JDI Journal of Diabetes Investigation Open access
Official Journal of the Asian Association for the Study of Diabetes
ORIGINAL ARTICLE

# Electronic dashboard-based remote glycemic management program reduces length of stay and readmission rate among hospitalized adults

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**Keywords**
Inpatient glycemic management, Length of stay, Readmission

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*J Diabetes Investig* 2021; 12: 1697–1707

doi: 10.1111/jdi.13500

## ABSTRACT

**Aims/Introduction:** Currently, the impact of hospital-wide glycemic control interventions on length of hospital stay (LOS) and readmission rates are largely unknown. We investigated the impact of a 4-year hospital-wide remote glycemic management program on LOS and 30-day readmission rates among hospitalized adults who received glucose monitoring.

**Materials and Methods:** In this retrospective study, hospitalized patients who received glucose monitoring were classified into groups 1 (high glucose variability), 2 (hypoglycemia), 3 (hyperglycemia) and 4 (relatively stable). The monthly percentage changes, and average monthly percentage changes of hyperglycemia, hypoglycemia and treat to target were determined using joinpoint regression analysis.

**Results:** A total of 106,528 hospitalized patients (mean age 60.9 ± 18.5 years, 57% men) were enrolled. We observed a significant reduction in the percentage of inpatients in poor glycemic control groups (groups 1, 2 and 3, all $P < 0.001$), and a reciprocal increase in the relatively stable group (group 4) from 2016 to 2019. We found a significant reduction in LOS by 11.4% (10.5–9.3 days, $P = 0.002$, after adjustment for age, sex, and admission department). The 30-day readmission rate decreased from 29.9% to 29.3%, mainly among those in group 4 in 2019 ($P < 0.001$ after adjustment of sex, age, admission department and LOS).

**Conclusions:** Improved glycemic control through a hospital-wide electronic remote glycemic management system reduced LOS and 30-day readmission rates. Findings observed in this study might be associated with the reduction in cost of avoidable hospitalizations.

## INTRODUCTION

The prevalence of diabetes and its complications are still growing, and pose an enormous threat to public and global health[1,2]. Furthermore, diabetes is an important driver of direct and indirect costs and burdens, caused by frequent hospitalizations, disability and absence from work[1–4].

Previous studies showed that patients with diabetes not only have a higher risk of hospital admission, but also have longer length of stay (LOS) and more frequent hospital readmissions than those without diabetes[5,6]. In addition, patients with diabetes had a significantly increased risk of in-hospital mortality[5]. Inpatients who experienced hyperglycemia and hypoglycemia events were also found to have higher readmission and mortality rates[7,8].

The benefits of intensive glycemic control for inpatients remain controversial[9,10]. An early study reported that inpatient

Received 28 August 2020; revised 22 December 2020; accepted 6 January 2021

glycemic control managed by an integrated team of healthcare professionals shortened LOS for patients with diabetes, albeit with a non-significant increase in hypoglycemia events[11]. Another retrospective observational study reported that LOS and 30-day readmission rates decreased in patients co-managed by a specialized diabetes team[12]. However, it is unclear whether a hospital-wide remote glycemic intervention system could influence hospital LOS and subsequent readmission.

Our previous study showed that a hospital-wide inpatient remote glycemic management program, supported by a team led by endocrinologists, efficiently decreased hyperglycemia and hypoglycemia events in hospitalized adults from 2016 to 2018[13]. In the study presented here, the observation was extended to another year (2019), during which several intensified steps were implemented for the glycemic management program. We examined whether the beneficial effects of our hospital-wide glycemic management program could translate into shortened LOS and lower 30-day readmission rates among hospitalized adults.

## MATERIALS AND METHODS

### Study design

We retrospectively analyzed the effects of implementing a hospital-wide glycemic management program on the LOS and 30-day readmission rates among hospitalized adults who received glucose monitoring. The glycemic management program was initiated in 2017 and fully implemented in 2018. In 2019, several intensified steps were introduced that included repeated reinforced education training programs for attending physicians, residents and nurse practitioners among all departments, and provided automatic real-time warning messages of hypoglycemia included checking all medication orders for hypoglycemic patients and informing the primary care team to stay alert for hypoglycemia-prone medications. We divided the observation period into pre-implementation (2016), development (2017), implementation (2018) and intensification (2019).

### Study population

All study participants were enrolled from Taichung Veterans General Hospital (TCVGH), a 1,500-bed public medical center in central Taiwan. We excluded patients from the pediatric and emergency departments. To minimize selection bias, we did not exclude specific medical condition, insurance situation and scheduled readmissions while analyzing the readmission rates. Details on the implementation of this program have been presented previously[13]. The study was approved by the institutional review board of TCVGH, and the requirement for informed consent (approval certificate number: CE20061A) was waived.

### Hospital-wide monitoring system and glycemic management program

The glycemic management team was formed and led by endocrinologists. The inpatient glucose bedside point-of-care devices data management systems, in combination with the CONTOUR™ PLUS, BGMS blood glucose monitoring system (Ascensia Diabetes Care Holdings AG, Basel, Switzerland, through the acquisition of Bayer Diabetes Care by PHC Holdings), met the ISO 15197: 2013 and US Food and Drug Administration blood glucose meter accuracy standards[14–16]. Glucometer data were uploaded to the electronic medical record system directly and automatically through a wireless connection.

We established an electronic dynamic glucose dashboard that monitored all hospitalized inpatient point-of-care and plasma glucose values. Information from the dashboard was automatically updated every night at 00.00 hours. Poor glycemic control included hyperglycemia, defined as two or more glucose values ≥300 mg/dL, and hypoglycemia, defined as a glucose level <70 mg/dL, during the previous 24 h. Inpatients were classified into four groups. Group 1 (high glucose variability) included those who had two hyperglycemia events plus at least one hypoglycemia event within 24 h during hospitalization. Group 2 (hypoglycemia) patients had at least one hypoglycemia event during hospitalization. Group 3 patients (hyperglycemia) had at least one hyperglycemia event during hospitalization. Group 4 patients (relatively stable) did not have any hyperglycemia or hypoglycemia episodes during hospitalization.

The glycemic management program integrated the following: (i) an electronic glucose dashboard that analyzed and monitored all hospitalized inpatient glucose point-of-care glucose and plasma glucose data from the biochemistry laboratory (Figure S1). Both automatic and manual mode are available; information was automatically updated every night at 00.00 hours, and we can also update the real-time data by manual model; (ii) a glycemic management system that could send daily warning messages (Figure S2); (iii) remote glycemic management recommendations (Figure S2); and (iv) timely warnings and recommendations for the prevention of hypoglycemia (Figure S2)[13].

The automatic real-time warning messages included checking all medication orders for hypoglycemic patients and informing the primary care team to stay alert for hypoglycemia-prone medications. Virtual glycemic management recommendations summarized the suggestions of administration of glucose-lowering drugs, dose and administration method[13]. We informed the primary care team members that these recommendations were only a part of the clinical decision support system based on the patient's recent blood glucose status and clinical data without visiting patients. Their consideration of the patient's clinical status is extremely important. The formal endocrinology consultation services were available if required[13].

### Statistical analysis

Characteristics of the inpatients are presented as descriptive statistics, and include sex, age, glucose monitoring during the admission period, LOS and 30-day readmission rate from 2016 to 2019. Continuous descriptive variables are presented as means ± standard deviations, glucose coefficient of variation (standard deviation/mean) data are listed as medians with interquartile ranges in parentheses, and categorical variables are presented as percentages. The proportion (%) of patients with poor glycemic control treated to target range were expressed as 'per day per 100 patients with glucose monitoring.' The joinpoints (years at which trends change significantly) and average monthly percentage changes and the corresponding 95% confidence intervals (CIs) were calculated using joinpoint regression analysis via Joinpoint Trend Analysis Software (version 4.8.0.1) from the Surveillance Research Program of the US National Cancer Institute[17–19]. The Cochran–Armitage trend test was used to estimate the linear association of LOS and readmission for the years of the study period. We adjusted for factors associated with 30-day readmissions, including sex, age, department of admission and LOS. Statistical significance was defined as $P < 0.05$. All statistical analyses were carried out with SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA).

We presented data on a total of 106,528 inpatients with a mean age of 60.9 years; the men enrolled in the study slightly outnumbered the women during the 4-year monitoring period (Table 1). Although the percentage of hospitalized adults requiring glucose monitoring increased by 24% from 2016 to 2019 (23,739 and 29,447 patients in 2016 and 2019, respectively), we found a significant reduction in the number of participants with poor glycemic control (group 1, 2 and 3, all $P < 0.001$) after implementation of the hospital-wide glucose management program. Our efforts also resulted in a significantly increased percentage of patients in group 4 (those with relatively stable glycemic levels) during the 4-year observation period (Table 1).

## RESULTS

### Glycemic control

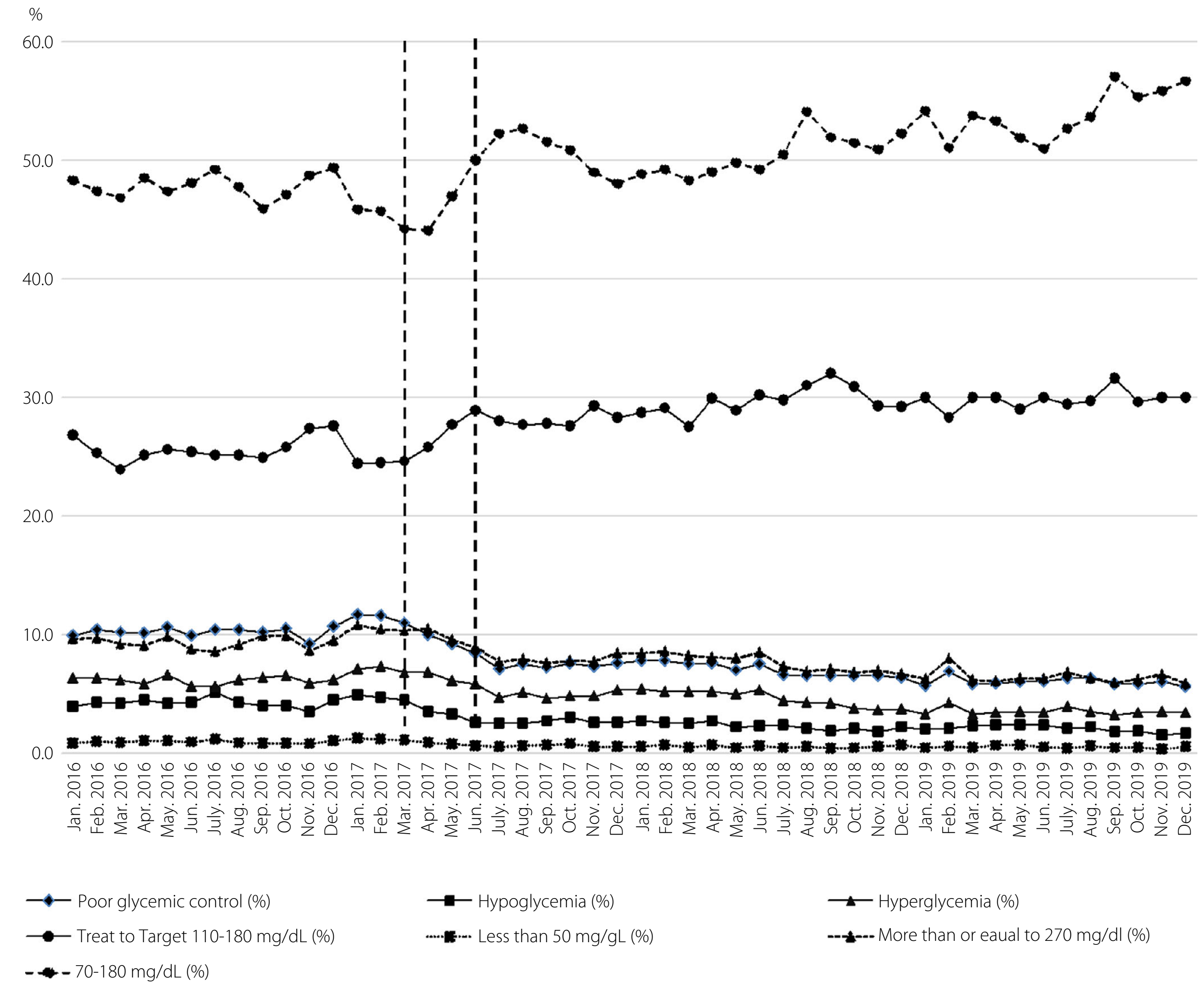
Figure 1 shows the trend in glycemic control from January 2016 to December 2019. Although the proportion of patients with poor glycemic control (including those with hypoglycemia and hyperglycemia) did not change during the pre-implementation period (2016), we found a significant and persistent lower rate of poor glycemic control over the following 3 years (2017–2019, $P$ trend <0.001). Specifically, the mean proportion of patients with poor glycemic control decreased by 41% (from 10.2% to 6.0%), the rate of those with hyperglycemia decreased by 43% (from 6.1% to 3.5%) and the rate of those with hypoglycemia decreased by 50% (from 4.2% to 2.1%), all $P < 0.001$ (Table 2). In addition, the rate of patients with glucose level ≥270 mg/dL decreased by 40% (from 9.6% to 5.8%, $P < 0.001$), and the rate of severe hypoglycemia (defined as a glucose level

**Table 1** | Clinical characteristics and glucose coefficient of variation (%) of hospitalized adults with glucose monitoring

| Clinical characteristics | Total | | Year | | | | | | | | *P* for trend |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2016 Pre-implementation | | 2017 Development | | 2018 Implementation | | 2019 Intensification | | |
| | *n* | % | *n* | % | *n* | % | *n* | % | *n* | % | |
| Total hospitalizations | 106,528 | | 23,739 | 100.0 | 25,868 | | 27,474 | | 29,447 | | 0.001 |
| Men | 60,835 | 57.1 | 13,764 | 58.0 | 14,983 | 57.9 | 15,975 | 58.1 | 16,113 | 54.7 | |
| Age, years (mean ± SD) | 60.9 ± 18.5 | | 61.3 ± 18.5 | | 61.0 ± 18.9 | | 61.0 ± 18.8 | | 60.6 ± 18.0 | | |
| Group 1: high glucose variability | | | 161 | 0.7 | 154 | 0.6 | 106 | 0.4 | 80 | 0.3 | <0.001 |
| Group 2: hypoglycemia | | | 1,150 | 4.8 | 1,008 | 3.9 | 829 | 3.0 | 1,005 | 3.4 | <0.001 |
| Group 3: hyperglycemia | | | 3,099 | 13.1 | 3,281 | 12.7 | 3,403 | 12.4 | 2,940 | 10.0 | <0.001 |
| Group 4: relatively stable | | | 19,329 | 81.4 | 21,428 | 82.8 | 23,136 | 84.2 | 25,442 | 86.3 | <0.001 |

| Glucose coefficient of variation (%) | Years | | | | | | | | *P* for trend |
|---|---|---|---|---|---|---|---|---|---|
| | 2016 | | 2017 | | 2018 | | 2019 | | |
| | Mean | Median (IQR) | Mean | Median (IQR) | Mean | Median (IQR) | Mean | Median (IQR) | |
| Total | 9.0 | 18.6 (8.6–33.2) | 8.4 | 17.4 (8.5–31.0) | 8.1 | 17.2 (7.9–30.0) | 7.7 | 17.3 (8.0–30.2) | <0.001 |
| Group 1: high glucose variability | 17.8 | 20.6 (11.5–43.3) | 15.5 | 21.1 (11.6–40.3) | 14.8 | 24.7 (9.4–40.8) | 12.8 | 17.0 (8.7–27.5) | 0.300 |
| Group 2: hypoglycemia | 12.3 | 19.6 (9.4–35.7) | 12.9 | 21.9 (10.2–40.0) | 13.6 | 22.1 (11.1–41.3) | 13.0 | 23.1 (12.4–39.2) | 0.250 |
| Group 3: hyperglycemia | 10.1 | 18.8 (9.0–32.8) | 10.7 | 17.7 (8.8–32.5) | 10.3 | 18.4 (8.7–32.0) | 10.6 | 18.2 (8.1–31.2) | 0.735 |
| Group 4: relatively stable | 7.8 | 18.3 (8.1–32.6) | 6.8 | 16.3 (7.9–29.6) | 6.7 | 15.8 (7.3–27.6) | 6.3 | 16.4 (7.3–28.5) | <0.001 |

Group 1: patients with glucose values <70 mg/dL and two or more glucose values ≥300 mg/dL within 24 h during the admission period. Group 2: patients with glucose values <70 mg/dL within 24 h during the admission period. Group 3: patients with two or more glucose values ≥300 mg/dL within 24 h during the admission period. Group 4: patients not having glucose values <70 mg/dL or two or more glucose values ≥300 mg/dL within 24 h during the admission period. Glucose coefficient of variation (standard deviation/mean). Glucose coefficient of variation data are listed as means, and medians with interquartile ranges in parentheses. IQR, interquartile range; SD, standard deviation.




<50 mg/dL) decreased by 49% (from 1.06% to 0.54 %, $P$ < 0.001; shown in Table 2 and Figure 1). The proportion of patients with glucose levels within the target range (110–180 mg/dL) increased significantly by 16% (25.7–29.8%) from 2016 to 2019 (Table 2). We analyzed data of reaching the target range frequently used for continuous glucose monitoring study (70–180 mg/dL) shown in Table 2 and Figure 1. The proportion of patients who adopted treat to target in range (70–180 mg/dL) increased by 15% (49.2–56.7%, $P$ = 0.004) during the study period (Table 2; Figure 1). Significant improvement of glucose variability was also founded by the decrease of patients of group 1 and reduction of glucose coefficient of variation (shown in Table 1).

Table 3 shows the estimated trends for the proportions of patients (per day per 100 patients with glucose monitoring) with hyperglycemia, hypoglycemia and treat to target, based on analysis of the joinpoint regression model. From 2016 to 2019, significant improvements of the average monthly percentage changes for hyperglycemia, hypoglycemia and treat to target were − 0.2%, –0.2% and 0.1%, respectively (Table 3). For inpatients with hyperglycemia, the monthly percentage changes increased significantly for trend 1, which was followed by a significant decrease in trends 2 and 3. For inpatients with hypoglycemia, we found significant decreases in both trend 2 and trend 3. Regarding the proportion of treat to target, significant increases were found for trend 2 and trend 3. Univariate regression for trend analysis was carried out, and the results were consistent with the joinpoint regression: significant improvements of glycemic control were found for trend 2 and trend 3 (footnote of Table 3).

## LOS

From 2016 to 2019, we observed an 11.4% reduction in the mean LOS from 10.5 to 9.3 days ($P$ = 0.002) after adjusting for

**Figure 1** | Trends of glycemic control among hospitalized adults: 2016–2019. The proportion of patients (%): per day per 100 patients with glucose monitoring. Hyperglycemia: two or more glucose values of ≥300 mg/dL during the previous 24 h. Hypoglycemia: a glucose level of <70 mg/dL during the previous 24 h. Treat to target: all glucose values within 110–180 mg/dL in the previous 24 h.

Univariate regression analysis:
1 January 2016 to 31 December 2016 (pre-implementation period)
Poor glycemic control rate: Coefficient = –0.002 (95% confidence interval [CI] –0.077 to 0.081, *P* trend = 0.962)
Hypoglycemia rate: Coefficient = –0.012 (95% CI –0.087 to 0.064, *P* trend = 0.733)
Hyperglycemia rate: Coefficient = –0.003 (95% CI –0.068 to 0.062, *P* trend = 0.926)
Treat to target: Coefficient = 0.134 (95% CI –0.056 to 0.323, *P* trend = 0.148)

1 January 2017 to 31 December 2019 (development, implementation and intensification periods)
Poor glycemic control rate:
Coefficient = –0.128 (95% CI –0.157 to –0.100, *P* trend <0.001)

Hypoglycemia rate:
Coefficient = –0.058 (95% CI –0.074 to –0.041, *P* trend <0.001)

Hyperglycemia rate:
Coefficient = –0.100 (95% CI –0.117 to –0.083, *P* trend <0.001)

Treat to target:
Coefficient = 0.126 (95% CI 0.085–0.167, *P* trend <0.001)

Trends of joinpoint trend analysis:
Hyperglycemia
Trend 1: January 2016–March 2017
Trend 2: March 2017–July 2017
Trend 3: July 2017–December 2019

Hypoglycemia
Trend 1: January 2016–March 2017
Trend 2: March 2017–June 2017
Trend 3: June 2017–December 2019

Treat to target
Trend 1: January 2016–March 2017
Trend 2: March 2017–June 2017
Trend 3: June 2017–December 2019

age, sex and admission department (Figure 2). Patients in group 1 who experienced hyperglycemia and hypoglycemia over a 24-h period during their hospitalization had the longest average hospital LOS, whereas patients with relatively stable glycemic control (group 4) had the shortest mean LOS (Table S1).

### 30-day readmission

The results of total and group-specific 30-day readmission rates are presented in Table 4. The 30-day readmission rates of patients with glucose monitoring are higher than hospital-wide readmission rates (10.0–11.0%, unadjusted *P* trend = 0.084), and decreased from 2016 to 2019 (29.9–29.3%, $P < 0.001$ after adjustment for sex, age, admission department and LOS). However, none of the readmission rates reached statistical significance for groups 1, 2 and 3. For group 4, we did find that 30-day readmission rates increased in 2017 and 2018, and decreased greatly in 2019, with a significant trend of reductions in 30-day readmission rates (Table 4).

## DISCUSSION

We recently reported on the successful experiences of a hospital-wide glycemic management program that reduced hyperglycemia and hypoglycemia in hospitalized adults[13]. This present study was an extension of our previous observations with addition of several intensified management measures. Our study showed further reductions in the number of inpatients with poor glycemic control (hyperglycemia and hypoglycemia), and more inpatients had glucose levels within the target ranges. Compared with other institution-wide inpatient glycemic management systems[20–23], our program enrolled relatively more hospitalized adults, had a longer observation term (observed for 4 years), and ranked highly in improvements in glycemic control and maintenance. Interestingly, as compared with usual care (a referral-based consultation service), a recent study reported that proactive or early intervention by endocrinologists decreased the proportion of patients with hyperglycemia (>270 mg/dL) to 3.3%[24], which was similar to our study.

**Table 2** | Proportion of inpatients with poor glycemic control and treat to target

| | 2016 Pre-implementation | 2017 Development | 2018 Implementation1 | 2019 Intensification | *P* for trend |
|---|---|---|---|---|---|
| Mean proportion of patients, % (expressed as "per day per 100 patients with glucose monitoring") | | | | | |
| Poor glycemic control (group 1 + 2 + 3) | 10.2 | 8.9 | 7.0 | 6.0 | <0.001 |
| Hyperglycemia | | | | | |
| Glucose values of ≥300 mg/dL (group 1 + 3) | 6.1 | 5.7 | 4.6 | 3.5 | <0.001 |
| Glucose values of ≥270 mg/dL | 9.6 | 8.5 | 6.7 | 5.8 | <0.001 |
| Hypoglycemia | | | | | |
| Glucose level of <70 mg/dL (group 1 + 2) | 4.2 | 3.3 | 2.3 | 2.1 | <0.001 |
| Glucose level of <50 mg/dL | 1.06 | 0.53 | 0.66 | 0.54 | <0.001 |
| Treat to target (110–180 mg/dL) | 25.7 | 27.1 | 29.7 | 29.8 | <0.001 |
| Treat to target in range (70–180 mg/dL) | 49.2 | 49.9 | 50.3 | 56.7 | 0.004 |

Automated update of the electronic medical record-based dashboard database at 00.00 am. Hyperglycemia: two or more glucose values of ≥300 mg/dL during the previous 24 h. Hypoglycemia: a glucose level of <70 mg/dL during the previous 24 h. Treat to target: all glucose values within 110–180 mg/dL in the previous 24 h. Treat to target in range: all glucose values within 70–180 mg/dL in the previous 24 h. Group 1: patients with glucose values <70 mg/dL and two or more glucose values ≥300 mg/dL within 24 h during the admission period. Group 2: patients with glucose values <70 mg/dL within 24 h during the admission period. Group 3: patients with two or more glucose values ≥300 mg/dL within 24 h during the admission period. Glucose values of ≥270 mg/dL: patients with two or more glucose values ≥270 mg/dL within 24 h during the admission period. Glucose values <50 mg/dL: patients with glucose values <50 mg/dL within 24 h during the admission period.

However, in that work, there was no significant reduction in the proportion of patients with hypoglycemia (<72 mg/dL), which is contrary to the present study, which had a 50% decrease in the prevalence of hypoglycemia (<70 mg/dL, from 4.2% to 2.1%). According to the results of joinpoint regression, we can find a steep improvement in hypoglycemia, hyperglycemia and treat to target during trend 2. Significant progress has been made in the 3rd to 6th months after implementation of the program, and with additional significant improvement throughout the following observation period of our study (trend 3).

We analyzed the antidiabetes drugs used during hospital stay (Table S2). These drugs have good glucose-lowering efficacy and stable safety. The use of these newer antidiabetes drugs increased over the study period, especially sodium–glucose cotransporter 2 inhibitors. However, the use of glucagon-like peptide-1 receptor agonists or sodium–glucose cotransporter 2 inhibitors remained <5% throughout the observation periods. These new drugs used in hospitalized patients were limited due to the acute illness or stress conditions (poor appetite, renal function impairment, metabolic acidosis, preparation for operations), and considerations of the adverse effects. The use of antidiabetes drugs might not be the main cause of the improvements in glycemic control, LOS or readmission rate.

Our findings are quite timely, as the world is grappling with a new pandemic of COVID-19[25,26]. A reduction of the hospital-wide formal endocrinology consultation rate from 2016 to 2019 (from 1.32% to 1.20%, not shown in tables) was found according to our observation. We believe that the remote glycemic recommendations led by endocrinologists could help to improve inpatient glycemic control, and minimize the risk of exposure and subsequent nosocomial infections.

Patients with diabetes are at a higher risk of prolonged LOS than those without diabetes[5,6,27,28]. Several studies have shown a relationship between poor glycemic control and an increased LOS[29–31], especially among those with associated comorbidities, such as stroke, hospitalization for bone marrow transplantation and heart failure[32–35]. The association between hospital hyperglycemia and prolonged LOS was also observed among those without a previous history of diabetes (including undiagnosed diabetes and new-onset hyperglycemia during hospitalization)[35,36]. Additionally, those with hypoglycemia were more likely to have prolonged LOS and poor disease outcomes. There was an increase of 0.75 days in LOS per each event of hypoglycemia during hospitalization[31]. A retrospective study also showed that patients with hypoglycemia are prone to increased LOS and a higher mortality rate[37,38]. Recently, an introduction of inpatients' early glycemic intervention (an inpatient diabetes team electronically identified individuals with diabetes and aimed to provide bedside management within 24 h of admission) reduced the proportion of inpatients with hyperglycemia and hospital-acquired infection, but did not affect LOS, as compared with traditional glycemic intervention[24]. The present findings clearly show that the implementation of a hospital-wide glycemic management program not only improved glycemic control, but also significantly decreased LOS by 11.4% (from 10.5 to 9.3 days) during the 4-year observation period after adjustment for age, sex and admission department ($P$ = 0.002). The underlying condition might be the main factor affecting the LOS. We analyzed the principal diagnosis during the four different periods (shown in Table S3) and established that the distribution of principal diagnoses was similar throughout the observation period. Furthermore, we did not adjust for the department of admission and diagnosis at the

**Table 3** | Annual percentage change of glycemic control among hospitalized adults according to the joinpoint regression analysis

| | Trend 1 | | Trend 2 | | Trend 3 | | AMPC (95% CI) |
|---|---|---|---|---|---|---|---|
| | Period | MPC (95% CI) | Period | MPC (95% CI) | Period | MPC (95% CI) | |
| Hyperglycemia (group 1 + 3) | 201,601–201,703 | 0.16 (0.0–0.4)† | 201,703–201,707 | −7.52 (−13.3 to −3.2)† | 201,707–201,912 | −0.19 (−0.2 to −0.1)† | −0.2 (−0.2 to −0.1)† |
| Hypoglycemia (group 1 + 2) | 201,601–201,703 | 0.16 (−0.0 to 0.4) | 201,703–201,706 | −14.34 (−22.1 to −7.7)† | 201,706–201,912 | −0.13 (−0.2 to −0.1)† | −0.2 (−0.3 to −0.2)† |
| Treat to target | 201,601–201,703 | −0.04 (−0.1 to 0.0) | 201,703–201,706 | 5.11 (1.9–6.7)† | 201,706–201,912 | 0.02 (0.0–0.0)† | 0.1 (0.0–0.1)† |

Hyperglycemia: two or more glucose values of ≥300 mg/dL during the previous 24 h. Hypoglycemia: a glucose level of <70 mg/dL during the previous 24 h. Treat to target: all glucose values within 110–180 mg/dL in the previous 24 h. Group 1: patients with glucose values <70 mg/dL and two or more glucose values ≥300 mg/dL within 24 h during the admission period. Group 2: patients with glucose values <70 mg/dL within 24 h during the admission period. Group 3: patients with two or more glucose values ≥300 mg/dL within 24 h during the admission period. Group 4: patients not having glucose values <70 mg/dL or two or more glucose values ≥300 mg/dL within 24 h during the admission period. Univariate regression analysis (*$P < 0.05$): hyperglycemia – trend 1: coefficient = 0.055 (95% confidence interval [CI] −0.011 to 0.121, $P$ trend = 0.095); trend 2: coefficient = −0.520 (95% CI −0.842 to −0.198, $P$ trend = 0.014)*; trend 3: coefficient = −0.078 (95% CI −0.096 to −0.060, $P$ trend <0.001)*. Hypoglycemia – trend 1: coefficient = 0.022 (95% CI −0.039 to 0.083, $P$ trend: 0.446); trend 2: coefficient = −0.490 (95% CI −0.754 to −0.226, $P$ trend <0.001)*; trend 3: coefficient = −0.031 (95% CI −0.042 to −0.021, $P$ trend <0.001)*. Treat to target – trend 1: coefficient = 0.020 (95% CI −0.144 to 0.184, $P$ trend = 0.266); trend 2: coefficient = 0.990 (95% CI 0.071–1.909, $P$ trend = 0.042)*; trend 3: coefficient = 0.069 (95% CI 0.025–0.114, $P$ trend = 0.003). AMPC, average monthly percentage change; MPC, monthly percentage change. †Indicates the annual percentage change is significantly different from zero at the alpha = 0.05 level.

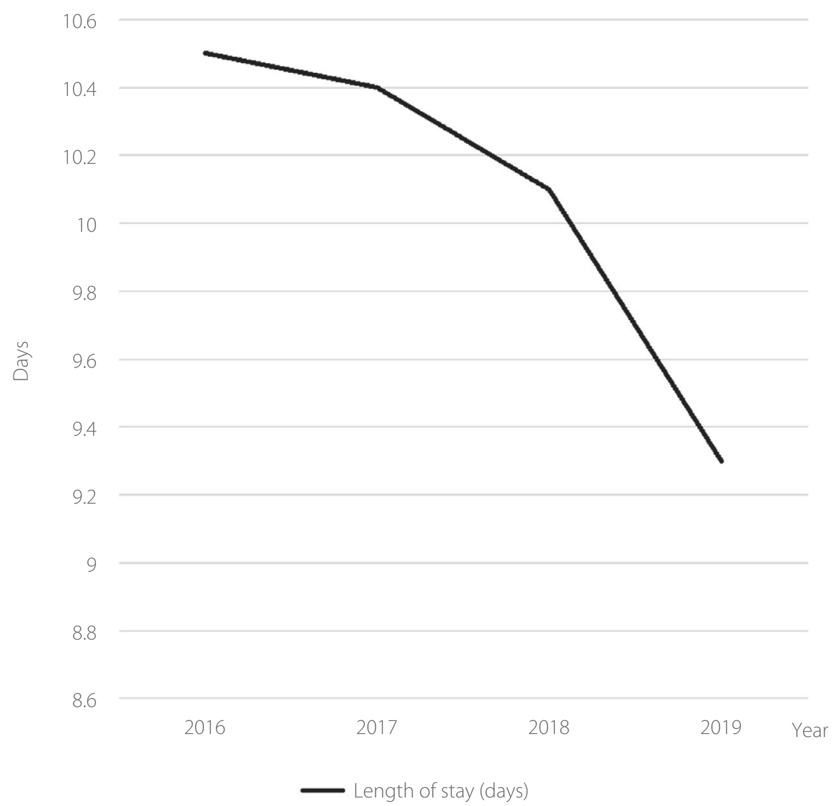
same time, because diagnosis is strongly correlated to the department of admission. According to recent research aimed at evaluating the costs and LOS of hospitalizations due to the most common diabetes-related complications in Taiwan, the average hospitalization costs per day ranged from approximately NT$7,464.5 (NT$1 = $US0.034; $US253.7, the lowest hospitalization cost among the classification of their study, caused by peptic ulcer) to NT$31,574.4 ($US1,072.6, the highest hospitalization cost, caused by fatal ischemic heart disease). Thus, a decrease in LOS of 1.2 days observed in the present study might be associated with a $US304.4–1,287.1 reduction in hospitalization costs per admission[39].

In addition, previous research found that inpatients with glycemic variability had a longer LOS and higher mortality[40]. The present study also found that patients who experienced high glucose variability (group 1) had the longest average hospital LOS, which is in line with the findings of a previous report[40]. The mean LOS in the present study ranged from 21.8 to 24.7 days, which was similar to the LOS in patients with diabetes and a history of amputation, reported as the complication of diabetes with the longest LOS in Taiwan[39].

According to the results of the present study, 30-day readmission rates for inpatients with glucose monitoring were higher than the rate for all hospitalized patients (10.0–11.0%), consistent with previous findings. Our study showed the benefits of a hospital-wide glycemic management program, which included a significant reduction in the 30-day readmission rate after adjusting for sex, age, admission department and LOS (29.9–29.3% from 2016 to 2019, $P < 0.001$). There was no policy related to admission or discharge in our hospital during the observation periods.

Previous evidence shows that both patients with diagnosed and with newly onset diabetes have higher readmission rates[6,28,41]. An urban teaching hospital-based study reported that the 30-day readmission rates were higher in patients with diabetes than those without diabetes (15.3% vs 8.4%, respectively, $P < 0.001$)[28]. Another study reviewed 7,763 admissions at the University of Michigan Health System, and found that 30-day readmission rates for hospitalized patients with diabetes were up to 22.7% and were higher than the rate for all hospitalized patients (8.5–13.5%)[41]. It was also shown that patients who experienced hypoglycemia were at risk for readmission[7,38]. Thus, although patients with either hyperglycemia or hypoglycemia were known to have higher risks of readmission, the benefits of intensive glycemic control on readmission rates remain largely unknown[9,10].

The readmission rate of the present study is higher than in a previous review[41], which might be related to the disease severity of our hospital (TCVGH is a major medical center of central Taiwan). Furthermore, to minimize selection bias, we did not exclude any specific medical condition or insurance situation. The exclusion criteria of previous studies for evaluation readmission rate varied, such as scheduled readmission for




| | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2016 Pre-implementation | | 2017 Development | | 2018 Implementation | | 2019 Intensification | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Length of stay (days) | 10.5 | 14.6 | 10.4 | 14.2 | 10.1 | 13.5 | 9.3 | 12.3 |

**Figure 2** | Mean length of stay of hospitalized adults with glucose monitoring: 2016–2019. The detailed data and *P* for the trend for length of stay (mean ± standard deviation) among different groups are shown in Table S1. *P* for trend: adjusted for sex, age and admission department. SD, standard deviation.

chemotherapy or operation, some excluded patients who were transferred to other hospitals on the day of discharge and patients who were discharged on the day of admission, some excluded underlying conditions, patients admitted with exceptionally long LOS or insurance situation, and so on.[6,7,12,28,38,41,42] We tried to avoid distortion of accounting information caused by human factors.

Many factors were shown to influence readmission, including socioeconomic status, belonging to a racial or ethnic minority, comorbidity burden, public insurance availability, emergent or urgent admission, inherently complicated disease processes, patient characteristics and the diversity of patient conditions[6,7,42]. Only one recent study showed that 30-day readmission decreased significantly among patients co-managed by a specialized diabetes team (mean 30-day readmission decreased by 10.71%)[12]. Nevertheless, this will take time and considerable resources, and might be impractical due to the growing number of inpatients with glucose monitoring.

Data from the present study showed that the reduction in 30-day readmissions is likely on account of patients in group 4 (which accounted for >80% of all discharges) having relatively stable glucose levels (5% reduction from 32.1% to 30.4%, adjusted $P < 0.001$). Given that the inherent conditions of this group were quite heterogenous, with various causes of hospitalization, we believe that they also benefited from our hospital-wide glycemic management program.

During the observation period, a significant improvement of glucose variability analyzed by glucose coefficient of variation was found, mainly in group 4 (Table 1); we can also find a significant improvement of treat to targets, and these improvements could affect the patients among group 4, the relatively stable group. The educational programs and warning messages

**Table 4** | Thirty-day readmission rates among hospitalized adults with glucose monitoring

| Variables | Year | | | | | | | | | | | | *P* for trend[§] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2016 Pre-implementation | | | 2017 Development | | | 2018 Implementation | | | 2019 Intensification | | | |
| | *n* | Event | 30DR (%) | *n* | Event | 30DR (%) | *n* | Event | 30DR (%) | *n* | Event | 30DR (%) | |
| Total | 23,739 | 7,105 | 29.9 | 25,868 | 8,560 | 33.1 | 27,474 | 9,210 | 33.5 | 29,447 | 8,620 | 29.3 | <0.001 |
| Men | 13,764 | 3,993 | 29.0 | 14,983 | 4,780 | 31.9 | 15,975 | 5,204 | 32.6 | 16,113 | 4,582 | 28.4 | |
| Age, years (mean ± SD) | 57.5 ± 18.7 | | | 57.5 ± 18.6 | | | 57.5 ± 18.0 | | | 57.9 ± 16.9 | | | |
| Patient groups | | | | | | | | | | | | | |
| Group 1: high glucose variability | 161 | 35 | 21.7 | 154 | 34 | 22.1 | 106 | 31 | 29.3 | 80 | 23 | 28.8 | 0.227 |
| Group 2: hypoglycemia | 1,150 | 208 | 18.1 | 1,008 | 205 | 20.3 | 829 | 149 | 18.0 | 1,005 | 183 | 18.2 | 0.289 |
| Group 3: hyperglycemia | 3,099 | 668 | 21.6 | 3,281 | 837 | 25.5 | 3,403 | 851 | 25.0 | 2,940 | 695 | 23.6 | 0.165 |
| Group 4: relatively stable | 19,329 | 6,194 | 32.1 | 21,425 | 7,484 | 34.9 | 23,136 | 8,179 | 35.4 | 25,422 | 7,719 | 30.4 | <0.001 |

Mean 30-day readmission rates of all hospitalized patients of year 2016, 2017, 2018 and 2019 were 10.0%, 10.7%, 10.9% and 11.0%, respectively (unadjusted *P* for trend 0.084). Specific medical condition, insurance situation, scheduled readmissions or extremely long hospital days were not excluded when analyzing the readmission rates. 30DR (%), 30-day readmission rate = events of each group/discharge numbers of each group; SD, standard deviation. [§]Adjusted for sex, age, admission department and hospitalized length of stay (LOS). Group 1: patients with glucose values <70 mg/dL and two or more glucose values ≥300 mg/dL within 24 h during the admission period. Group 2: patients with glucose values <70 mg/dL within 24 h during the admission period. Group 3: patients with two or more glucose values ≥300 mg/dL within 24 h during the admission period. Group 4: patients not having glucose values <70 mg/dL or two or more glucose values ≥300 mg/dL within 24 h during the admission period.

were of tremendous value[13]. The recommendation by endocrinologists might also improve the ability of glycemic control[13,23]. The ways to improve glycemic control and treat to target included better management of underlying conditions, and these improvements might lead to a consequent improvement of readmission rate.

The main limitation of the present study was its retrospective and observational design. Although external validity might be lacking, the demographic characteristics of the patients in this study were similar to the nationwide population, based on the overall distribution of diabetes in Taiwan[4]. The hospital featured in this study is a major medical center of central Taiwan and a place that cares for the more severely ill patients. We analyzed the principal diagnosis; furthermore, we did not adjust for department of admission and diagnosis simultaneously, as diagnosis is strongly correlated to the department of admission. The raw data of all hospitalizations were not available (limited by the study population approved by the institutional review board), and we were not able to adjust for the confounders while analyzing the LOS and readmission of all hospitalized patients. This study aimed to observe the general effects of our institutional-wide glucose management program on the LOS and readmission rates of the entire inpatient population receiving glucose monitoring. However, the underlying condition might be the main factor affecting LOS and readmission. Therefore, further studies are warranted to validate the impact of glycemic management programs on disease-specific LOS, readmissions, mortality and health expenditures among hospitalized patients. We did not consider the responses of primary care teams to our recommendations. Finally, with different definitions of poor glycemic control and clinical conditions for the study inpatients, the present results cannot be compared with those of previous studies directly.

The present findings show that the implementation of a hospital-wide glycemic management program not only further improves glycemic control, but also significantly reduces LOS and 30-day readmission rate among hospitalized adults. These improvements might alleviate many current health burdens. Further prospective studies are required to investigate the effects of glycemic management among inpatients, and how this affects healthcare quality measurements and disease outcomes.

## ACKNOWLEDGMENTS

We express our deep gratitude to Chia-Hui Shen and Jun-Peng Chen for data collection and analysis. We also extend our thanks to the Biostatistics Task Force and Division of Clinical Information, Center of Quality Management of Taichung Veterans General Hospital, Taichung, for their help in offering us resources and analysis. This study was supported in part by the Taichung Veterans General Hospital, Taiwan (TCVGH-1090101C, and TCVGH-1090102D); from the Ministry of Science and Technology, Taiwan (MOST 107-2314-B-075A-

001-MY3, and MOST 109-2321-B-075A-001); and from National Health Research Institutes (NHRI-EX109-10927HT).

## DISCLOSURE

The authors declare no conflict of interest.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**Figure S1** | A dynamic electronic blood glucose monitoring dashboard for hospitalized patients.

**Figure S2** | An electronic glycemic management system for hospitalized patients.

**Table S1** | Length of stay of hospitalized adults with glucose monitoring.

**Table S2** | Use of oral diabetes medications in hospitalized patients.

**Table S3** | The principal diagnosis of the four periods.