A Quality Improvement Initiative to Reduce Hospitalizations for Low-risk Diabetic Ketoacidosis

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BACKGROUND AND OBJECTIVES: Children with established type 1 diabetes (T1D) who present to the emergency department (ED) with mild diabetic ketoacidosis (DKA) are often hospitalized, although outpatient management may be appropriate. Our aim was to reduce hospitalization rates for children with established T1D presenting to our ED with mild DKA who were considered low risk for progression of illness.

METHODS: We conducted a quality improvement initiative between January 1, 2012, and December 31, 2018 among children and young adults ≤21 years of age with established T1D presenting to our tertiary care ED with low-risk DKA. Children transferred to our institution were excluded. DKA severity was classified as low, medium, or high risk on the basis of laboratory and clinical criteria. Our quality improvement initiative consisted of development and implementation of an evidence-based treatment guideline after review by a multidisciplinary team. Our primary outcome was hospitalization rate, and our balancing measure was 3-day ED revisits. Statistical process control methods were used to evaluate outcome changes.

RESULTS: We identified 165 patients presenting with low-risk DKA. The baseline preimplementation hospitalization rate was 74% (95% confidence interval 64%–82%), and after implementation, this decreased to 55% (95% confidence interval 42%–67%) (−19%; P = .011). The postimplementation hospitalization rate revealed special cause variation. One patient in the postimplementation period returned to the ED within 3 days but did not have DKA and was not hospitalized.

CONCLUSIONS: Hospitalization rates for children and young adults presenting to the ED with low-risk DKA can be safely reduced without an increase in ED revisits.

Approximately 208,000 children in the United States have type 1 diabetes (T1D),1 and the incidence is increasing by 1.8% annually.1,2 Up to 30% of children present with diabetic ketoacidosis (DKA) at initial diagnosis of T1D,3,4 and 20% to 47% have at least 1 subsequent readmission for DKA,5,6 resulting in substantial medical expenditure. Recent literature suggests that the mean cost of hospital admission for DKA is ~$7140.5 Much of this cost is attributable to inpatient care, including treatment with intravenous (IV) insulin and admission to an ICU.5,7

Current treatment recommendations allow for variability in the care of children with DKA.8,9 As a result, there

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remains uncertainty regarding optimal treatment strategies, particularly for those presenting with mild DKA, defined as follows: (1) venous pH of 7.2 to 7.3 or a bicarbonate level of 10 to 15 mmol/L; (2) hyperglycemia, with blood sugar levels > 200 mg/dL; and (3) ketonemia or ketonuria. This is supported by recent literature suggesting that resource use and readmission rates for DKA vary significantly across US children’s hospitals. Previous research has suggested that patients with DKA who receive IV insulin, which may be appropriate for children with mild DKA in whom discharge is anticipated, have similar time to recovery of acidosis compared with those treated with IV insulin. More recent studies suggest that patients with DKA who are managed with subcutaneous insulin, which may be appropriate for children with mild DKA in whom discharge is anticipated, have similar time to recovery of acidosis compared with those treated with IV insulin.

Children who present to the emergency department (ED) with mild acidosis, established T1D, knowledge of sick-day management and ability to perform home care, and no social conditions or comorbid illness that would impede discharge may be considered low risk and managed at home with outpatient care.

Preliminary data from our institution revealed that 74% of children with established T1D presenting to our ED with low-risk DKA were hospitalized. We hypothesized that we could safely reduce admission rates in this population. Therefore, our aim for the quality improvement (QI) initiative was to reduce hospitalization rates by 10% for children with established T1D presenting to our ED with low-risk DKA over a 2-year period.

METHODS

Study Design and Setting

We conducted a QI initiative among children and young adults ≤21 years of age with DKA who presented to 2 urban, tertiary care pediatric EDs. The QI initiative was implemented April 1, 2016, and we examined patients from January 1, 2012, to December 31, 2018 (pre- and postimplementation). Both EDs are part of a single pediatric health system, staffed by the same pediatric emergency medicine physicians and subspecialist services, and have a combined 95,000 visits annually. The study was approved by our institutional review board.

Study Population and DKA Risk Categorization

We identified children with DKA via a combination of an electronic medical record (EMR) query and manual chart review. First, we developed an automated monthly query of our EMR database to identify all children with an ED discharge diagnosis for DKA (International Classification of Diseases, Ninth Revision and International Classification of Diseases, 10th Revision codes 250.11 and 250.13 and E10.10 and E10.11, respectively). Second, we performed a manual chart review to confirm the presence of DKA among children with T1D.

DKA was defined as having all of the following: (1) venous pH < 7.3 or a bicarbonate level < 15 mmol/L, (2) urine or serum sample positive for ketones, and (3) a glucose level > 200 mg/dL. Although definitions of DKA severity may vary slightly, classically, DKA severity has been defined solely by laboratory criteria, in which mild is pH < 7.30 or a bicarbonate level < 15 mmol/L, moderate is pH < 7.20 or a bicarbonate level < 15 mmol/L, and severe is pH < 7.10 or a bicarbonate level < 5 mmol/L. However, given that factors other than the degree of acidosis may influence the true severity of DKA, related complications, and, in particular, the decision to hospitalize a child, we further classified children with DKA as follows: low risk (pH > 7.2 or bicarbonate level > 10 mmol/L, established T1D, reliable home cares as determined by the treating provider after discussion with the family or patient, or insulin pump failure with ability to correct), medium risk (pH of 7.1–7.2 or bicarbonate level of 6–10 mmol/L, newly diagnosed T1D, or concern for unreliable home care), or high risk (pH < 7.1 or bicarbonate level ≤ 5 mmol/L, Glasgow Coma Scale ≤ 13 or abnormal neurologic examination result, age ≤ 36 months, glucose level > 1000 mg/dL, blood urea nitrogen level > 30 mg/dL, serum osmolality level > 330 mOsm/kg, or potassium level < 3 mEq/L). We excluded children who were transferred to our institution from an outside ED or hospital and children who did not have DKA.

Interventions

Key Drivers

Through collaboration with key stakeholders, we identified 3 key drivers of care (Fig 1). To address our key drivers, we implemented multiple change strategies, including development of an evidence-based guideline (EBG), EMR order set updates, regular updates to ED physicians and stakeholders, and nursing education.

Guideline Development and Implementation

Our EBG (Supplemental Fig 4) was developed by using a multidisciplinary approach over the course of 6 months by a guideline implementation team that included experts in the management of children with T1D (pediatric emergency medicine physicians, pediatric endocrinologists, nursing supervisors, ED nurses, and pharmacists), a data and cost analysis (health economist and statistician), and a member of our hospital’s family advisory council. Current medical literature and available practice
standards were reviewed extensively and incorporated into our treatment guideline. Our EBG was presented to key stakeholders, including ED physicians, endocrinologists, intensive care physicians, and hospitalists, on multiple occasions. Feedback from stakeholders was used to refine our treatment guideline through an iterative process. Our EBG was implemented in April 2016, which included placement of the guideline on our intranet clinical guideline webpage, a nested link within our ED DKA order set, and printed version manually placed within our 2 EDs to promote accessibility.

**EMR Order Set and Discharge Updates**

Before our QI initiative, multiple order sets specific to diabetes evaluation were available to ED providers. We reviewed all available order sets and refined these to be more specific to presenting concerns. Through collaboration with Information Technology, we created an ED DKA order set, which is consistent with our EBG. Key updates included the following: embedding our EBG within the order set for ease of reference; integration of point-of-care testing to shorten time to laboratory results (ie, blood gas, glucose, and electrolytes); options for normal saline bolus amounts of 10 mL/kg if the patient was ≤36 months or 20 mL/kg if the patient was >36 months, given over 1 hour; standard dosing of 0.1 U/kg for administration of fast-acting subcutaneous insulin; and automated repeat point-of-care glucose checks 1 and 2 hours after insulin administration. Given that we wanted 1 order set for all children with DKA, including those with moderate or severe (medium or high risk) DKA, we updated our order set to include treatment options for these patients. In addition, we updated our ED discharge instructions for sick-day management for children treated with subcutaneous insulin and insulin pumps.

**Nursing and Provider Education**

Several nursing and provider change strategies were used to promote shared awareness of and adherence to our EBG. We conducted 5 nursing education sessions during June 2016 and July 2017 to refine nursing skills and knowledge of T1D management, specifically subcutaneous and IV insulin administration, and IV fluid management. These sessions included case-based education using treatment recommendations from our EBG, hands-on training with trifuse IV kits for fluid and medication compatibility, education on insulin drip management, and education on signs of complications from insulin or IV fluid therapy (ie, hypoglycemia, altered mental status). To further increase the success of our EBG implementation, we held quarterly presentations to ED physicians, during which time interim results were presented and key aspects of the treatment guideline were reinforced. Updates were provided to endocrine physicians on an annual basis.

**Measures**

Our primary outcome was the proportion of children with low-risk DKA who were hospitalized. Our balancing measure was ED return visits within 3 days of the index ED visit. Secondary outcomes were the proportion of children who received rapid or fast-acting subcutaneous insulin in the ED, ED length of stay (LOS), and ED charges.

**Study of the Intervention**

The hospitalization rate was monitored by using statistical process control methods. Specifically, the percentages of hospitalizations were assessed via p-charts.

**Analysis**

Patient characteristics before (January 1, 2012, to March 31, 2016) and after implementation (April 1, 2016, to December 31, 2018) of the QI initiative were compared. Differences in numeric and categorical data were assessed by using the Mann–Whitney U test and \( \chi^2 \) test (or Fisher’s exact test), respectively. Hemoglobin A1C was reported as \( \leq 7.5\% \) or \( >7.5\% \). Because of small sample sizes within each quarter, sequential groups of 9 consecutive patients were used for p-charts. Because of small sample sizes within each sequential group, the normal approximation to the binomial distribution did not apply. Therefore, control limits for p-charts were calculated by using exact binomial percentiles corresponding to 2 and 3 SDs from the mean under a normal distribution (ie, 2.3 and 97.7 percentiles and 0.1 and 99.9 percentiles, respectively). Trial limits were calculated after 11 points, corresponding to the
preimplementation period, and hospitalization rates were compared to this baseline. The centerline was then shifted when special cause variation was seen. Western Electric rules23 were used to indicate an out-of-control process. A cumulative summation chart was used to estimate the number of avoided hospitalizations after implementation with respect to the preintervention hospitalization rate.25 A post hoc logistic regression was performed to account for potential confounders that might impact hospitalization, including age, sex, race, insurance status, hemoglobin A1C at ED presentation, and implementation period. Total ED and hospital charges were reported as medians with interquartile ranges (IQRs) and were adjusted to 2018 dollars by using the Bureau of Labor Statistics Consumer Price Index for hospital and related services. The total adjusted ED charges represent all ED charges, excluding any hospital facility charges from an ED visit. Total adjusted ED charges represent all ED charges, excluding any hospital facility charges from an ED visit. Total adjusted hospital charges, unadjusted analysis (preimplementation: 75% [95% CI 65%–83%]; postimplementation: 54% [95% CI 42%–67%]) (Supplemental Table 4). The hospitalization rate in the postimplementation period revealed special cause variation between sequential groups 3 and 4 (Fig 2).

### RESULTS

We identified 3132 total T1D-related ED encounters, of which 974 involved children with DKA. We excluded 381 and 236 encounters for moderate and severe DKA, respectively. We further excluded 136 encounters in which the child presented with newly diagnosed T1D and 56 encounters resulting from transfers from another hospital. This resulted in a study cohort of 165 children with low-risk DKA (Table 1).

The baseline hospitalization rate in the preimplementation period was 74% (95% confidence interval [CI] 64%–82%), and this decreased to 55% (95% CI 42%–67%) in the postimplementation period (Table 2). Children presenting in the postimplementation period were significantly older than children in the preimplementation period ($P = .013$). An adjusted post hoc logistic regression analysis revealed that hospitalization rates were comparable with those in the unadjusted analysis (postimplementation: 75%[ 95% CI 65%–83%]; preimplementation: 54% [95% CI 42%–67%]) (Supplemental Table 4). The hospitalization rate in the postimplementation period revealed special cause variation between sequential groups 3 and 4 (Fig 2).

### Table 1: Demographics for Children With Established T1D Presenting to the ED With Low-risk DKA

<table>
<thead>
<tr>
<th></th>
<th>Preimplementation</th>
<th>Postimplementation</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>January 1, 2012, to March 31, 2016</td>
<td>April 1, 2018 to December 31, 2018</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(N = 99)</td>
<td>(N = 68)</td>
<td></td>
</tr>
<tr>
<td>Age, y, median (IQR)</td>
<td>12 (9–15)</td>
<td>15 (10–17)</td>
<td>.013</td>
</tr>
<tr>
<td>Male sex, n (%)</td>
<td>37 (37)</td>
<td>30 (48)</td>
<td>.301</td>
</tr>
<tr>
<td>Race and/or ethnicity, n (%)</td>
<td></td>
<td></td>
<td>.124</td>
</tr>
<tr>
<td>White</td>
<td>34 (55)</td>
<td>43 (65)</td>
<td></td>
</tr>
<tr>
<td>African American</td>
<td>34 (34)</td>
<td>14 (21)</td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>3 (3)</td>
<td>2 (3)</td>
<td></td>
</tr>
<tr>
<td>American Indian</td>
<td>2 (2)</td>
<td>3 (3)</td>
<td></td>
</tr>
<tr>
<td>&gt; 1 race</td>
<td>2 (2)</td>
<td>4 (6)</td>
<td></td>
</tr>
<tr>
<td>Other, unknown or declined</td>
<td>4 (4)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>Insurance status, n (%)</td>
<td></td>
<td>.602</td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>54 (55)</td>
<td>38 (55)</td>
<td></td>
</tr>
<tr>
<td>Medical assistance</td>
<td>33 (33)</td>
<td>23 (35)</td>
<td></td>
</tr>
<tr>
<td>Medicare or Medicaid</td>
<td>12 (12)</td>
<td>6 (9)</td>
<td></td>
</tr>
<tr>
<td>Self-pay</td>
<td>0 (0)</td>
<td>1 (1)</td>
<td></td>
</tr>
<tr>
<td>Hemoglobin A1C, n (%)(a)</td>
<td></td>
<td>.380</td>
<td></td>
</tr>
<tr>
<td>&lt;7.5</td>
<td>6 (6)</td>
<td>2 (3)</td>
<td></td>
</tr>
<tr>
<td>≥7.5</td>
<td>88 (84)</td>
<td>62 (97)</td>
<td></td>
</tr>
</tbody>
</table>

\(a\) Seven encounters had missing values for hemoglobin A1C.

### Table 2: Pre- and Postimplementation Outcomes and Resource Use for Children With Established T1D Presenting to the ED With Low-risk DKA

<table>
<thead>
<tr>
<th></th>
<th>Preimplementation</th>
<th>Postimplementation</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>January 1, 2012, to March 31, 2016</td>
<td>April 1, 2018 to December 31, 2018</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(N = 99)</td>
<td>(N = 66)</td>
<td></td>
</tr>
<tr>
<td>Hospital admission, n (%)</td>
<td>73 (74)</td>
<td>36 (55)</td>
<td>.011</td>
</tr>
<tr>
<td>ED return visits, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within 5 d</td>
<td>0 (0)</td>
<td>1 (2)</td>
<td>.400</td>
</tr>
<tr>
<td>Within 7 d</td>
<td>2 (2)</td>
<td>2 (3)</td>
<td>.219</td>
</tr>
<tr>
<td>Within 14 d</td>
<td>5 (5)</td>
<td>2 (3)</td>
<td>.528</td>
</tr>
<tr>
<td>Subcutaneous rapid or fast-acting insulin given in ED, n (%)</td>
<td>33 (33)</td>
<td>23 (35)</td>
<td>.840</td>
</tr>
<tr>
<td>Median NS bolus, mL/kg, (IQR)</td>
<td>10 (10–10)</td>
<td>12.5 (10–19)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Median ED LOS, min, (IQR)</td>
<td>215 (180–263)</td>
<td>241 (195–300)</td>
<td>.031</td>
</tr>
<tr>
<td>Median hospital LOS, h, (IQR)</td>
<td>25 (15–36)</td>
<td>18 (10–28)</td>
<td>.066</td>
</tr>
<tr>
<td>Total adjusted median ED charges, $a, (IQR)</td>
<td>1680 (1485–1853)</td>
<td>1546 (1387–1701)</td>
<td>.002</td>
</tr>
<tr>
<td>Total adjusted median hospital charges, $a, (IQR)</td>
<td>11 942 (4144–16 518)</td>
<td>10 374 (5072–14 238)</td>
<td>.121</td>
</tr>
</tbody>
</table>

\(a\) Adjusted for inflation by using the Consumer Price Index for hospital and related services for 2018 dollars. Total adjusted ED charges represent all ED charges, excluding any hospital facility charges from an ED visit. Total adjusted charges represent all facility and professional charges for a given encounter.
After special cause variation was seen, there was a 37–percentage point (95% CI 14%–59%) decrease in hospitalizations ($P$, .001). A cumulative summation analysis revealed that hospitalizations began to decrease after EBG implementation, and this trend continued throughout the QI initiative (Fig 3). Thirteen potential hospitalizations were avoided, which surpassed our goal of a 10% reduction (ie, a 10% reduction corresponds 7 avoided hospitalizations). The median ED LOS was significantly longer in the postimplementation period (241 minutes; IQR 195–300 minutes) compared with the preimplementation period (215 minutes; IQR 180–263 minutes; $P$ = .031) (Table 2). The number of children with 3-day ED revisits did not change significantly.

In the postimplementation period, children who were hospitalized were similar in median age, pH, and bicarbonate levels (Supplemental Table 5) compared with those discharged from the ED. The total adjusted mean charge was $16 125 (SD $14 534) for those hospitalized, compared with $3102 (SD $2889) for those discharged from the ED (mean difference: $13 022; 95% CI $11 418–$14 627). The most common reason for hospitalization was initiation of IV insulin (Table 3).

**DISCUSSION**

Through implementation of a QI initiative, we safely reduced hospitalization rates by an absolute difference of 19% for children with low-risk DKA, without an increase in 3-day ED revisits. Special cause variation was seen after implementation of a nursing algorithm and nursing education, suggesting that these efforts influenced practice change. The total adjusted mean charges were $13 022 higher among children hospitalized compared with those discharged from the ED.

Children with DKA are often hospitalized, leading to substantial medical expenditure. Recent investigation of insurance claims data suggests that inpatient care accounts for substantial medical expenditure.
for >40% of total annual medical expenditures for youth with DKA, which is estimated to be $14,200 for those with 1 episode of DKA compared with $8,400 for those with no episodes, an excess of $5,800. This is similar to results from a large study across 38 US children’s hospitals in which the total cost of hospitalization for DKA was estimated to be $7160 per encounter.

Our results suggest that reducing admissions for children with low-risk DKA may lead to substantial cost savings.

As the number of children with T1D rises, it is increasingly important to develop management strategies for diabetes-related complications. Previous investigation has revealed that children with mild DKA have resolution of acidosis within 3 to 7 hours, suggesting that hospitalization may be avoidable in this population. One recent pre- and postimplementation study revealed that hospitalizations and 30-day readmissions for children with DKA decreased after standardization of T1D education, increasing intensive insulin regimens, and community engagement.

However, this study was conducted in a diabetes ambulatory clinic, limiting generalizability to an ED population. Additional efforts in ambulatory settings have been focused on telephone follow-up, text-messaging support, and use of a diabetes hotline. However, the impact on hospitalization with these interventions is unclear. One retrospective study revealed that use of a diabetes hotline was associated with decreased frequency of DKA, whereas a more rigorous study in which patients were randomly assigned to scheduled telephone support compared with usual care revealed no difference in hospitalization rates for DKA.

Current treatment guidelines note that children with established T1D and reliable home care who present with hyperglycemia and ketosis without vomiting or severe dehydration may be managed at home or an outpatient setting. However, there are no specific recommendations for children who present with mild DKA for whom discharge may be appropriate. As a result, there remains uncertainty about which treatment options are optimal for this population. For instance, treatment with high fluid volumes (20 mL/kg of isotonic bolus + 1.5 × maintenance rate) has been shown to shorten time to metabolic normalization compared with treatment with lower fluid volumes (10 mL/kg of isotonic bolus + 1.25 × maintenance rate) and may be more appropriate for children with mild DKA for whom discharge from the ED is anticipated. Importantly, the incidence of clinically apparent brain injury and cognitive function after recovery from DKA have been shown to be similar among children randomly assigned to receive larger (20 mL/kg) compared with smaller volumes of isotonic fluid boluses (10 mL/kg).

During our QI initiative, the median isotonic fluid bolus volume increased significantly in the postimplementation period, suggesting adherence to our EBG and adoption of this practice among ED providers. In addition, providers who care for children with DKA must consider risk factors that may influence provision of adequate home care. This includes parent and child knowledge of sick-day management, psychological comorbidities, availability of home insulin, and blunting of further dehydration. Implementation of an EBG like the one we developed leads to standardization of care and reduced treatment variation and may guide providers who treat such children with less frequency.

We encountered many challenges when implementing our QI initiative. First, some providers were concerned about discharging patients who were mildly acidic and might have progression of illness at home and therefore return with more severe DKA. This led to our classification of low-risk DKA, which includes a combination of laboratory parameters and clinical variables that are used to identify patients who are unlikely to have progression of illness. Second, our guideline was developed with the intent of prolonging isotonic IV fluid administration for low-risk patients, which led to concern that our EBG would increase ED LOS and constrain bed space. Although ED LOS did increase in the postimplementation period, this was easy for providers to accept because low-risk patients with DKA present relatively infrequently. Third, we found it necessary to regularly increase provider awareness of our EBG.
regular educational presentations and updates at staff meetings and sent electronic reminders to providers. For the few providers who were hesitant to use our EBG in practice, this provided an opportunity to review cases, which helped to obtain buy-in. Fourth, we found that administration of subcutaneous insulin in the ED did not change over the QI initiative. This may have been due to treatment with home insulin shortly before ED presentation, treatment with home insulin pens in the ED, deferring insulin treatment to the admitting provider, or provider discretion. This represents an area on which we can further improve care.

Our study has several limitations. First, we could not evaluate for secular trends because our study population was defined by laboratory and clinical criteria that are not included in large data sets from US children’s hospitals. Second, it is possible that children may have returned to another ED, leading to an underestimate of ED revisits. However, this is unlikely because children with T1D are managed closely by our endocrinology clinic and often have next-day follow-up. Third, although we found a 19% absolute reduction in the hospitalization rate, special cause variation was not seen until sequential groups 3 to 4 after implementation of our initiative, around the time of the second ED nursing education session. Because of this, we introduced a process change after sequential group 3. Although this analysis revealed a 37–percentage point reduction in hospitalizations, we feel that further data collection is needed to determine if this improvement is sustained. Finally, our results may not be generalizable to hospitals without a robust T1D program. Future efforts may be focused on provider-driven variations in care and implementation of telephone follow-up with our EBG.

CONCLUSIONS

Through implementation of a QI initiative, we safely reduced hospitalizations for children with established T1D presenting to our ED with low-risk DKA. Implementation of a QI initiative such as ours may lead to substantial cost savings.

ABBREVIATIONS

CI: confidence interval
DKA: diabetic ketoacidosis
EBG: evidence-based guideline
ED: emergency department
EMR: electronic medical record
IQR: interquartile range
IV: intravenous
LOS: length of stay
QI: quality improvement
T1D: type 1 diabetes

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