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Original Article

The Association of Diabetes and Hyperglycemia on Inpatient Readmissions

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ABSTRACT

Objective: To evaluate the association between inpatient glycemic control and readmission in individuals with diabetes and hyperglycemia (DM/HG).
Methods: Two data sets were analyzed from fiscal years 2011 to 2013: hospital data using the International Classification of Diseases, Ninth Revision (ICD-9) codes for DM/HG and point of care (POC) glucose monitoring. The variables analyzed included gender, age, mean, minimum and maximum glucose, along with 4 measures of glycemic variability (GV), standard deviation, coefficient of variation, mean amplitude of glucose excursions, and average daily risk range.
Results: Of 66 518 discharges in FY 2011-2013, 28.4% had DM/HG based on ICD-9 codes and 53% received POC monitoring. The overall readmission rate was 13.9%, although the rates for individuals with DM/HG were higher at 18.9% and 20.6% using ICD-9 codes and POC data, respectively. The readmitted group had higher mean glucose (169 ± 47 mg/dL vs 158 ± 46 mg/dL, $P < .001$). Individuals with severe hypoglycemia and hyperglycemia had the highest readmission rates. All 4 GV measures were consistent and higher in the readmitted group.
Conclusion: Individuals with DM/HG have higher 30-day readmission rates than those without. Those readmitted had higher mean glucose, more extreme glucose values, and higher GV. To our knowledge, this is the first report of multiple metrics of inpatient glycemic control, including GV, and their associations with readmission.

Introduction

Diabetes is common, affecting approximately 10% of the population; however, diabetes is disproportionately represented in the inpatient setting, present in roughly one third of hospitalized patients.[1,2] Individuals with diabetes are not only more likely to be admitted to the hospital, but when admitted, they have longer lengths of stay and are more likely to be readmitted.[3] Costs associated with diabetes are staggering, and inpatient care contributes to 30% of medical costs for individuals with diabetes.[4] Readmissions significantly contribute to overall healthcare costs; thus, healthcare organizations are seeking new strategies to reduce readmissions in the hopes of reducing costs and improving outcomes.[5]

Reported readmission rates for individuals with diabetes vary, ranging from 14% to 30%, although are consistently higher in individuals without diabetes.[3,6,7] Data from the UK shows that the readmission rates for individuals with diabetes are 59% higher than that of age-matched populations without diabetes.[8] While diabetes is rarely the primary cause of admission, it is a comorbidity that has the potential to affect the length of stay and risk of readmission.[7,9] For example, persons undergoing cardiac surgery, those with an advanced liver disease and heart failure, had higher readmission rates if they had a concurrent diagnosis of diabetes.[10-12] Reasons for readmissions are not well understood; possible contributors

Abbreviations: ADRR, average daily risk range; CV, coefficient of variation; DM/HG, diabetes or hyperglycemia group; FY, fiscal years; GV, glycemic variability; HbA1c, hemoglobin A1c; ICD-9, International Classification of Diseases, Ninth Revision; MAGE, mean amplitude of glycemic excursion; POC, point of care; SD, standard deviation.

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include poor health literacy, suboptimal discharge planning, and social factors.[7,13]

While efforts to reduce readmissions in individuals with diabetes have been developed, little is known about inpatient glycemic control and readmission.[8] Dungan et al showed both hemoglobin A1c (HbA1c) and time-weighted mean glucose were associated with readmission in patients with heart failure; however, glycemic variability (GV, measured by the glucose lability index) was not associated with readmission.[14] Evans et al found that higher admission glucose was associated with longer lengths of stay, readmissions, and mortality.[15] Moreover, the DICAMI study found an association between hyperglycemia on index admission and readmission, although others have not replicated this.[16-18] The discrepant data may be related to the study design, including differences in methodology utilized for measuring glycemic control.

A challenge in studying the associations between glucose control and readmissions is the lack of standardized glucometrics for inpatient glycemic control. Various measures have been reported in the literature; the Society of Hospital Medicine currently recommended various control measures: mean glucose, hypoglycemia and hyperglycemia rates, percentage of glucose readings within range, and percentage of patient days during which the mean glucose is within range.[19] In addition to the above metrics, GV has been recognized as another factor potentially contributing to adverse outcomes, conveying risks beyond conventional glucose data. GV is understood as "a propensity of a single patient to develop repeated episodes of excursions of BG over a relatively short period of time that exceeds the amplitude expected in normal physiology".[20] The impact of GV on long term outcomes is a subject of debate and ongoing research, although multiple studies in the inpatient setting have shown links between GV and outcomes, primarily in critical care populations.[21-23] The best way to measure GV has not been determined, although standard deviation (SD), coefficient of variation (CV), mean amplitude of glycemic excursion (MAGE), mean absolute glucose change, low blood glucose index, high blood glucose index, and average daily risk range (ADRR) have all been proposed.[24]

This study aimed to determine the association between the presence of diabetes and hyperglycemia, inpatient glycemic control, and readmission using multiple ways to evaluate GV, owing to the lack of an accepted standard of measurement. To study this, we compared the readmission rates of hospitalized patients with diabetes or inpatient hyperglycemia (DM/HG) to those without DM/HG. We hypothesized that patients with DM/HG were more likely to be readmitted within 30 days than those without DM/HG. In addition, within the DM/HG population, we suspected that those with worse inpatient glycemic control, assessed by measures of glucometrics, including rates of hypoglycemia, mean glucose, and measures of GV, would have increased readmission rates.

Research Design and Methods

This is a retrospective observational study comparing the readmission rates of patients with DM/HG to the overall readmission rates of individuals admitted to our institution during the fiscal years (FY) 2011-2013 (July 2010-June 2013). This cohort included individuals cared for by the inpatient diabetes team as well as individuals with glucose levels managed by their primary admitting team. Readmission was defined as a hospital discharge with a subsequent inpatient readmission within 30 days. A single data set was analyzed using 2 patient selection criteria for DM/HG: 1) International Classification of Diseases, Ninth Revision (ICD-9) codes for diabetes (249.xx, 250.xx) or hyperglycemia (790.2x) and 2) receipt of 3 or more bedside point of care (POC) glucose tests during a hospitalization, regardless of the ICD-9 code.

ICD-9 Data

Inclusion criterion for the ICD-9 data included all inpatient adults (≥ 18 years old) with ICD-9 codes for diabetes or hyperglycemia during FY 2011-2013. Patients with scheduled readmissions unrelated to glycemic control were excluded (psychiatric transfers, scheduled chemotherapy or radiation admissions, bone marrow transplant admissions, and vaginal or cesarean deliveries).

POC Data

A separate analysis was performed for all inpatient adults (≥ 18 years old) during FY 2011-2013 who received at least 3 bedside POC glucose tests during their hospitalization. This was performed with the intent to capture additional patients with diabetes or hyperglycemia not identified by ICD-9 codes. Values were electronically recorded. Our hospital policy follows the Endocrine Society guidelines recommending that all patients without a history of diabetes, but with a random blood glucose value of 140 mg/dL be monitored with bedside POC glucose testing for at least 24 to 48 hours.[2] Values <11 mg/dL were excluded from the analysis. Values >500 mg/dL were recorded as 500 mg/dL.

Additional variables analyzed in this group that were not captured in the ICD-9 group included age, gender, mean glucose, minimum and maximum glucose as well as measures of GV described below.

Mean glucose was obtained by averaging all POC values during the entire stay. For the purpose of data analysis, we divided patients into 3 categories based on the mean glucose: <140 mg/dL, 140 to 180 mg/dL, and >180 mg/dL. Minimum glucose was defined as the lowest glucose value obtained during the patient hospital stay, while maximum glucose was defined as the highest glucose value obtained during the hospital stay. Minimum and maximum glucose values were divided into 6 categories: <41 mg/dL, 41 to 70 mg/dL, 71 to 140 mg/dL, 141 to 180 mg/dL, 181 to 300 mg/dL, and >300 mg/dL. Patients were analyzed according to 4 different age categories: <41, 41 to 65, 66 to 80, and >80 years old.

GV was evaluated using metrics recommended for patients receiving regular POC monitoring: SD, CV, MAGE, and ADRR. MAGE was defined as the mean of the absolute value of any change in blood glucose from consecutive measurements that exceed one SD of the entire set of blood glucose values. ADRR was defined as the sum of the peak risks of hypoglycemia and hyperglycemia for the day.

Metrics were calculated as follows:

SD: $\sqrt{\frac{\sum(x_i-\bar{x})^2}{n-1}}$

MAGE: $\sum\frac{\lambda}{n}$ where $\lambda > SD$

ADRR: $\frac{1}{M}\sum_{j=1}^{M}(LR^j + HR^j)$, where $LR^j = max(r_l(x_1), \ldots, r_l(x_k))$ and $HR^j = min(r_h(x_1), \ldots, r_h(x_k))$ with $r_l(x_i) = 22.77 \times f(x_i)^2$ if $f(x_i) < 0$ and 0 otherwise, $r_h(x_i) = 22.77 \times f(x_i)^2$ if $f(x_i) > 0$ and 0 otherwise, where $f(x_i) = (ln(x_i)^{1.084} - 5.381)$

Mean glucose or mean BG: $\bar{x} = \frac{1}{n}\sum_{i}^{n} x_i$, n = number of observations, λ = absolute value of each BG increase or decrease.[24]

Descriptive statistics (95% confidence interval, mean, max, min, median, standard error, and range) for each variable were obtained. *T* test was used to compare the glucose and age between the readmission and nonreadmission groups in the POC data. Readmission rates were compared between groups using a chi-square test (or chi-square linear test for trend where appropriate). Statistical significance was defined as $P < .05$. Spearman correlation was

Table 1
Total Number of Patients Admitted During FY 2011-2013

FY	Total no. admitted	% with Diagnosis of DM/HG, (*n*%)	
		ICD-9 codes	POC data
2011	23 225	6224 (26.8%)	12 193 (52.5%)
2012	21 962	6457 (29.4%)	11 618 (52.9%)
2013	21 331	6229 (29.2%)	11 455 (53.7%)

Total number of patients admitted to our institution during FY 2011-2013, showing the percentage of patients with an ICD-9 diagnosis for diabetes or hyperglycemia as well as the percentage of patients that received POC monitoring during their inpatient stay.
Abbreviations: DM/HG = diabetes or hyperglycemia group; FY = fiscal years; ICD-9 = International Classification of Diseases, Ninth Revision; POC = point of care.

used to examine associations between GV measures. All analyses were performed on SAS 9.4 (SAS Institute Inc). This study was approved by the authors' Institutional Regulatory Board.

Results

Prevalence of Diabetes and Hyperglycemia

Of those admitted to our institution during FY 2011-2013, 18 910 individuals out of 66 518 (28.4%) had a diagnosis of diabetes or hyperglycemia using ICD-9 codes. However, 53% of admitted patients met criteria for diabetes/hyperglycemia based on 3 or more POC values (Table 1).

Of those who received POC testing, only 51.1%, 54.4%, and 55.5% had a known diagnosis of diabetes based on the ICD-9 diagnosis of DM/HG in FY 2011, 2012, and 2013, respectively (data not shown).

Readmission Rates

Readmission rates for our overall hospital population as well as those with DM/HG are presented in Table 2. The overall hospital readmission rates were significantly lower than the readmission rates for patients with DM/HG using either the ICD-9 or POC group (all *P* values < .0001). Furthermore, FY 2013 had significantly lower readmission rates for patients with DM/HG in both the ICD-9 and POC groups than FY 2011 ($P = .0004$ and .0007, respectively). The POC group (20.6%) had significantly higher readmission rates than the ICD-9 group (18.9%) ($P < .0001$) over the entire 3-year period. The prevalence of diabetes in the initial admitted group was 28.4%, while that in the readmitted group was 38.7%.

Baseline Data (POC Data Set)

Women had higher readmission rates than men (19.2% vs 17.8%, $P = .005$). Age was similar in the readmitted and nonreadmitted groups (58.5 vs 59 years old, $P = .05$). There was a significant association between readmission and age in women ($P = .0003$), although this difference was not observed in men ($P = .16$).

The readmission rates were highest in those aged 41 to 65 years, at 20.2% (2353/11 680), and lowest in those aged >80 years, at 15.1% (343/2274) (Fig. 1 *A*); 16.4% of individuals (575/3513) <41 years and 17.9% of those aged 66 to 80 years (1176/6572) were readmitted. All comparisons between age groups (except <41 vs 66-80 years) were statistically significant ($P < .05$).

Glucometrics

The readmitted group had a significantly higher mean glucose than the nonreadmitted group (169 ± 47.4 mg/dL vs 157.5 ± 45.5 mg/dL, $P < .001$). Dividing the mean glucose into categories, we found a positive association between glucose and readmission rates (Fig. 1 *B*).

Patients with severe hypoglycemia and hyperglycemia had the highest readmission rates (Fig. 1 *C*, *D*). Figure 1C shows that those with lower minimum glucose values (defined by the lowest glucose recorded during the stay) had increased readmission rates. The <41 mg/dL and 41 to 70 mg/dL categories had the highest readmission rates at 24.7% and 24.4%, respectively ($P = .82$) than those that never experienced hypoglycemia. Patients with extreme hyperglycemia, measured by maximum glucose >300 mg/dL, had readmission rates of 25.3% (Fig. 1 *D*). Those with sustained hyperglycemia, never had a POC value <180 mg/dL, had readmission rates of 20.2%.

GV Metrics and Readmission

High GV was associated with increased readmission rates using all 4 metrics (Table 3). Spearman correlations demonstrated high correlations (0.71-0.95) among the 4 measures of GV; therefore, no measure of GV was identified as superior to the other.

Discussion

Our data confirms that individuals admitted to our institution with DM/HG had higher rates of readmission than those without DM/HG, consistent with previous reports.[7,9] Our data sheds new light on the relationship between inpatient glycemic control and readmission. While several studies have cited HbA1c or admission glucose as risk factors for readmission; to our knowledge, this is the first report of multiple metrics of glycemic control, including GV, and their associations with readmission.

Identifying Diabetes and Hyperglycemia in the Inpatient Setting

Characterizing readmissions in patients with DM/HG depends on the ability to accurately identify DM/HG at the index admission. History alone (from ICD codes) is insufficient to adequately capture individuals with diabetes. Guidelines recommend combining history, inpatient glucose data, and HbA1c to make a diagnosis.[2,25] This is challenging to implement in the real world due to constraints of electronic medical records and inaccuracies related to data capture. While ICD codes are relatively easy to capture, the use of these codes depends on accurate coding by providers, and there is evidence to suggest that these codes poorly reflect diagnoses.[26] Successful transitions of care for diabetes hinge on it first being identified. Our POC data identified almost twice as many individuals with DM/HG compared with the use of ICD codes alone, highlighting that much of this population is not being recognized. This is a lost opportunity for interventions around the time of discharge in a population at a high risk for readmission.

Of all patients admitted from FY 2011 to 2013, 53% received POC monitoring (Table 1), indicating that approximately one half of all inpatients at our institution had hyperglycemia at some point during their stay, consistent with previous reports.[2] Interestingly, only 54% of our patients who received POC monitoring had an ICD-9 diagnosis of diabetes or hyperglycemia in their discharge summary. This difference is clinically meaningful, as the POC data included 16 335 more individuals than the ICD-9 data. This emphasizes the significance of monitoring glucose in not only patients with a preexisting diagnosis of diabetes, but also those who are noted to have hyperglycemia during their stay.

Readmission Rates

The POC data set had significantly higher readmission rates than the ICD-9 data set (20.6% vs 18.9%, $P < .0001$), likely because we

Table 2
Readmission Rates for Inpatients During FY 2011-2013

FY	ICD-9 data		POC data
	Overall hospital readmission rate, n (%)	DM/HG readmission rate, n (%)	DM/HG readmission rate, n (%)
2011	3399 (14.6%)	1251 (20.1%)	2662 (21.8%)
2012	3092 (14.1%)	1225 (19.0%)	2304 (19.9%)
2013	2741 (12.8%)	1095 (17.6%)	2293 (20.0%)

Readmission rates for inpatients during FY 2011-2013 at our institution using 3 different data sets.
Abbreviations: FY = fiscal years; DM/HG = diabetes or hyperglycemia group; ICD-9 = International Classification of Diseases, Ninth Revision; POC = point of care

were able to capture more patients with hyperglycemia without a prior diabetes diagnosis. Indeed, several studies have found that hyperglycemia in patients without a prior diagnosis of diabetes carries higher risk of adverse outcomes.[27-29] The readmission rates at our institution improved during the 3-year study. One potential explanation may be that during this time, we created the role of diabetes resource nurses and inpatient nurse case managers. These case managers helped coordinate care prior to discharge for individuals with DM/HG during their hospital stay, and we consider that these changes played a role in improving the readmission rates over the 3-year study.[30]

Interestingly, we noted lower readmission rates in those >80 years old, and the reasons for this are unclear. Unfortunately, we do not have data on mortality rates after discharge or discharges to hospice, which could impact the reported readmission rates. On the other hand, this age group may be more likely to be discharged to a facility, and this supervised environment may have led to fewer readmissions.

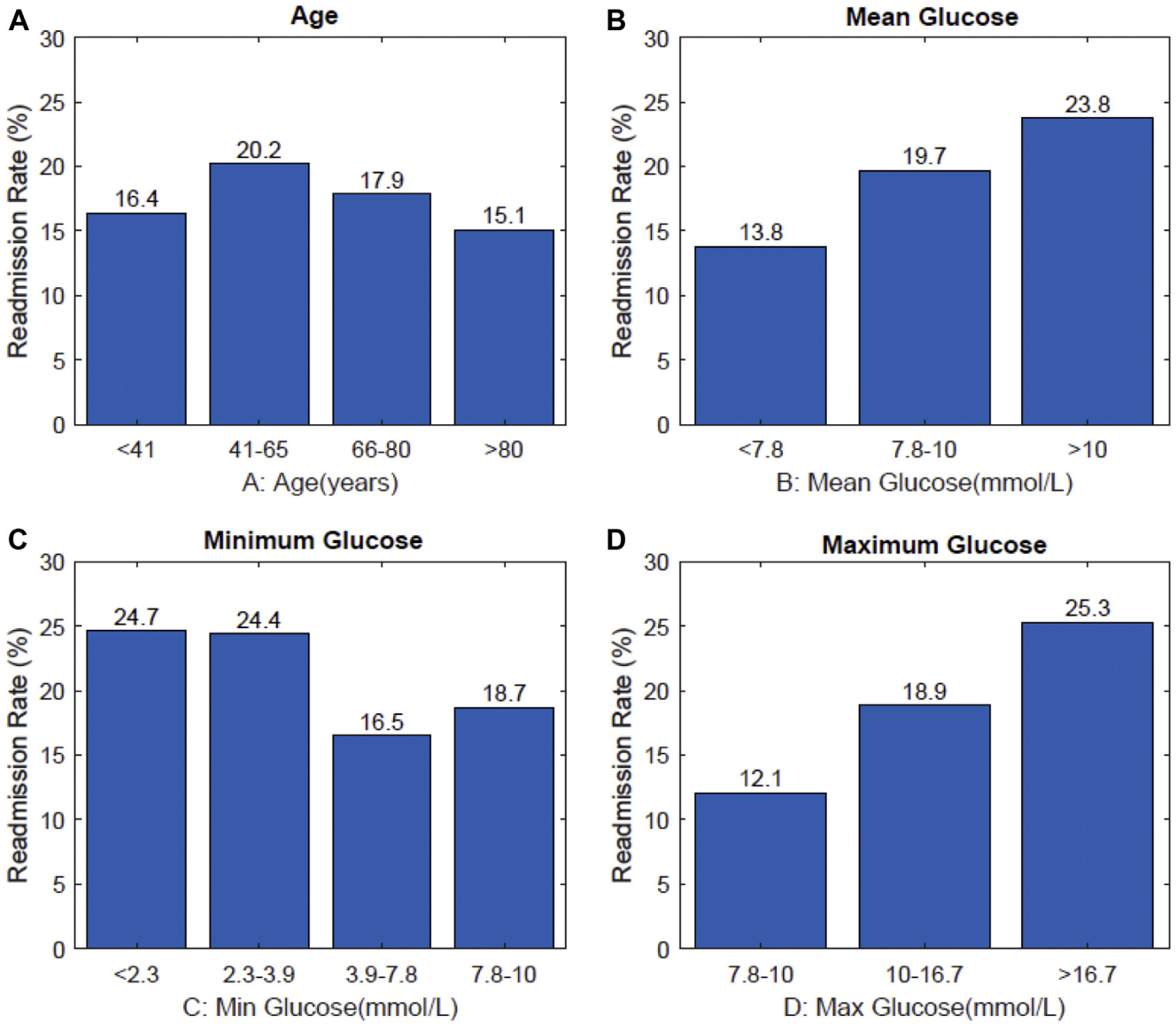

Fig. 1. Readmission rates for categories of *A*, age; *B*, mean glucose during inpatient stay; *C*, minimum glucose during inpatient stay; and *D*, maximum glucose during inpatient stay.

Table 3
Metrics of Glycemic Variability for Both Groups

GV metric	Readmitted group	Nonreadmitted group	*P* value
SD (mg/dL)	52	42.3	< .0001
CV (%)	30.3	26.0	.04
MAGE (mg/dL)	91.4	74	< .0001
ADRR	19.0	14.4	< .0001

Metrics of glycemic variability for both the readmitted and nonreadmitted groups with associated *P* values, using POC data.
Abbreviations: ADRR = average daily risk range; CV = coefficient of variation; GV = glycemic variability; MAGE = mean amplitude of glycemic excursion; POC = point of care; SD = standard deviation.

The lowest readmission rates, at 16%, were seen in individuals with a mean glucose <140 mg/dL, and the rates increased in categories of higher mean glucose, reaching 27% when the mean glucose >180 mg/dL. Our data supports current American Diabetes Associaton guidelines, allowing for more stringent control, if this can be accomplished without a significant hypoglycemia.[25]

Furthermore, we evaluated hypoglycemia and hyperglycemia, as represented by the minimum and maximum glucose recorded during the stay, to assess the role of extreme glucose values on readmission. Hypoglycemia has been identified as an adverse prognostic sign; however, its association with readmission has not been fully elucidated. The highest readmission rates, at approximately 25%, were seen in individuals experiencing any episodes of hypoglycemia or severe hyperglycemia (Fig. 1). We did not observe a significant difference in the readmission rates in patients with glucose values <40 mg/dL compared with those with glucose values 40 to 70 mg/dL. This may be due to the small number of patients in these groups or the reflection of a detrimental effect of any hypoglycemia. Our study is the first to show increased readmission rates in patients with both hypoglycemia and hyperglycemia. These findings of increased readmission rates in patients with extreme glucose values, along with well-recognized limitations of mean glucose as a single metric, prompted the analysis of GV data.

Recently, awareness has been raised on the role that GV plays in outcomes in the inpatient setting.[21-23,31,32] While not for certain, the underlying cause is theorized to be glycemic fluctuations leading to endothelial dysfunction and oxidative stress, which contributes to end-organ dysfunction.[33] Most available literature focuses on critical care populations and the association between a high GV and an increased mortality, but there is currently no consensus on which GV metric is most appropriate. MAGE is a commonly used indicator of glucose variability within 1 day; however, it is inherently biased toward hyperglycemia. Su et al showed that MAGE >70.3 mg/dL predicted 1 year major adverse cardiac event rates better than admission glucose and HbA1c in patients with acute myocardial infarction.[34] Alternatively, ADRR represents an average of maximum daily amplitudes of glucose excursions across several days and is designed to be equally sensitive to hypoglycemia and hyperglycemia.[35] Farhy et al showed an association between higher ADRR values and mortality in an ICU/burn unit.[36] In that study, ADRR was stratified into 4 quartiles based on risk: low (<6.36), medium to low (6.36-10.31), medium to high (10.31-16.13), and high risk (>16.13). The mortality rates progressively increased in each quartile. Applying this to our data, ADRR was 19 in the readmitted group, which would fall into the highest risk quartile.

Little data is available linking GV to readmissions. Our data consistently showed a higher GV in the readmitted group for the 4 different GV metrics (SD, CV, ADRR, and MAGE) and also showed correlation between all metrics. While one metric did not emerge superior, the authors' opinion is that SD and CV may suffice, as these are easily calculated, easily comprehended, and followed in the outpatient setting routinely as part of the ambulatory glucose profile. As CGM becomes more utilized in the inpatient setting, we believe that GV data reporting will become more common. The use of inpatient CGM also allows for intervention studies looking at whether efforts to improve GV are associated with improved outcomes.

It is unclear whether GV directly contributes to readmissions or whether a higher GV indicates a higher severity of illness, and it is the severity of illness leading to the readmission. Lipska et al found that patients with more comorbidities and greater acuity of illness at presentation had a higher GV, suggesting that GV may simply be a marker for higher acuity patients.[32] Similarly, a study looking at over 4000 critical care patients showed that a higher GV was associated with an increased mortality in individuals without diabetes, although mortality among individuals with diabetes was not affected by GV.[37] Given our findings, intervention studies are needed to see whether efforts to improve inpatient GV can affect readmissions. Additionally, having a consensus in terms of which GV metric to use would allow better comparison among studies and help standardize results.

Strengths/Limitations

This is one of few studies evaluating the association of inpatient glucose control, including markers of GV, with readmission. We also reported multiple commonly used GV metrics and found that all metrics correlated with one another. Another strength of the study is that we did not solely focus on critical care patients, but rather included all admitted patients.

In addition, we were able to evaluate 2 different strategies to identify individuals with diabetes and hyperglycemia and collect data on readmissions from both data sets. Our POC data set captured over 16 000 more patients and identified both patients with diabetes and those with hyperglycemia without preexisting diabetes.

One limitation in our POC data analysis is our inability to separate patients with hyperglycemia without diabetes from those with diabetes. Moreover, our data set did not allow us to separately analyze patients in ICU and non-ICU settings. Additionally, due to the nature of our data set, we could not assess for other potential factors contributing to the readmission, such as comorbidities, severity of illness, ethnicity, HbA1c, reason for admission, problem list, medications (including steroids), and length of hospital stay. We were also unable to capture the number of POC tests per patient and acknowledge that a person's inpatient treatment regimen (subcutaneous vs intravenous insulin) would affect the number of POC values during each stay. A small number of individuals may have been admitted for hypoglycemia evaluations during this time, which require regular POC values not related to diabetes or hyperglycemia. While our data set was unable to extract and exclude these instances, we believe the effect on our findings was small, given the large size of our data set.

Additionally, we were unable to separate patients based on the service managing blood glucose (ie, inpatient diabetes team vs primary admitted team). A 2018 study showed that inpatient diabetes managed by a specialty diabetes service reduced readmissions and cost despite no difference in GV and a mean glucose >190 mg/dL in each group.[38] While our study evaluated GV over the course of the entire stay, future studies should consider evaluating changes in GV at the beginning and end of an admission, to assess the impact of interventions by a specialist team. Though we were unable to evaluate the impact of inpatient diabetes education and diabetes nurse specialists in this study, we have shown in a

previous work that individuals evaluated by an inpatient diabetes case manager had lower readmission rates.[30]

Another limitation, as is the case in much of readmission literatures, is that we were only able to use our own hospital readmission data, which does not include patients readmitted to another hospital system. Readmission to a different hospital is estimated to be anywhere from 20% to 40% of readmissions.[39] Currently, only third-party payer systems and government programs are able to track patients across multiple health care systems. Also, like most others reporting on readmissions, we used 30-day windows, whereas a larger window, such as 90 days, may be more relevant.[40]

In conclusion, we have shown that individuals with DM/HG are at a higher risk of readmission than those without DM/HG. We have shown an association between inpatient glycemic control and readmission rates, demonstrating that both hypoglycemia and severe hyperglycemia were associated with higher readmission rates. Lastly, we have shown that the increased GV, across multiple measurements, is associated with the increased readmission rates. The results of our study underscore the significance of adequate glucose control and minimization of hypoglycemia during inpatient hospitalizations.

Disclosure

The authors have no multiplicity of interest to disclose.

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Author Contributions

L.E. contributed to study design, data interpretation, and wrote the manuscript. J. L. performed the data analysis. W.G. contributed to initial study design, data interpretation, and reviewed/edited the manuscript. A.D. contributed to study design, data interpretation, and wrote the manuscript.

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