions during the study period. There was a small increase in the proportion of male patients, which is of undetermined, and likely insignificant clinical consequence. The mean length of stay (LOS) increased from 5.4 days to 6.1 days, consistent with national trends, also of undetermined, and likely insignificant clinical consequence. The mean age was stable for the duration of the study. There was a slight increase in the proportion of patients with diabetes (from 32 to 34%), which might be related improved documentation practices or a true increase in established diagnoses related to prompts from the andon board to evaluate patients with hyperglycemia for diabetes.

We analyzed blood glucose values and insulin orders for 99,884 patient days, 63% of those were in patients without diabetes. There was a small statistically significant decrease in mean blood glucose for all patients. However, there was not a concordant decrease in the proportion of patient days with hyperglycemia 180 mg/dL (10 mmol/mol) or above. The proportion of patients without diabetes that had hypoglycemia (<70 mg/dL (3.9 mmol/mol)) increased from 1.6 to 2.0%, but this was not observed in patients with diabetes. Orders for both basal and correctional insulin increased for all patients. Specifically, as per protocol, in patients with diabetes, orders for correctional insulin improved by 15% and orders for basal insulin once blood glucose was >180 mg/dL (10 mmol/mol) improved by 21%.

There is a sharp decrease in the number of red andons observed in the first quarter of 2016. This coincides with the installation of the large screen displays, i.e., the CAB, from January 2016 until the end of February 2016. (Although we do not have andon data prior to January 2016, note that the improved rates of protocol based prescribing demonstrated in Table 2 would translate to an equivalent improvement in the rate of red andons.)

This figure demonstrates an inverse, linear relationship between a high percentage of green andons and lower rates of patient days with hyperglycemia $\geq$ 180 mg/dL (10 mmol/mol), correlation coefficient = −0.612 (p = 0.004).

**Table 1 – Patient and encounter characteristics.**

| | Pre-intervention 1/1/12–6/30/14 | During intervention 7/1/14–1/31/16 | Post-intervention 2/1/16–12/31/17 | Sig p* |
|---|---|---|---|---|
| Patients | | | | |
| Admits, number | 9168 | 6214 | 7949 | |
| Admits/day | 10.1 | 10.7 | 11.4 | 0.020 |
| Male, number [%] | 4745 [52] | 3202 [52] | 4239 [53] | 0.040 |
| Age, mean [SD] | 65 [18] | 65 [17] | 65 [17] | 0.36 |
| Diabetes, number [%] | 2949 [32] | 1985 [32] | 2702 [34] | 0.011 |
| Hospitalization | | | | |
| LOS, mean [SD] | 5.4 [5.3] | 5.8 [5.8] | 6.1 [6.1] | <0.001 |
| LOS > 7 days, number [%] | 1834[20] | 1429[23] | 1987[25] | <0.001 |
| Discharge Status, number [%] | | | | <0.001 |
| Home | 7468 [81] | 5068 [82] | 6636 [83] | |
| SNF | 1089 [12] | 772 [12] | 810 [10] | |
| Expired | 159 [2] | 105 [2] | 157 [2] | |
| Other | 452 [5] | 269 [4] | 346 [4] | |
| Any Andon (%) | 0 [0] | 0 [0] | 5570 [70] | |

* Significant p compares pre- vs. post-intervention.

**Table 2 – Blood glucose values and insulin orders before and after intervention, by patient day.**

| | Pre-intervention 1/1/12–6/30/14 | Implementation period 7/1/14–1/31/16 | Post-intervention 2/1/16–12/31/17 | Sig p* |
|---|---|---|---|---|
| Patient days, number | 38,155 | 27,046 | 34,683 | |
| Patient Days without Diabetes | 24,549 | 16,854 | 20,642 | |
| Glucose, mean mg/dL (mmol/mol) [SD] | 113 (6.3) [26.8] | 113 (6.3) [27.9] | 112 (6.2) [28.0] | 0.001 |
| Days with any glucose < 70 mg/dL (3.9 mmol/mol) [%] | 384 [1.6] | 294 [1.7] | 404 [2.0] | 0.001 |
| Days with any glucose ≥ 180 mg/dL (10 mmol/mol) [%] | 1352 [5.5] | 1005 [6.0] | 1206 [5.8] | 0.13 |
| Order for correctional insulin [%] | 329 [1] | 287 [2] | 693 [3] | <0.001 |
| Order for correctional if any BG ≥ 180 (10 mmol/mol) [%] | 206 [15] | 212 [21] | 452 [37] | <0.001 |
| Order for basal insulin [%] | 296 [1] | 240 [1] | 511 [2] | <0.001 |
| Order for basal insulin if any BG ≥ 180 (10 mmol/mol) [%] | 188 [14] | 184 [18] | 368 [31] | <0.001 |
| Patient Days with Diabetes | 13,606 | 10,192 | 14,041 | |
| Glucose, mean mg/dL (mmol/mol) [SD] | 163 (9.1) [56.3] | 158 (8.8) [53.5] | 161 (8.9) [53.9] | 0.001 |
| Days with any glucose < 70 mg/dL (3.9 mmol/mol) [%] | 696 [5.1] | 552 [5.4] | 708 [5.0] | 0.78 |
| Days with any glucose ≥ 180 mg/dL (10 mmol/mol) [%] | 7461 [54.8] | 5201 [51.0] | 7613 [54.2] | 0.30 |
| Order for correctional insulin [%] | 6237 [46] | 5448 [53] | 8565 [61] | <0.001 |
| Order for correctional if any glucose ≥180 mg/dL (10 mmol/mol) [%] | 4599 [62] | 3800 [73] | 6071 [80] | <0.001 |
| Order for basal insulin [%] | 5725 [42] | 5359 [53] | 8148 [58] | <0.001 |
| Order for basal if any glucose ≥180 mg/dL (10 mmol/mol) [%] | 4178 [56] | 3734 [72] | 5869 [77] | <0.001 |

* Significant p compares pre- vs. post-intervention.

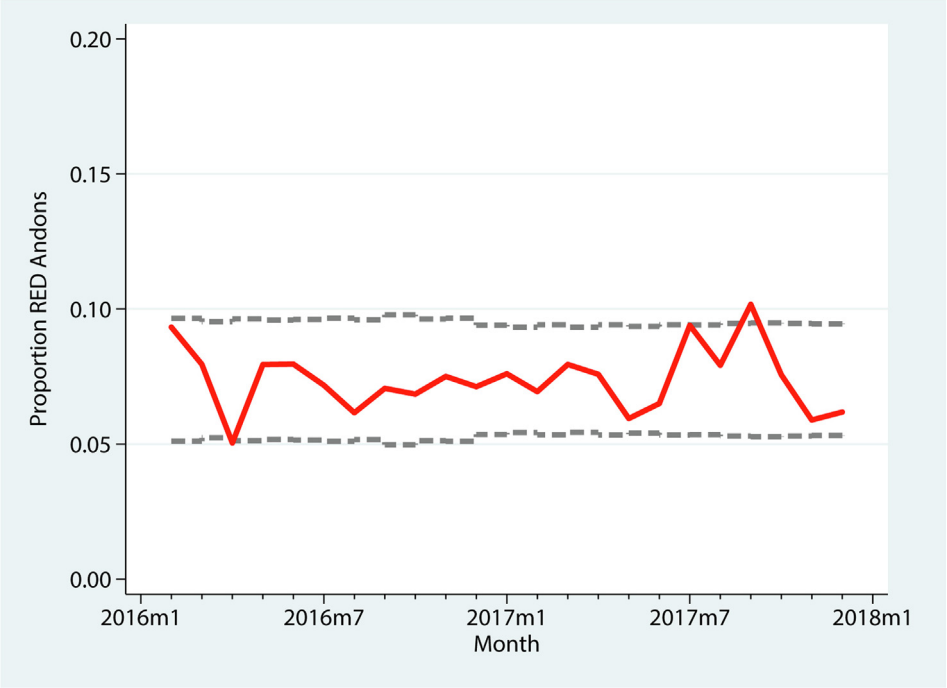


**Fig. 1 – Statistical process control chart for red andons per all patient days by month.**

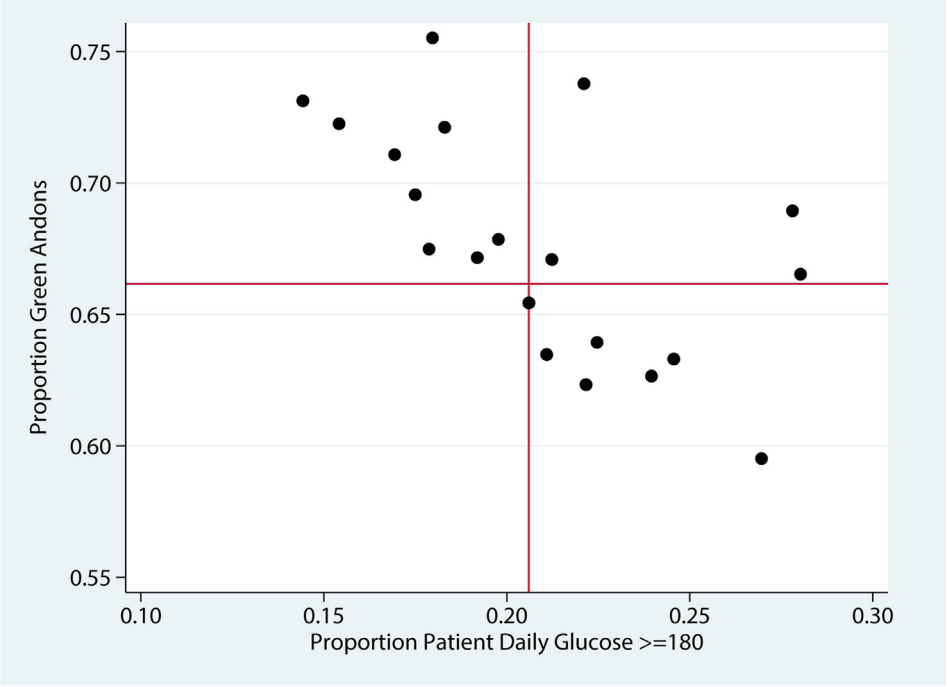


**Fig. 2 – Daily patient glucose ≥180 mg/dL (10 mmol/mol) and green andons for hospitalist providers with ≥400 andons.**

## 4. Discussion

We implemented a real-time, algorithm-driven, publicly displayed automated signal (CAB) to improve insulin prescribing practices and glycemic control. There was a large and statistically significant increase in standardized insulin prescribing practices. However, efficacy in improving glycemic control was mixed with a small statistically significant decrease in

mean blood glucose for all patients, but no observed decrease in the proportion of patient days with incidents of hyperglycemia (≥180 mg/dL (10 mmol/mol)). There was an increase in rates of hypoglycemia (<70 mg/dL (3.9 mmol/mol)) for patients without diabetes.

In an increasingly complex, resource strained system, healthcare providers must find an effective and efficient way to meet the needs of the large number of patients with diabetes and hyperglycemia. In this work, we leveraged technology to present the information in the EHR in a simple and actionable format. In addition, the public display of the CAB was associated with an increase in compliance with standardized glycemic control protocols as can be seen in Fig. 1. This association may be due to increased situational awareness by the multidisciplinary care team, or perhaps it is due to a Hawthorne-like effect.

We acknowledge that although technology is certainly an important consideration in developing a strategic approach to glycemic control, integration of a highly customized CAB system like ours may be challenging for other institutions. Nonetheless, access to a computer programmer may be more readily available than an endocrinologist [10]. Further, the CAB, in combination with appropriate order sets, local operational leadership and telemedicine has potential to reach a large number of patients and providers in remote hospitals with relative ease. Such an encounter for remote glycemic monitoring would likely be an additional service rather than a substitutive service, so would add cost. However, this option is more feasible and presumably less costly than transferring patient or provider. An integrated system of remote monitoring with the CAB could thus be viewed as a wise investment, particularly if it prevents costly complications of uncontrolled hyperglycemia [2].

While there seems to be a role for electronic surveillance of glucose and insulin orders, it is clear that providers need to be engaged with whichever technology and/or team is providing recommendations. The fact that the CAB provides real-time and actionable feedback for all patients 24 h a day is unique and critical to its efficacy. Early warning systems (EWS) may create a sense of urgency, but can contribute to an already high noise to signal ratio in the hospital. On last review, evidence for efficacy of EWS was equivocal [15]. On the other hand, retrospective aggregated blood glucose reports, periodic audits and routine feedback have been shown to improve performance [16,17]. Unfortunately, retrospective aggregate data does nothing to resolve suboptimal care already administered.

Despite improvement in adherence to our protocols and provider specific data demonstrating that good individual performance on the CAB predicts better glycemic control (Fig. 2), we did not observe an improvement of similar magnitude in rates of hyperglycemia. This paradox is most probably related to our protocol. The conservative dose and higher threshold were chosen to obtain buy-in from stakeholders who expressed significant fear of hypoglycemia, a well-known barrier to implementation of basal-bolus prescribing. However, this high threshold may have limited the effectiveness of the protocol in improving glycemic control. Nonetheless, the implementation of the CAB supported increased standardization of care, which allowed us to identify the limitations in the existing glycemic control protocol. As a result, this system, which was designed to give feedback to providers, will also inform development of future iterations of our order sets.

The increase in the rate of hypoglycemia in patients without diabetes is concerning. The rate of basal insulin orders in patients without diabetes doubled from 1% to 2% for all patient days, and from 14% to 31% if the blood glucose was ≥180 mg/dL (10 mmol/mol). Correctional insulin is not administered unless there is hyperglycemia, so this is less likely to be the cause for the observed increase in hypoglycemia. Interestingly, the percentage of patient days without diabetes with orders for basal insulin is two percent, equal to the rate of hypoglycemia. This is compelling evidence that prescribing basal insulin to patients without diabetes may be associated with hypoglycemia. Further study is needed to find a safe and effective protocol for treatment of hyperglycemia in hospitalized patients without diabetes, especially outside the critical care setting.

The drivers of de novo hyperglycemia are diverse, and it seems reasonable that the appropriate treatment should vary accordingly. Development and maintenance of algorithms can be complex and labor intensive, but the benefit of shaping safe prescribing practices is worthwhile. In the era of predictive analytics and machine-learning, there may be some temptation to automate a more patient specific, data driven, predictive algorithm. However, in that scenario, there is a risk of lost learnings such that our understanding of the underlying physiologic processes may be lessened. The use of a simple algorithm to rapidly triage patients may be a reasonable compromise.

There are limitations to our study. Study participants were identified by billing data, which we did not evaluate for accuracy. However, billing accuracy is routinely audited by administrators and payors. Due to a lack of clear evidence or guidelines, the acute hyperglycemia portion of the treatment algorithm was driven by local consensus. While this is arguably acceptable in treating our local population, it does potentially limit generalizability. As our work progressed, the need for more operational resources to address inpatient hyperglycemia became apparent. Thus, in the latter half of 2017, we restructured our section of endocrinology to serve as clinical lead for an inpatient glycemic control service which remains primarily driven by pharmacy review of the CAB. This potentially confounds the data, but the benefits were observed prior to the reorganization and have been stable since that time.

In conclusion, the CAB is a real-time, algorithm-driven, publicly displayed automated signal that is effective in alerting and engaging providers to prescribe insulin in a standardized manner with potential to improve glycemic control.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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