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Association Between a Virtual Glucose Management Service and Glycemic Control in Hospitalized Adult Patients

An Observational Study

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Background: Inpatient hyperglycemia is common and is linked to adverse patient outcomes. New methods to improve glycemic control are needed.

Objective: To determine whether a virtual glucose management service (vGMS) is associated with improved inpatient glycemic control.

Design: Cross-sectional analyses of three 12-month periods (pre-vGMS, transition, and vGMS) between 1 June 2012 and 31 May 2015.

Setting: 3 University of California, San Francisco, hospitals.

Patients: All nonobstetric adult inpatients who underwent point-of-care glucose testing.

Intervention: Hospitalized adult patients with 2 or more glucose values of 12.5 mmol/L or greater (≥225 mg/dL) (hyperglycemic) and/or a glucose level less than 3.9 mmol/L (<70 mg/dL) (hypoglycemic) in the previous 24 hours were identified using a daily glucose report. Based on review of the insulin/glucose chart in the electronic medical record, recommendations for insulin changes were entered in a vGMS note, which could be seen by all clinicians.

Measurements: Proportion of patient-days classified as hyperglycemic, hypoglycemic, and at-goal (all measurements ≥3.9 and ≤10 mmol/L [≥70 and ≤180 mg/dL] during the pre-vGMS, transition, and vGMS periods).

Results: The proportion of hyperglycemic patients decreased by 39%, from 6.6 per 100 patient-days in the pre-vGMS period to 4.0 per 100 patient-days in the vGMS period (difference, −2.5 [95% CI, −2.7 to −2.4]). The hypoglycemic proportion in the vGMS period was 36% lower than in the pre-vGMS period (difference, −0.28 [CI, −0.35 to −0.22]). Forty severe hypoglycemic events (<2.2 mmol/L [<40 mg/dL]) occurred during the pre-vGMS period compared with 15 during the vGMS period.

Limitation: Information was not collected on patients' concurrent illnesses and treatment or physicians' responses to the vGMS notes.

Conclusion: Implementation of the vGMS was associated with decreases in hyperglycemia and hypoglycemia.

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Diabetes mellitus or hyperglycemia is present in approximately one third of hospitalized patients (1–4) and is associated with increased risk for complications, costs of care, and mortality (1, 3–6). Despite compelling evidence showing the importance of maintaining normoglycemia in hospitalized adults, blood glucose levels in inpatients are often far from recommended targets (2) for various reasons, including low priority given to glycemic control, suboptimal insulin regimens chosen for simplicity rather than effectiveness, and difficulty with titrating insulin in acutely ill patients. Moreover, treatment of hyperglycemia may lead to hypoglycemia, which is associated with mortality, increased likelihood of readmission, and longer length of stay (7–9).

The involvement of diabetes specialists and inpatient diabetes teams can reduce length of stay and improve glycemic control and clinical outcomes (10, 11), but these interventions are time- and resource-intensive. Different models exist for such teams to target all or prespecified groups of hyperglycemic patients (10–18) but may be impractical given that 30% to 40% of inpatients may have hyperglycemia.

Although infrastructure and educational efforts have led to decreased errors in insulin administration (19) and improved glucose control (20), internal audits continued to show inappropriate initial insulin orders and therapeutic inertia for prescribers at our institution (Appendix Table 1, available at Annals.org). With the introduction of a new electronic medical record (EMR) in 2012, we sought to leverage its power to improve inpatient diabetes management. We automated detection of inpatients with uncontrolled blood glucose with a daily report generated by the EMR. This report was reviewed by a diabetes specialist who then remotely reviewed an insulin/glucose chart in the EMR. The chart contained enough information about the patient's insulin regimen to make appropriate recommendations without extensively reviewing the chart or interviewing the patient. Rather than relying on manually contacting clinical teams individually, we conveyed these recommendations in a new diabetes management note. The automated reports, clinician review, and clinical notes created a virtual glucose management service (vGMS),

See also:

Editorial comment 1

which we hypothesized would improve glycemic control among hospitalized patients.

METHODS

Design Overview

In this cross-sectional study, we examined the association between implementation of the vGMS and glycemic control in adult inpatients over a 3-year period (1 June 2012 to 31 May 2015). The study period was divided into three 12-month intervals: pre-vGMS, transition, and vGMS. The study was approved by the Institutional Review Board at the University of California, San Francisco (UCSF), with waiver of informed consent.

Setting and Participants

Participants were adult inpatients in all medical and surgical wards and intensive care units at the 3 UCSF acute care hospitals located in different areas of San Francisco. Because these 3 hospitals share the same services, medical and nursing staff, administration, EMR, order sets, and formulary, they were analyzed as a single hospital with 3 locations. Obstetric patients were excluded.

Intervention

In June 2012, an EMR developed by Epic Systems was implemented at UCSF (a quaternary referral center). At that time, our complex paper-based glycemic management order sets were converted to electronic order sets (21). Glucose levels were measured with a point-of-care (POC) device (ACCU-CHEK Inform [Roche Diagnostics]), with results uploaded to the EMR in real time. Insulin orders were accepted by the pharmacy only when an insulin order set was used, and POC glucose tests were automatically ordered for patients on one of the insulin order sets (eating, nothing by mouth, or intravenous insulin), with tests performed 5 times per day for patients who were eating; 6 times per day for those who were receiving nothing by mouth, total parenteral nutrition, or enteral feedings; and hourly for those receiving intravenous insulin infusions.

In October 2012, we developed a report identifying all adult inpatients who had 2 or more glucose values of 12.5 mmol/L or greater (≥225 mg/dL), had a glucose level less than 3.9 mmol/L (<70 mg/dL), or used an insulin pump, all in the previous 24 hours (**Appendix Figure 1**, available at Annals.org). These trigger points were determined by our inpatient diabetes management committee to potentially decrease morbidity from hypoglycemia and hyperglycemia. This committee is a systemwide multidisciplinary group that oversees all aspects of inpatient management of hyperglycemia. The daily report was generated through an automated query of the EMR database at 5:00 a.m. and was e-mailed to the vGMS team at 5:30 a.m., 7 days per week.

After receiving the daily report, a vGMS team member would log into the EMR; review the glucose chart of each patient; and, if required, enter a glucose management note (vGMS note). Specifically, we reviewed patients' insulin/glucose flow sheets (**Appendix Figure 2**, available at Annals.org) to assess previous metabolic status and treatment, current insulin orders, and recent notes (process details are in **Appendix Table 2**, available at Annals.org). On the basis of this review, the team member would enter a vGMS note with insulin recommendations into the patient's chart. If the previous day's hyperglycemia did not require insulin recommendations (for example, if appropriate insulin changes were already ordered), no note was entered. The list of all criteria that led to no note is provided in **Appendix Table 3** (available at Annals.org).

We ascertained that the best strategy for communicating with and advising clinicians about possible changes in glucose management for their patients was to place a specific vGMS note in the EMR that would be available for early-morning rounds. The vGMS became functional in June 2013 and has operated 7 days a week without interruption since then.

vGMS Note

Members of the vGMS team logged into the EMR under a service called "Glucose Management Service" and used a vGMS template to write their note (**Appendix Figure 3**, available at Annals.org). The template included drop-down boxes with specific recommendations based on whether the patient was eating, receiving glucocorticoids, or receiving enteral feedings (cyclic or continuous). Suggested insulin doses were entered in the template (preformatted to match how insulin orders are written in the EMR). The end of the note included a disclaimer stating that the note was merely a recommendation and the treating team should take into account the patient's current clinical condition and obtain a formal endocrinology consultation if necessary. The signed note appeared in the EMR as a "glucose management" note, not an endocrinology consultation note.

vGMS Team

At UCSF, we do not have an inpatient diabetes service. When requested by the primary care team, formal diabetes consultations are performed by the endocrinology fellow and the attending physician. The vGMS team consisted of the 3 providers who participated in the daily review of the glucose reports and wrote vGMS notes. The providers were a board-certified endocrinologist (an MD), a nurse educator (a DNP and Certified Diabetes Educator), and a pharmacist diabetes educator (a PharmD and Certified Diabetes Educator) with more than 25, 30, and 10 years of inpatient diabetes experience, respectively. During the initial 4 months of the study, the MD and the DNP each managed 50% of the patients on the daily report. After that, the MD reviewed and intervened on the hyperglycemic patients, and the PharmD reviewed and intervened on the hypoglycemic patients. The remaining clinician would review both hypoglycemic and hyperglycemic patients when the other providers were on vacation.

Outcomes and Covariates

The primary outcomes were the proportion of patient-days classified as hyperglycemic, at-goal, and

hypoglycemic. Patient-day mean glucose level was a secondary outcome.

We queried the EMR database and extracted all POC glucose measurements for nonobstetric adult patients admitted to UCSF between 1 June 2012 and 31 May 2015. We eliminated spurious and repeated values by using a previously described protocol (20), as well as any glucose measurements taken after the 28th hospital day. Hospitalized patients with any POC glucose measurements were defined as "glucose-monitored" patients.

Using the daily inpatient census of nonobstetric patients, we defined the aggregate daily hyperglycemia proportion as the number of patients with 2 or more glucose values of 12.5 mmol/L or greater (≥225 mg/dL) per 100 hospitalized patients on a given calendar day. We normalized by hospitalized patients rather than glucose-monitored patients to avoid bias due to secular changes in the proportion of hospitalized patients undergoing blood glucose measurement.

We defined an at-goal patient-day as one in which all measured glucose values were between 3.9 and 10 mmol/L (70 and 180 mg/dL). For the hypoglycemia and severe hypoglycemia proportions, the numerator was the number of patient-days with a single glucose value less than 3.9 mmol/L (<70 mg/dL) or less than 2.2 mmol/L (<40 mg/dL), respectively. The at-goal and hypoglycemia proportions were also standardized to 100 hospitalized patients rather than glucose-monitored patients. The daily hyperglycemia, at-goal, and hypoglycemia proportions are aggregate (not patient-level) measures with 1 value per calendar day. The patient-day mean glucose value was the average of all of a patient's glucose measurements on a given calendar day.

For the glucose-monitored patients, we also collected patient- and visit-level data on demographic characteristics (age, sex, and race), admitting service, number of days since admission (admission day), and whether the hospitalization included at least 1 vGMS note. To track the effect of the vGMS service on formal endocrinology consultations, we calculated the proportion of all hospitalizations that included a formal endocrinology consultation.

Statistical Analysis

The interval from 1 June 2012 to 31 May 2013 was termed "pre-vGMS," 1 June 2013 to 31 May 2014 was termed "transition," and 1 June 2014 to 31 May 2015 was termed "vGMS." We compared glucose-monitored hospitalized patients during the 3 periods on age, sex, race, length of stay, and hospital service by using the Kruskal–Wallis test for continuous variables and the chi-square test for categorical variables. For hospital service, we report the *P* value for medicine versus nonmedicine, and for race, we report the *P* value for white versus nonwhite. We compared the pre-vGMS, transition, and vGMS patient-day mean glucose values by using the Kruskal–Wallis test. The daily aggregate measures—hyperglycemia, at-goal, and hypoglycemia proportions—were compared among the 3 periods by using a univariate linear regression model that estimated the magnitude of the discontinuous decrease in the outcome measurement and any change in the previous time trend (details are provided in **Appendix Table 4**, available at Annals.org). Hyperglycemia proportions tend to be highest on the first day of hospitalization and decrease as the hospitalization progresses. For this reason, we used a logistic regression model to compare the proportion of hospitalized patients with 2 or more measurements of 12.5 mmol/L or greater (≥225 mg/dL) between the pre-vGMS and vGMS periods, stratified on admission day 1 through 9. Because the intervention might have a differential effect based on days since admission, we assessed for an interaction between study period and admission day by using a likelihood ratio–based test.

Limiting the adjusted multivariate analysis to the glucose-monitored hospitalizations on which we had individual-level data on service and race, we compared hospitalizations in the pre-vGMS, transition, and vGMS periods using Poisson regression, in which the outcome was the number of hyperglycemic days during the hospitalization and the offset was the number of glucose-monitored days. The average (marginal) incidence rate from this regression model, when expressed as a percentage, represents the number of hyperglycemic patient-days per 100 glucose-monitored days; we report this with robust SEs. The regression model controlled for hospital service and patient race. Because the effect of the intervention might depend on hospital service, we tested for an interaction between hospital service and intervention period. The Poisson regression model used PROC GENMOD in SAS, version 9 for Windows (SAS Institute). All other statistical analyses were performed using Stata, version 13 for Windows (StataCorp).

Role of the Funding Source

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RESULTS

During the 36-month study period, there were 68 505 adult nonobstetric hospitalizations at our 3 campuses. Of these, 19 294 (28%) were glucose-monitored, representing 12 535 distinct patients (1.34 hospitalizations per patient per period) who had at least 1 valid POC glucose measurement recorded during their hospitalization. Of these patients, 55% were men. The proportion of white patients decreased from 47% during the pre-vGMS period to 44% during the vGMS period. The proportion of patients on the medicine service remained stable at 38% to 40% (**Table 1**).

The percentage of hospitalizations with at least 1 vGMS note was 3.9% during the transition period and

Table 1. Admission Characteristics During the 3 Study Periods*

Variable	Pre-vGMS (1 June 2012 to 31 May 2013)	Transition (1 June 2013 to 31 May 2014)	vGMS (1 June 2014 to 31 May 2015)	*P* Value
Admissions, *n*	22 025 (60.3 per day)	22 401 (61.4 per day)	24 079 (66.0 per day)	
Admissions with POC glucose monitoring, *n (%)*	6410 (17.6 per day) (29)	6581 (18.0 per day) (29)	6303 (17.3 per day) (26)	
Patients with POC glucose monitoring, *n*	4753	4890	4748	
Mean age (SD), *y*	61.3 (15.2)	61.3 (15.1)	61.2 (15.2)	0.66
Men, *n (% of glucose-monitored admissions)*	3483 (54)	3585 (54)	3502 (55)	0.31
Race, *n (%)*				
White	3000 (47)	3071 (47)	2803 (44)	0.008†
African American	764 (12)	807 (12)	738 (12)	
Asian	1177 (18)	1111 (17)	1078 (17)	
Other	1469 (23)	1592 (24)	1684 (27)	
Mean length of stay (SD), *d*	8.3 (12.3)	8.1 (10.8)	8.2 (11.7)	0.23
Service, *n (%)*				
Medicine	2466 (38)	2549 (39)	2497 (40)	0.38‡
Surgery	2187 (34)	2353 (36)	2135 (34)	
Transplant	941 (15)	868 (13)	994 (16)	
Oncology	409 (6)	423 (6)	327 (5)	
Neurology	285 (4)	251 (4)	255 (4)	
Other	122 (2)	137 (2)	95 (2)	
Formal endocrinology consultation, *% of admissions*	0.78	1.00	0.91	0.015§
Virtual inpatient glucose management consultation, *% of admissions*	NA	3.8	4.7	<0.001
Mean vGMS notes written per day, *n*	NA	4.0	5.3	

NA = not applicable; POC = point-of-care; vGMS = virtual glucose management service.
* Percentages may not sum to 100 due to rounding.
† Chi-square test for white vs. nonwhite patients.
‡ Chi-square test for medicine vs. nonmedicine services.
§ Chi-square test for vGMS vs. pre-vGMS.

increased to 4.8% during the vGMS period ($P < 0.001$). Formal endocrinology consultations increased from 0.8% of admissions during the pre-vGMS period to 1.0% during the transition period and then decreased slightly to 0.9%. This translated into approximately 4 additional formal endocrinology consultations per month.

The average number of glucose-monitored new admissions per day remained between 17 and 18 throughout the study. The average daily census of nonobstetric inpatients increased from 335 during the pre-vGMS period to 349 during the vGMS period ($P < 0.001$). The percentage of all patient-days that were glucose-monitored decreased from 32% to 28% ($P < 0.001$) (Table 2).

Compared with the pre-vGMS period, the average patient-day mean glucose level was 0.41 mmol/L (7.3 mg/dL) lower during the transition period and 0.24 mmol/L (4.3 mg/dL) lower (95% CI, −0.28 to −0.19 mmol/L [−5.1 to −3.5 mg/dL]) during the vGMS period (Table 2). The proportion of patients with 2 or more glucose values of at least 12.5 mmol/L (≥225 mg/dL) per day decreased by 39%, from 6.6 per 100 patients in the pre-vGMS period to 5.4 per 100 patients in the transition period and 4.0 per 100 patients (difference, −2.5 [CI, −2.7 to −2.4]) in the vGMS period.

The univariate regression showed that the aggregate daily proportion of hyperglycemic patients decreased slightly (−0.106 per 100 patients per day [CI,

Table 2. Proportion of Patient-Days With Hyperglycemia, At-Goal Glucose Levels, and Hypoglycemia and Patient-Day Mean Glucose Levels During the 3 Study Periods

Variable	Pre-vGMS	Transition	vGMS	vGMS vs. Pre-vGMS		
				Risk Ratio (95% CI)	Difference (95% CI)	*P* Value
Average daily census, *n*	335	339	349	–	14.1 (10.4 to 17.8)	<0.001
Average patients with glucose monitoring per day, *n*	106	106	97	–	−9.0 (−10.7 to −7.3)	<0.001
Glucose-monitored patients, %	31.7	31.3	27.9	–	−3.9 (−4.3 to −3.4)	<0.001
Patient-day mean glucose level (SD)						
mmol/L	9.48 (3.15)	9.08 (2.96)	9.24 (3.03)	–	−0.24 (−0.28 to −0.19)	<0.001
mg/dL	170.7 (56.8)	163.4 (53.3)	166.4 (54.5)	–	−4.3 (−5.1 to −3.5)	<0.001
Proportion per day per 100 hospitalized patients						
Hyperglycemia*	6.6	5.4	4.0	0.61 (0.59 to 0.63)	−2.5 (−2.7 to −2.4)	<0.001
At-goal†	10.8	11.6	11.4	1.05 (1.03 to 1.08)	0.6 (0.3 to 0.8)	<0.001
Hypoglycemia‡	0.78	0.89	0.49	0.64 (0.57 to 0.70)	−0.28 (−0.35 to −0.22)	<0.001
Severe hypoglycemia§	0.032	0.028	0.010	0.31 (0.15 to 0.59)	−0.022 (−0.03 to −0.01)	<0.001

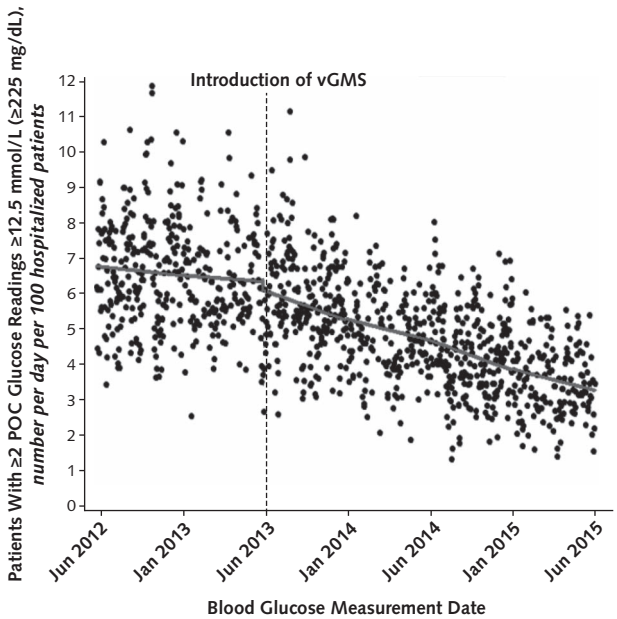
vGMS = virtual glucose management service.
* ≥2 glucose readings ≥12.5 mmol/L (≥225 mg/dL).
† All glucose readings between 3.9 and 10.0 mmol/L (70 and 180 mg/dL).
‡ ≥1 glucose reading <3.9 mmol/L (<70 mg/dL).
§ ≥1 glucose reading <2.2 mmol/L (<40 mg/dL).

−0.236 to 0.023]; $P = 0.108$) during the pre-vGMS period and more steeply (slope difference, −0.278 [CI, −0.415 to −0.140]; $P < 0.001$) during the following 24 months (**Figure**). In each study period, the proportion of hospitalized patients with 2 or more glucose values of 12.5 mmol/L or greater (≥225 mg/dL) was highest on admission day 1 and tended to decrease as admission duration increased (**Appendix Figure 4**, available at Annals.org). Compared with the pre-vGMS period, the day-1 hyperglycemia proportion was significantly lower during the vGMS period (risk ratio [RR], 0.80 [CI, 0.74 to 0.86]; $P < 0.001$), and the effect of the intervention increased with admission day (RR on day 9, 0.58 [CI, 0.48 to 0.70]; $P = 0.008$ for interaction).

The proportion of at-goal patient-days (days with all measurements between 3.9 and 10 mmol/L [70 and 180 mg/dL]) improved from the pre-vGMS period (10.8 per 100 patients per day) through the transition and vGMS periods (11.6 and 11.4 per 100 patients per day, respectively) (difference, 0.6 [CI, 0.3 to 0.8]; $P < 0.001$). The already low proportion with hypoglycemia (0.78 per 100 patients per day) in the pre-vGMS period decreased by 36% in the vGMS period (0.49 per 100 patients per day) (difference, −0.28 [CI, −0.35 to −0.22]; $P < 0.001$). The proportion with severe hypoglycemia (<2.2 mmol/L [<40 mg/dL]) decreased to approximately 0.01 per 100 patients per day. No patient had more than 1 discrete severe hypoglycemic event (<2.2 mmol/L [<40 mg/dL]) in a calendar day; there were 40 such events occurred during the pre-vGMS period compared with 15 during the vGMS period ($P < 0.001$).

Results from the Poisson regression analysis of individual glucose-monitored hospitalizations that adjusted for patient race and hospital service showed that the hyperglycemia rate decreased by 30% between the pre-vGMS and vGMS periods (RR, 0.70 [CI, 0.66 to 0.74]), from 21.5 to 15.1 per 100 glucose-monitored patient-days (**Appendix Table 5**, available at Annals.org). Compared with the rate on the medicine service, the hyperglycemia rate was 39% higher on the transplant service (RR, 1.39 [CI, 1.30 to 1.48]) and 32% higher on the oncology service (RR, 1.32 [CI, 1.22 to 1.43]). The only statistically significant interaction between study period and hospital service was on the transplant service, which showed a smaller decrease in hyperglycemia rate between the pre-vGMS and vGMS periods than the medicine service ($P = 0.009$ for interaction). In contrast, the oncology service had a greater decrease in the hyperglycemia rate than the medicine service ($P = 0.121$).

Figure. Trend in proportion of inpatients with ≥2 POC glucose readings ≥12.5 mmol/L (≥225 mg/dL) per day, before and after introduction of the vGMS.



The proportion with hyperglycemia decreased slightly ($P = 0.108$) in the 12 mo before introduction of the vGMS and more steeply ($P < 0.001$) in the ensuing 24 mo. POC = point-of-care; vGMS = virtual glucose management service.

DISCUSSION

We implemented a vGMS, which leveraged automated surveillance of all hyperglycemic inpatients across a multisite medical center and allowed a diabetes specialist to convey recommendations via the EMR. This approach was associated with significant reductions in the proportion of patients with hyperglycemia and hypoglycemia and increases in the proportion of inpatients with at-goal glucose levels at our institution.

Despite national efforts to improve patient safety and adoption of EMR systems (22), it remains unclear how to leverage technology (23) to improve inpatient care on important issues, such as hyperglycemia. Inpatient glucose management requires daily assessment of a patient's response to insulin, as well as such factors as nutritional status and medications that affect insulin needs. Institutions have tried physician education (24–29) or daily rounding by an endocrinologist as a member of the medical team (30) to improve insulin prescribing in the hospital. Such efforts either are ineffective or require extensive resources and are difficult to implement in large health systems.

We automated the detection of hyperglycemic patients, allowing accurate screening of those who may benefit from additional oversight of insulin prescribing without requiring a formal consultation or extensive chart review. The chart review was facilitated by creation of a flow sheet that presented the relevant information in a single location. Rather than paging or calling teams to modify orders, we used asynchronous communication within the EMR by entering a clinical note that was visible to anyone reviewing a patient's chart. Anecdotally, providers reported that because receiving a vGMS note indicated a failure to control diabetes, they now proactively write appropriate initial insulin orders or actively modify current orders to prevent receiving vGMS notes. Moreover, the notes served as a timely educational tool on how to modify insulin orders in hospitalized patients. The brief and to-the-point

vGMS notes complied with Venkat's recommendation that effective notes in the EMR era should be "short and sweet" (31).

Since implementing the vGMS, we have observed that the improved glycemic control has been sustained and the number of patients on the daily high glucose report has decreased, suggesting that providers are more effectively managing insulin orders. The proportion of patients with hyperglycemia decreased by a greater amount on each day following admission after introduction of the vGMS. These changes were not due to any increase in formal endocrinology consultations, which are generally not related to diabetes and remained largely stable throughout the study period.

A high percentage of the patients with elevated glucose levels were initially on the oncology and transplant services. Beyond the general complexity of their care, most of these patients receive glucocorticoids. The providers on these services now seem to be more aggressive with insulin dosing and making appropriate adjustments. In addition, after initial prompting by the vGMS notes, the providers on the oncology service now review insulin use during prior hospitalizations for chemotherapy and plan accordingly.

To date, 2 other groups have reported on remote interventions. Amor and colleagues evaluated ongoing daily observation and intervention in all noncritical surgical patients supported by remote review of POC blood glucose readings. This strategy resulted in improved glycemic control, including higher use of basal–bolus insulin therapy and a lower frequency of hyperglycemic episodes without an increase in the frequency of hypoglycemia (32). Although a remote glucose service is more efficient than rounding, monitoring and intervening on as many as one third of our inpatients would not have been feasible. Mendez and associates found modest improvements in glucose levels in a Department of Veterans Affairs hospital with implementation of a "daily inpatient glycemic control service" but also found a concomitant 3-fold increase in formal glucose management consultations (33). In this study, glucose levels greater than 19.4 mmol/L (>350 mg/dL) triggered review of glucose levels and a possible remote note or formal consultation; 4 to 8 charts were reviewed per day, requiring 1 to 2 hours for review plus the time for the formal consultations. With our online insulin/glucose chart and note templates, the time to review our daily report and insert all of the glucose management notes is 20 to 40 minutes.

The vGMS and similar inpatient services may become economically important for cost savings as medicine moves toward bundled care (34). In a bundled-care payment model without additional payment for time-consuming in-person consultations, virtual consultations may result in significant cost savings.

Our study has several limitations. The vGMS was evaluated at UCSF, an academic medical center with residents and attending physicians rotating monthly on different services. With a more stable medical staff, the effect may be greatest initially and decrease over time. We did not collect data on patients' concurrent illnesses and treatments that might influence glycemic outcomes or information on physicians' orders. Finally, the vGMS was possible only with a well-established infrastructure that included a long-standing inpatient diabetes committee establishing policies and procedures for all aspects of inpatient diabetes management; mandatory use of standard order sets; and well-trained and motivated medical, nursing, and pharmacy staff.

In conclusion, the vGMS was associated with a sustained 39% decrease in the daily number of inpatients with 2 or more glucose values of 12.5 mmol/L or greater (≥225 mg/dL) and a simultaneous decrease in the number of patients with hypoglycemia. An inpatient vGMS is a potentially scalable model that harnesses automated glucose screening and expedited clinical review to enhance the management of patients with diabetes.

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Reproducible Research Statement: *Study protocol:* Not available. *Statistical code and data set:* Available from Dr. Kohn (e-mail, Michael.kohn@ucsf.edu).

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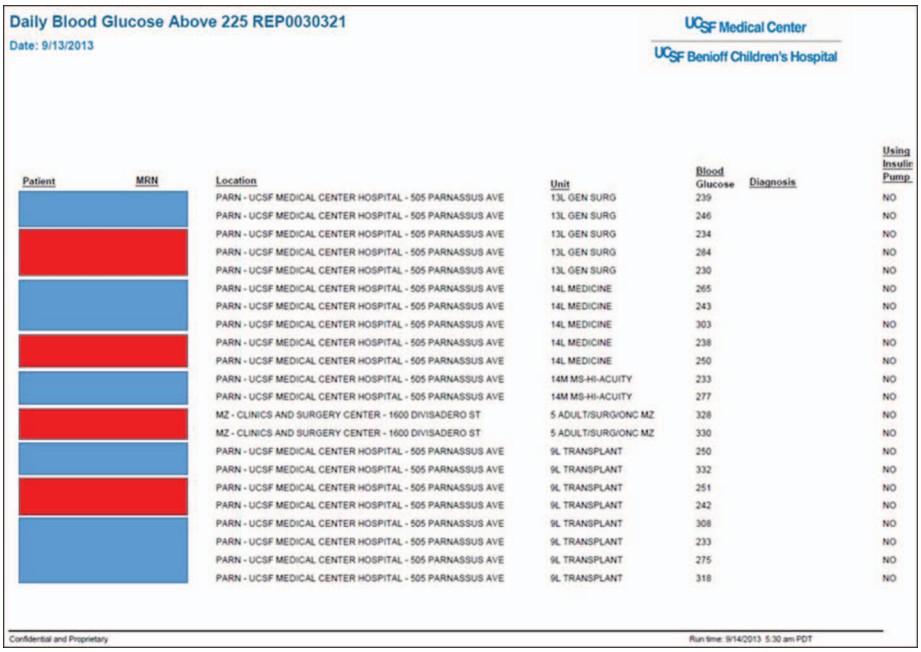
Appendix Table 1. Historical Infrastructure, Educational Milestone Events, and Mean Glucose Levels

Year	Milestone Event	Mean Glucose Level	
		IV Insulin Infusions	**Subcutaneous Insulin**
1989	Bedside glucose monitoring	Moffitt-Long Hospital (no IV protocol): >11.1 mmol/L (>200 mg/dL) Mount Zion Hospital (with protocol): 7.8 mmol/L (140 mg/dL)	Limited data from past chart reviews; >11.1 mmol/L (>200 mg/dL)
1990	IV insulin order set	Moffitt-Long Hospital (no IV protocol): >11.1 mmol/L (>200 mg/dL) Mount Zion Hospital (with protocol): 7.8 mmol/L (140 mg/dL)	Limited data from past chart reviews; >11.1 mmol/L (>200 mg/dL)
Mid-1990s	Subcutaneous insulin order sets	Moffitt-Long Hospital (no IV protocol): >11.1 mmol/L (>200 mg/dL) Mount Zion Hospital (with protocol): 7.8 mmol/L (140 mg/dL)	Limited data from past chart reviews; >11.1 mmol/L (>200 mg/dL)
1999	Intranet education	Moffitt-Long Hospital (no IV protocol): >11.1 mmol/L (>200 mg/dL) Mount Zion Hospital (with protocol): 7.8 mmol/L (140 mg/dL)	Limited data from past chart reviews; >11.1 mmol/L (>200 mg/dL)
2004	Mandatory use of new IV insulin order sets for all campuses Mandatory nursing education (online) Mandatory physician education (online and small group case-based)	7.7 mmol/L (138 mg/dL) in year after protocol initiation (all campuses)	10.3 mmol/L (185 mg/dL) in year after mandatory education as of 2004; between 2006 and 2012, mean glucose level in 9-mmol/L range (mid-170s mg/dL)
2012	Inpatient electronic health record for orders (Epic Systems)	–	See text
2013	vGMS begins	–	See text

IV = intravenous; vGMS = virtual glucose management service.

Appendix Figure 1. Daily glucose report.



Daily Blood Glucose Above 225 REP0030321

Date: 9/13/2013

UCSF Medical Center

UCSF Benioff Children's Hospital

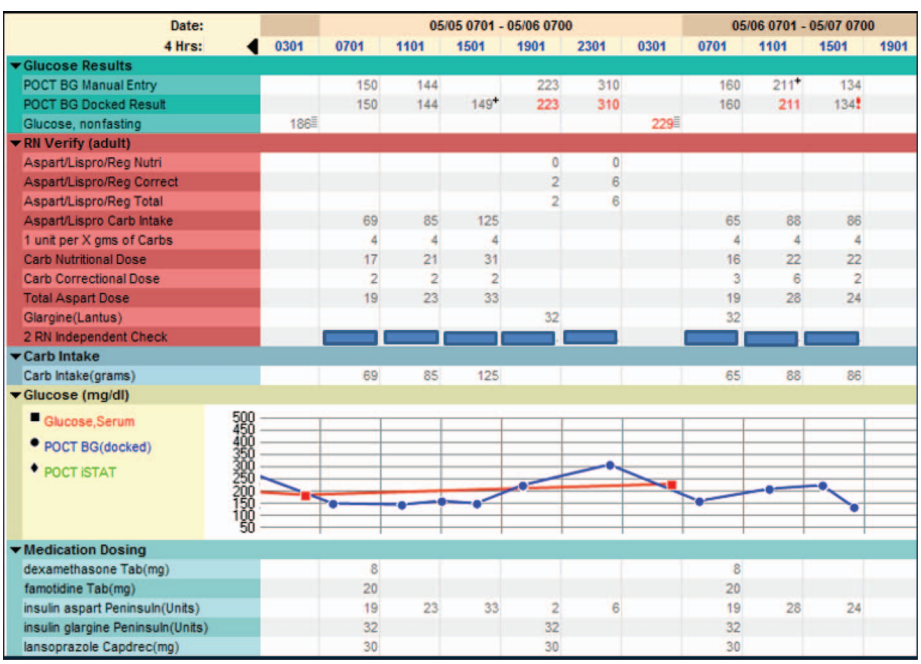
Patient	MRN	Location	Unit	Blood Glucose	Diagnosis	Using Insulin Pump
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	13L GEN SURG	239		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	13L GEN SURG	246		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	13L GEN SURG	234		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	13L GEN SURG	284		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	13L GEN SURG	230		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	14L MEDICINE	265		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	14L MEDICINE	243		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	14L MEDICINE	303		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	14L MEDICINE	238		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	14L MEDICINE	250		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	14M MS-HI-ACUITY	233		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	14M MS-HI-ACUITY	277		NO
		MZ - CLINICS AND SURGERY CENTER - 1600 DIVISADERO ST	5 ADULT/SURG/ONC MZ	328		NO
		MZ - CLINICS AND SURGERY CENTER - 1600 DIVISADERO ST	5 ADULT/SURG/ONC MZ	330		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	9L TRANSPLANT	250		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	9L TRANSPLANT	332		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	9L TRANSPLANT	251		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	9L TRANSPLANT	242		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	9L TRANSPLANT	308		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	9L TRANSPLANT	233		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	9L TRANSPLANT	275		NO
		PARN - UCSF MEDICAL CENTER HOSPITAL - 505 PARNASSUS AVE	9L TRANSPLANT	318		NO

Confidential and Proprietary

Run time: 9/14/2013 5:30 am PDT

To convert glucose values to mmol/L, multiply by 0.0555.

Appendix Figure 2. Insulin/glucose flow sheet.



Date:		05/05 0701 - 05/06 0700						05/06 0701 - 05/07 0700			
4 Hrs:	0301	0701	1101	1501	1901	2301	0301	0701	1101	1501	1901
Glucose Results											
POCT BG Manual Entry		150	144		223	310		160	211+	134	
POCT BG Docked Result		150	144	149+	223	310		160	211	134!	
Glucose, nonfasting	186						229				
RN Verify (adult)											
Aspart/Lispro/Reg Nutri					0	0					
Aspart/Lispro/Reg Correct					2	6					
Aspart/Lispro/Reg Total					2	6					
Aspart/Lispro Carb Intake		69	85	125				65	88	86	
1 unit per X gms of Carbs		4	4	4				4	4	4	
Carb Nutritional Dose		17	21	31				16	22	22	
Carb Correctional Dose		2	2	2				3	6	2	
Total Aspart Dose		19	23	33				19	28	24	
Glargine(Lantus)					32			32			
2 RN Independent Check											
Carb Intake											
Carb Intake(grams)		69	85	125				65	88	86	
Glucose (mg/dl)											
Glucose,Serum POCT BG(docked) POCT iSTAT											
Medication Dosing											
dexamethasone Tab(mg)		8						8			
famotidine Tab(mg)		20						20			
insulin aspart Peninsuln(Units)		19	23	33	2	6		19	28	24	
insulin glargine Peninsuln(Units)		32			32			32			
lansoprazole Capdrec(mg)		30			30			30			

To convert glucose values to mmol/L, multiply by 0.0555.

Appendix Table 2. Process Details for Reviewing Patient Chart

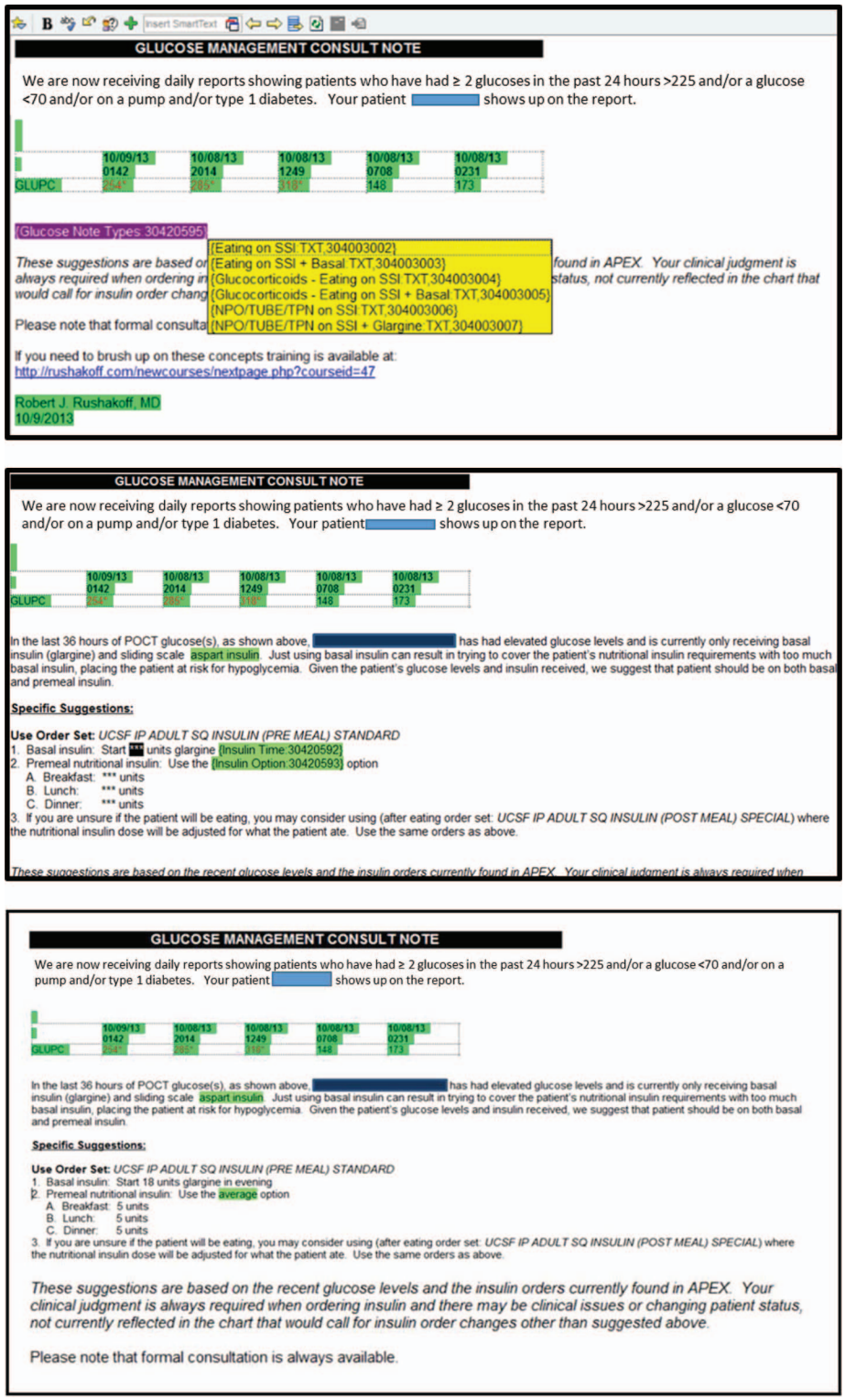
The insulin/glucose flow sheet was reviewed to assess previous metabolic status and treatment (**Appendix Figure 2**). The flow sheet displays:
Insulin administration: Administered doses labeled as nutritional, correction, and basal; for patients using insulin pumps, all insulin doses; for patients receiving insulin drips, the infusion rate
Nutrition: Percentage of each meal consumed or the amount of carbohydrates consumed for patients on carbohydrate counting; for patients on tube feeding, the enteral feeding rates and times
Relevant medications: Timing and dosages of medications, such as oral diabetes medications and glucocorticoids
Relevant laboratory studies: Test results, including creatinine levels and results of liver function testing
Current orders for insulin, meals, glucocorticoids, and enteral and total parenteral nutrition were checked to determine whether changes had already been made.
Recent notes may be reviewed to determine whether a significant change in treatment was anticipated.

Appendix Table 3. Reasons a vGMS Note Was Not Placed in the Chart

Patient already being followed by an endocrinology consult team
Random high glucose reading
Glucose levels were fine before and after
No new medications were started (e.g., glucocorticoids)
Changing orders on the basis of the 2 higher numbers would be dangerous
No pattern
New orders already written
Seem appropriate
Shows understanding of how to adjust
Receiving IV insulin infusion
Single glucocorticoid pulse
Glucocorticoid discontinued
One-time issue
Received dextrose with medication (although may put in note to avoid the dextrose)
Procedure: Glucose levels were fine before and would be expected to be fine after
New orders written (often day of admission)
Cannot yet assess effect of changes already made

IV = intravenous; vGMS = virtual glucose management service.

Appendix Figure 3. Glucose management note template.



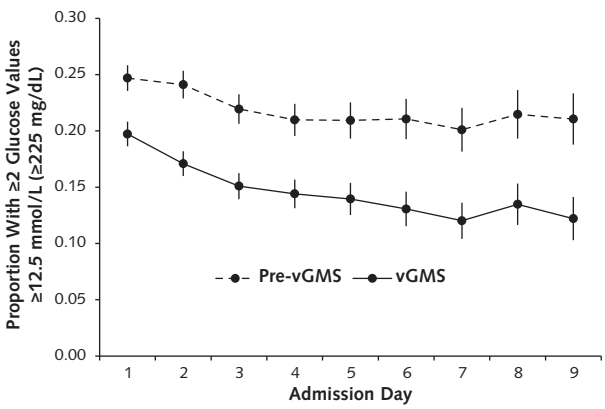
To convert glucose values to mmol/L, multiply by 0.0555. **Top.** Initial information is placed automatically when a new glucose management note is opened. **Middle.** Example note for a patient who is eating but receiving only basal insulin and correction dosing. The suggested insulin dose can be made by using the F2 key to move from the "starred" item to the next. **Bottom.** Example of a completed note for a patient who is eating but had been receiving only basal insulin and correction dosing. The suggested insulin doses are now in place.

Appendix Table 4. Linear Regression Model for Analysis of Percentage of Hyperglycemic Patients per Day*

Y_i = B0 + B1($vGMS_i$) + B2(Day_i from introduction of vGMS) + B3($vGMS_i$ × Day_i)
365 × 3 = 1095 observations, 1 for each calendar day (Day_i)
i = −365 to 730
Y_i = percentage of hyperglycemic patients (per total adult nonobstetric inpatients) on Day_i
B0 = predicted value for 1 June 2013 = 6.75 per 100 inpatient-days
B1 = discontinuous effect of introducing vGMS = −0.27 (95% CI, −0.61 to 0.062)
B2 = slope before 1 June 2013 = −0.00106 (95% CI, −0.00236 to −0.000233)
B3 = change in trend after introducing vGMS = −0.00278 (95% CI, −0.00415 to −0.00140)

vGMS = virtual glucose management service.
* The same model was used for the analysis of at-goal and hypoglycemic patients.

Appendix Figure 4. Proportion of glucose-monitored patients with serum glucose levels ≥12.5 mmol/L (≥225 mg/dL), by admission day.



In each study period, the hyperglycemia proportion was highest on admission day 1 and tended to decrease as admission duration increased. Compared with the pre-vGMS period, the day-1 hyperglycemia proportion was significantly lower during the vGMS period (risk ratio, 0.80 [CI, 0.74 to 0.86]), and the effect of the intervention increased with admission day (risk ratio for day 9, 0.58 [CI, 0.48 to 0.70]; *P* = 0.008 for interaction). Error bars represent 95% CIs. vGMS = virtual glucose management service.

Appendix Table 5. Poisson Regression Model Controlling for Hospital Service and Race*

Variable	Incidence Rate per 100 Glucose-Monitored Days (95% CI)	Incidence Rate Ratio (95% CI)
Study period		
Pre-vGMS	21.5 (20.5–22.5)	Reference
Transition	18.0 (17.2–18.9)	0.84 (0.79–0.89)
vGMS	15.1 (14.3–15.8)	0.70 (0.66–0.74)
Service		
Medicine	18.0 (17.3–18.7)	Reference
Surgery	12.4 (11.8–13.0)	0.69 (0.65–0.73)
Transplant	25.0 (23.8–26.2)	1.39 (1.30–1.48)
Oncology	23.7 (22.1–25.4)	1.32 (1.22–1.43)
Neurology/other	14.3 (12.6–16.3)	0.80 (0.70–0.91)
Race		
White	17.4 (16.7–18.1)	Reference
Nonwhite	18.6 (17.9–19.4)	1.07 (1.02–1.13)

vGMS = virtual glucose management service.
* Outcome is the number of hyperglycemic days per glucose-monitored hospitalization.