Rising Readmission Rates After Diabetic Ketoacidosis Hospitalization Among Adults With Type 1 Diabetes Throughout a Decade in the United States

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Research on longitudinal trends in readmission rates after diabetic ketoacidosis (DKA) is lacking. This retrospective study was aimed at identifying trends in readmissions after hospitalization for DKA, as well as trends in outcomes after readmission, over time among adults with type 1 diabetes in the United States. Findings indicate that the DKA readmission rate increased from 53 to 73 events per 100,000 between 2010 to 2018, and low-income and uninsured patients had higher odds of readmission. There was no significant change in mortality after readmission over time. Improved access to care and affordable management options may play a crucial role in preventing readmissions.

Diabetic ketoacidosis (DKA) is one of the most serious complications of diabetes, especially in patients with type 1 diabetes. It is characterized by metabolic acidosis, elevated serum glucose, and elevated serum ketones (1). In 15–20% of adults and 30–40% of children, DKA is the initial presentation of diabetes. Other common causes of hospitalization for DKA include infection and nonadherence to medications (2). Data from the Diabetes Surveillance Systems of the Centers for Disease Control and Prevention showed that hospitalizations for DKA increased by an annual average of 6.3% between 2009 and 2014, with in-hospital mortality decreasing from 1.1 to 0.4% during that period (3). A recent study found one in five patients with type 1 diabetes who are hospitalized with DKA will be readmitted within 30 days, and more than half of them will have DKA as a principal readmission diagnosis (4).

The pathophysiology of DKA is well characterized. It is often driven by insulin deficiency with or without insulin resistance and excess glucagon. Other hormones such as catecholamines and cortisol, which counter the actions of insulin, can also contribute to the development of DKA (5).

Although it is known that hospitalizations for DKA increased between 2009 and 2014 after a period of decline, there is a lack of published information about the period after 2014. There is also a lack of research on longitudinal trends in readmission rates for DKA. We sought to outline the trend in readmissions after hospitalization for DKA, as well as trends in outcomes after readmission, over time. We sought to provide epidemiological insight into the performance of U.S. hospitals regarding DKA readmission rates and provide objective metrics to assess health care system performance in the management of type 1 diabetes over the past decade.

Research Design and Methods

Design and Data Source

This was a retrospective trends study involving hospitalizations for DKA among U.S. adults with type 1 diabetes. We abstracted data from the Nationwide Readmissions Database (NRD) for 2010, 2012, 2014, 2016, and 2018. The NRD is the largest publicly available all-payer inpatient health care readmission database in the United States, drawn from the Agency for Healthcare Research and Quality Healthcare Cost and Utilization Project (HCUP) state inpatient databases (6).

The NRD contains discharge data by calendar year from geographically dispersed states. It contains both patient- and hospital-level information. Hospitals are stratified according to ownership control, number of beds, teaching status, and metropolitan/nonmetropolitan location. The

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NRD allows for weighted analysis to obtain 100% of U.S. admissions within a given year. In the NRD, diagnoses are divided into two separate categories: principal diagnosis and secondary diagnoses. The principal diagnosis is the *International Classification of Diseases* (ICD) code attributed as the reason for a hospitalization. Secondary diagnoses included any ICD coded discharge diagnoses other than the principal diagnosis.

We used cross-sectional survey data from the National Center for Health Statistics National Health Interview Survey (NHIS) for the sample years to estimate the number of adults with diagnosed diabetes in the United States (7). We used these estimates as the denominator for readmission rate calculation. The NHIS is a nationally representative in-person household survey that relies on self-reported behaviors and medical conditions.

Study Population and Variables

The study involved hospitalizations from each studied year of the NRD with DKA as the reason for the index admission in adults with type 1 diabetes. We queried the database using ICD codes for DKA in type 1 diabetes (25011, 25013, and E101) as the principal/primary diagnosis. Hospitalizations of individuals who were <18 years of age, admissions occurring in December of each studied year, and elective hospitalizations were excluded. December admissions were excluded when searching for index admissions because these hospitalizations would lack data for at least 30 days after discharge within the same calendar year to determine whether there was a readmission according to the study design.

The NRD includes variables on patient demographics, including age, sex, median household income (income quartiles identified patients as 1 = low income, 2 = middle income, 3 = upper-middle income, and 4 = high income), and primary payer. It also contains hospital-specific variables, including size (based on number of beds), teaching status, and location. Using unique hospitalization identifiers, index hospitalizations were identified, and one subsequent hospitalization within 30 days was tagged as a readmission. Elective and traumatic admissions were excluded from readmissions. Comorbidity burden was assessed using Sundararajan's adaptation of the modified Deyo Charlson comorbidity index (CCI) (8).

Outcome Measures

Biodemographic and hospital trends of the studied populations over time were highlighted. We reported the crude number of 30-day readmissions in patients previously admitted with DKA. We calculated the 30-day all-cause readmission rate and the DKA-specific readmission rate during each calendar year. The event rate of DKA readmission was obtained by dividing the number of readmissions by the population of adults with diabetes for each sampled calendar year, obtained from the NHIS as used in a similar study (9). Trends in inpatient mortality rate, mean hospital length of stay (LOS), and mean total hospital cost (THC) for readmissions were calculated using multivariate logistic trend analysis. THC was obtained using the HCUP cost-to-charge ratio files and adjusted for inflation using the Medical Expenditure Panel Survey index for hospital care, with 2018 as the reference point (10,11).

Statistical Analysis

Data were analyzed using Stata, v. 16, statistical software (StataCorp, College Station, TX). We analyzed and reported the weighted sample following HCUP regulations for using the NRD database. The event rate of 30-day readmission was calculated following HCUP methodology for disease incidence and prevalence (12). We used multivariate regression analysis to calculate risk-adjusted odds of trend in all-cause 30-day readmissions, DKA-specific readmissions, mortality, LOS, and THC after adjustment for age, sex, grouped CCI, insurance type, median household income, hospital location, and size. All *P* values were two-sided, with 0.05 set as the threshold for statistical significance.

Ethical Considerations

The NRD database lacks patient identifiers. In keeping with other HCUP databases, the NRD database does not require Cook County Health Institutional Review Board approval for analysis.

Data Availability

The NRD is a large, publicly available all-payer inpatient care database in the United States, containing data on >18 million hospital stays per year. Its large sample size provides sufficient data for analysis across hospital types and the study of readmissions for relatively uncommon disorders and procedures.

Results

Sociodemographic and Hospital Characteristics of Readmissions After Index DKA Hospitalization

Table 1 details the characteristics of readmissions after DKA by studied year. There was an increase in the

TABLE 1 Yearly Biodemographic and Hospital Characteristic Trends in 30-Day Readmissions After Index DKA Admission

Variable	Year				
	2010	2012	2014	2016	2018
Readmissions, *n*	11,207	13,844	15,670	17,157	18,296
Readmission event rate*	53	65	72	74	73
Age, years, mean ± SE	35.7 ± 0.7	35.6 ± 0.5	36.3 ± 0.5	34.8 ± 0.4	35.3 ± 0.4
Female sex	55.0	54.1	54.8	54.8	52.8
CCI					
0	1.9	2.6	2.1	0.5	0.3
1	47.1	45.7	44.7	41.4	38.4
2	26.9	27.8	28.4	29.0	31.9
≥3	24.1	23.9	24.8	29.1	29.4
Insurance type					
Medicare	26.1	26.1	26.8	24.0	24.4
Medicaid	39.5	37.7	42.4	45.2	45.3
Private	17.5	17.1	18.2	19.6	17.8
Uninsured	16.9	19.1	12.6	11.2	12.5
Household income quartile					
1	40.3	42.8	41.4	40.5	40.3
2	27.6	25.1	26.5	28.3	29.9
3	21.2	20.6	21.0	21.3	20.2
4	10.9	11.5	11.1	9.9	9.6
Hospital characteristics					
Hospital size†					
Small	13.2	12.8	16.9	16.6	18.1
Medium	24.5	26.1	28.8	29.5	27.8
Large	62.3	61.1	54.3	53.9	54.1
Teaching status					
Metropolitan, nonteaching	43.4	40.3	30.2	28.0	22.2
Metropolitan, teaching	41.4	45.2	56.2	60.7	66.2
Nonmetropolitan	15.2	14.5	13.6	11.3	12.6

Data are % unless otherwise noted. *Per 100,000 patients with diabetes. †Based on number of beds.

number of 30-day readmissions after an index DKA hospitalization from 11,207 in 2010 to 18,296 in 2018 (P <0.001 for trend). The event rate for 30-day readmissions after DKA hospitalization rose from 53 to 72 per 100,000 adults with diabetes from 2010 to 2014; the event rate between 2014 and 2018 was about the same. Although a higher proportion of females were readmitted, there was a decreasing trend in female readmission (P <0.001 for trend). Patients readmitted for DKA were noted to have an increasing comorbidity burden over time. A higher proportion of these patients were in the low-income quartile. There was also an increasing trend in hospitalizations in small (based on number of beds) and metropolitan teaching hospitals over the study duration.

Trends in DKA-Specific Readmission Outcomes

From 2010 to 2018, there was an increasing rate of risk-adjusted 30-day all-cause readmission (from 16.0% in 2010 to 19.4% in 2018, P <0.001 for trend), an increasing risk-adjusted 30-day DKA-specific readmission rate (from 8.1% in 2010 to 11.3% in 2018, P <0.001 for trend), and an increasing proportion of DKA readmissions (Figure 1). Compared with patients in the low-income quartile, patients in the high-income quartile had 22.3% lower odds of being readmitted. Females had higher adjusted odds for readmission compared with males. There was a trend toward decreased LOS. However, there was no significant difference in readmission mortality over time among DKA hospitalizations (Table 2).

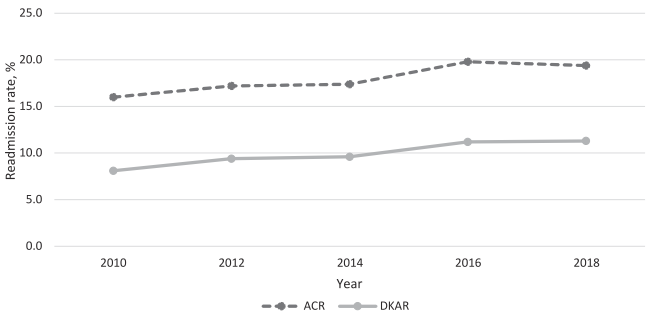

FIGURE 1 Trends in 30-day readmissions after an index DKA admission. ACR, all-cause readmission; DKAR, DKA-specific readmission.

Cost Burden of Readmissions After DKA

Over the study period, the total number of days of hospitalization attributable to DKA readmissions increased by 61.7%, from 44,405 in 2010 to 71,800 in 2018, with the total attributable hospital cost rising by 77.9% to >$166 million by 2018.

Discussion

Sociodemographic Influence and Trends in Readmission After Index DKA Hospitalization

Our study demonstrated that there was a steady increase in 30-day all-cause and DKA-specific readmissions from 2010 to 2018. This increase was 3.4% for all-cause readmissions and 3.2% for DKA-specific readmissions. These trends have been a continuation of increasing readmissions for DKA, as found in a study looking at readmissions rates between 2000 and 2014 (3). These two studies indicate that there has been little progress in reducing 30-day all-cause and DKA-specific readmissions in the last decade.

The cause of this lack of progress is likely multifactorial. Our study points toward a few influential characteristics of patients who are more likely to be readmitted. For example, we found an increase in the proportion of patients readmitted after hospitalization for DKA who had Medicare as their primary insurance. This finding is significant because a previous study demonstrated that both Medicare and Medicaid patients had a 3.3-fold increase in risk for four or more readmissions for DKA in a calendar year compared with patients with private insurance. This same study showed that patients in the first and second income quartiles had a 46% and 34% higher chance of having four or more readmissions for DKA, respectively, compared with those in the highest income quartile (13). Our data showed a higher proportion of readmissions in the lowest income quartile compared with the highest quartile, with no significant change in the past decade. Low-income patients are much more likely to be readmitted after hospitalization for DKA, indicating that access to care and affordable management options may play a crucial role in preventing readmissions. One study looking at the causes of readmissions for an inner-city population found that the most common cause was the discontinuation of insulin; patients discontinued insulin for varied reasons, including rationing to stretch their insulin supply, being away from their insulin supply, prohibitive insulin costs, and feeling too sick to take their insulin (14). Other studies have indicated that access to care and the cost of medications may be a significant and addressable cause of DKA readmissions (4,13–16). Dramatic increases in out-of-pocket costs of insulin has affected a significant number of patients with type 1 diabetes, with one in four reporting cost-associated underuse of their insulin (17).

TABLE 2 Yearly Trends in Rates and Outcomes of 30-Day Readmissions After Index DKA Admission

Outcome	Year					*P*
	2010	2012	2014	2016	2018	
All-cause readmission rate, %	16.0	17.2	17.4	19.8	19.4	<0.001*
DKA-specific readmission rate, %	8.1	9.4	9.6	11.2	11.3	<0.001*
Readmissions for DKA, %	50.8	54.5	55.2	56.7	58.4	<0.001*
Inpatient mortality rate, %	0.60	0.60	0.66	0.45	0.69	0.774
Mean LOS, days	4.0	3.9	3.9	3.9	3.9	0.044*
Mean THC, $	8486	8622	8349	8780	9079	0.698

P values are for trend. *Statistically significant.

We also discovered a decreasing trend in readmission for DKA among females. This finding is consistent with other studies showing the female sex is an independent risk factor for 30-day all-cause readmissions (4,16). Although the proportion of females readmitted with DKA is trending downward, the difference is surprising given that males are ∼1.8 times more likely to be diagnosed with type 1 diabetes (18,19). We hypothesize that females with type 1 diabetes are more likely than their male counterparts to seek out medical care. A study looking at readmission rates after a myocardial infarction also found that females were more likely than males to be readmitted (20).

CCI

The CCI can be used to predict 1- and 10-year mortality based on 17 comorbidities, including malignancy, renal disease, and myocardial infarction. It was created based on data collected from 600 patients through a hospital chart review (21). However, it has since been validated as a measure of comorbidity burden in administrative databases (8). We found that patients with a CCI of 2 had a significantly higher rate of 30-day readmission after DKA hospitalization compared with the baseline (CCI of 1 for diabetes). Higher CCI was associated with higher odds of readmission, with patients with a CCI of 2 having more than double the odds of readmission after adjusting for age, sex, and income.

LOS

We found a statistically significant decrease in hospital LOS throughout the study period. Health care providers have been encouraged to reduce the length of hospitalizations to avoid complications from hospital-acquired infections and decrease health care costs and utilization. The declining mean LOS may reflect improvements in the inpatient management of DKA. Studies have shown that protocol-driven care can result in decreases in ICU morbidity, LOS, mortality, and costs. The implementation of a mandatory protocol for the treatment of DKA in adult patients decreases intensive care time and hospital LOS, as well as time to anion gap closure and ketone clearance without a resulting increase in the rate of hypoglycemia (22–24). However, the comprehensive management of DKA may be affected by this trend in decreased LOS because adequate time is required to provide the patient education and training that could help to reduce readmission rates (24).

Limitations

Data from the NRD is subject to nonrandomization. We could not determine whether an index episode of DKA was the initial presentation of diabetes for some patients. The NRD reports information on hospitalizations rather than on individual patients; thus, patients admitted numerous times would be included more than once in the dataset. The NRD also does not include information about hyperglycemic medications, including insulin, or about patients' use of an insulin pump or continuous glucose monitoring. We could not determine what proportion of patients were managed in the ICU setting, which could affect outcomes. We could not determine the clinical features that led to presentation to the hospital. We also could not determine the precipitating etiology for DKA episodes in the study. The NRD also uses ICD codes to report hospitalizations; therefore, the database has coding-related limitations.

Conclusion

There has been an alarming and persistent increase in all-cause and DKA-specific readmissions after hospitalizations for DKA in the past decade. The goal of this study was to examine trends in readmissions after hospitalization for DKA from 2010 to 2018 to gain insight into possible causes of the increase in these readmissions. We found an increase in the proportion of patients readmitted with DKA after an index DKA hospitalization, as well as an increase in the proportion of readmitted patients who are using Medicare. Low-income patients are much more likely to be readmitted after hospitalization for DKA, indicating that access to care and affordable insulin may play a crucial role in preventing such readmissions. Our study indicates that more work needs to be done to reduce readmissions in this patient population. Finally, we found a decrease in LOS, which may be secondary to the implementation of protocol-driven treatments. Further use of such protocols may help to continue to effectively reduce LOS in patients with DKA.

DUALITY OF INTEREST

No potential conflicts of interest relevant to this article were reported.

AUTHOR CONTRIBUTIONS

H.S. contributed to the conception of the study and the acquisition, analysis, and interpretation of data. L.D. contributed to the design of the study, drafting of the manuscript, and revision of intellectual content. Z.E.-a. and F.W. contributed to the interpretation of data, literature review, and drafting of the manuscript. M.R. and A.K. contributed to the

interpretation of data, literature review, discussion, and revision of intellectual content. All authors critically reviewed the final manuscript, gave approval for publication, and are accountable for all aspects of the study. H.S. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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