Improving Emergency Department Management of Diabetic Ketoacidosis in Children

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BACKGROUND: Diagnostic delays in the pediatric emergency department (ED) can lead to unnecessary interventions and prolonged ED length of stay (LOS), especially in patients with diabetes mellitus evaluated for diabetic ketoacidosis (DKA). At our institution, baseline DKA determination time (arrival to diagnosis) was 86 minutes, and 61% of patients did not meet DKA criteria. Subsequently, intravenous (IV) placement occurred in 85% of patients without DKA. We aimed to use point-of-care (POC) testing to reduce DKA determination time from 86 to 30 minutes and to reduce IV placements in patients without DKA from 85% to 20% over 18 months.

METHODS: Four key interventions (POC tests, order panels, provider guidelines, and nursing guidelines) were tested by using plan-do-study-act cycles. DKA determination time was our primary outcome, and secondary outcomes included the percentage of patients receiving IV placement and ED LOS. Process measures included the rate of use of POC testing and order panels. All measures were analyzed on statistical process control charts.

RESULTS: Between January 2015 and July 2018, 783 patients with diabetes mellitus were evaluated for DKA. After all 4 interventions, DKA determination time decreased from 86 to 26 minutes ($P < .001$). In patients without DKA, IV placement decreased from 85% to 36% ($P < .001$). ED LOS decreased from 206 to 186 minutes ($P = .009$) in patients discharged from the hospital after DKA evaluation. POC testing and order panel use increased from 0% to 98% and 90%, respectively.

CONCLUSIONS: Using quality-improvement methodology, we achieved a meaningful reduction in DKA determination time, the percentage of IV placements, and ED LOS.
management. The 2014 International Society for Pediatric and Adolescent Diabetes consensus guidelines recommend that immediate evaluation and treatment are necessary to prevent DKA complications.3

Emergency departments (EDs) are frequently the frontline for rapid recognition and treatment of DKA. In 2012, >109,000 patients <18 years old presented to the ED for diabetes-related visits.8 In 2015, ED providers at our institution evaluated 176 pediatric patients with chief complaints of DKA, hyperglycemia, and/or DM for possible DKA. The standard DKA evaluation process at that time required intravenous (IV) placement before fluid bolus, laboratory draw, and laboratory processing. Although a high glucose level was determined rapidly, the process from arrival to confirmation of DKA diagnosis averaged 86 minutes. ED providers often tried to expedite the management of these patients by initiating treatment (including ordering fluid bolus, specialized IV fluids, and IV insulin drip) before laboratory confirmation of a metabolic acidosis. Baseline data showed that 61% of patients evaluated for a clinical suspicion of DKA did not meet our local laboratory definition of DKA (bicarbonate <18), and >85% of these patients received IV placement and IV fluids while awaiting laboratory results. IV placement can lead to pain and distress in patients and caregivers.9–11 Therefore, our goal with this project was to reduce the time from arrival to definitive laboratory diagnosis of DKA to reduce IV placements.

Point-of-care (POC) testing has been used since the 1990s in the critical care and ED setting to provide rapid and accurate laboratory evaluation for critically ill patients.12,13 A capillary POC test offers a rapid alternative method for DKA diagnosis because it can measure glucose and pH levels and calculate bicarbonate levels within 2 minutes at the bedside. Test accuracy has been confirmed when compared with published laboratory standards.14–18 Although previous studies have suggested that POC testing can reduce ED length of stay (LOS),13,19–21 to our knowledge, no published literature has examined if POC testing can rapidly exclude DKA with the goal of limiting interventions.

We theorized that if we rapidly ruled out DKA using POC testing, we could reduce medical interventions and ED LOS. We set 2 specific aims: first, reduce DKA determination time (arrival to initial bicarbonate value) in any patient presenting for possible DKA from 86 to 30 minutes, and second, reduce IV placements in patients not meeting DKA criteria from 85% to 20% over 18 months.

**METHODS**

**Local Context**

Our institution is a 296-bed, tertiary-care, pediatric academic center located in Milwaukee, Wisconsin. Being the only children’s hospital in southeastern Wisconsin, it serves as a primary referral site for surrounding urban and rural areas in Wisconsin, Illinois, and the upper peninsula of Michigan. In 2015, the hospital had >16,500 admissions and >66,000 ED visits. Patients presenting for DKA evaluation made up 176 ED visits. The ED is staffed by pediatric emergency medicine (PEM) physicians, PEM fellows, and advanced practice providers 24 hours per day. Learners in the ED include residents, medical students, and nurse practitioner students. In 2015, 45 ED nurses were trained in POC testing, and POC testing was approved for the confirmation of DKA.

**Interventions**

We established a multidisciplinary team including PEM physicians, an ED clinical nurse specialist, nursing champions, endocrinologists, laboratory supervisors of POC testing, and medical students. Technical support was provided by a data analyst. To inform process mapping, a chart review was completed for all ED patients with a DM-related chief complaint during the preimplementation period. The team further refined the intervention population to include ED patients ages 1 to 20 with chief complaints of DM, DKA, hyperglycemia, or blood sugar problems. Patients were
excluded if they did not have a bicarbonate measurement performed in the ED or if they received any DKA treatments before ED arrival. An extract reflecting this refined population, as well as process and outcome measures, was developed and automatically e-mailed to the project team members on a weekly basis for continuous outcome monitoring.

After process mapping and identification of the target population, feedback from our improvement team led to the creation of an initial key driver diagram (Fig 1). Failure mode and effects analysis and Pareto charts were used to identify delays in care. The first aim to decrease DKA determination time to <30 minutes from arrival was identified after process mapping demonstrated that both rooming and initial assessment occurred within 20 minutes. With the use of POC testing, a goal of 30 minutes allowed ample time for bedside evaluation of DKA. The second aim to reduce IV placements to 20% was determined after baseline data revealed a secondary reason for IV placement, such as dehydration or IV medication administration, in 20% of patients evaluated for DKA. With the intention of achieving these goals, 4 key interventions were identified, which included a POC test, DKA order panel, DKA provider guideline, and DKA nursing guideline (Fig 2).

**POC Testing**

To decrease time to DKA diagnosis, a capillary POC test that measures glucose, pH, and electrolyte levels and calculates a bicarbonate level was implemented. This test is performed at the bedside by using a finger stick similar to the child’s home glucometer. Results are available within 2 minutes, decreasing the time to DKA determination and immediately enabling providers to decide whether IV placement and further treatment are necessary.

**DKA Order Panel**

A DKA electronic order panel was created by the team with the goal of reducing variability of practice and improving ordering efficiency. However, provider feedback revealed the initial order panels were inconsistent with current DKA management and difficult to locate in the electronic health record. After receiving this feedback, in June 2016 the electronic DKA order panels were revised to incorporate the use of POC testing and relocated to a quick list in the electronic health record to improve access. The quick list is a default screen in the order activity that houses several ED order panels and eliminates the need to search for an order panel.

**DKA Provider Guideline**

On provider and nursing request to standardize DKA management, a multidisciplinary team developed an evidence-based guideline that incorporated national recommendations for DKA management, reinforced confirmation of DKA before IV
placement, and facilitated use of the DKA order panels.

**Studying the Intervention**

After successful implementation of the first 3 interventions, POC testing and order panel use improved; however, DKA determination time and proportion of IV starts continued to remain well above the goal. To achieve DKA determination within 30 minutes, the team recognized the need for a more radical change; therefore, process mapping, failure mode and effects analysis, and stakeholder interviews were repeated. The triage nurse role was identified as a crucial step in the early recognition of DKA, and the team identified that POC testing in triage could rapidly diagnose DKA. Given the unpredictability of the arrival of patients to the ED, case-based simulation was used for the initial plan-do-study-act (PDSA) cycles.

Triage nurses were asked to assess 5 clinical scenarios and assign a triage score as well as the level of concern for DKA. The scenario was repeated first by using glucose measurements and then bicarbonate measurements. Nursing feedback revealed appropriate escalation or deescalation of triage

### TABLE 1 Demographics and Summary of Patient Characteristics for Entire Cohort

<table>
<thead>
<tr>
<th>Patient Characteristics</th>
<th>Entire Cohort, ( N = 783 )</th>
<th>Preintervention, ( N = 156 )</th>
<th>Postintervention, ( N = 627 )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y, mean</td>
<td>12.8 (range 1–20)</td>
<td>12.6</td>
<td>12.8</td>
<td>.64</td>
</tr>
<tr>
<td>Female sex, %</td>
<td>49</td>
<td>47</td>
<td>51</td>
<td>.61</td>
</tr>
<tr>
<td>Race, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>60</td>
<td>67</td>
<td>59</td>
<td>.33</td>
</tr>
<tr>
<td>African American</td>
<td>32</td>
<td>28</td>
<td>33</td>
<td>.60</td>
</tr>
<tr>
<td>Other</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>.35</td>
</tr>
<tr>
<td>Average initial bicarbonate</td>
<td>18.4 (range 2–34)</td>
<td>19.1</td>
<td>18.3</td>
<td>.40</td>
</tr>
<tr>
<td>Initial bicarbonate &lt;18, %</td>
<td>42</td>
<td>39</td>
<td>43</td>
<td>.76</td>
</tr>
<tr>
<td>Chief complaint, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood sugar</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>—</td>
</tr>
<tr>
<td>Diabetes</td>
<td>37</td>
<td>33</td>
<td>38</td>
<td>—</td>
</tr>
<tr>
<td>Diabetes and hyperglycemia</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>DKA</td>
<td>13</td>
<td>10</td>
<td>14</td>
<td>—</td>
</tr>
<tr>
<td>DKA and hyperglycemia</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>Hyperglycemia</td>
<td>42</td>
<td>49</td>
<td>40</td>
<td>—</td>
</tr>
</tbody>
</table>

DKA is defined as initial bicarbonate <18. —, not applicable.

**FIGURE 3**

Percentage of patients evaluated for DKA each month by using POC testing (p-chart). LCL, lower control limit; UCL, upper control limit.
acuity scoring when bicarbonate measurements were added; however, knowledge of the laboratory definition of DKA was lacking. Subsequently, in February 2017, a nursing DKA guideline was developed.

Nursing DKA Guideline

ED nursing staff developed a nursing DKA guideline to facilitate rapid symptom recognition of DKA at the time of ED arrival. Per the guideline and on the basis of chief complaint and presenting symptoms, nurses were instructed to request a provider order for POC testing, perform the POC test, and deliver results to a provider for interpretation. The guideline was successfully implemented on all shifts, and both DKA evaluation time and reduction in IV placements improved.

Nursing DKA Protocol

The team received requests to convert the nursing DKA guideline into a protocol. At our institution, protocols are hospital policies that are sanctioned by a hospital committee and reviewed every 3 years. Implementation of the nursing DKA protocol in December 2017 ultimately enabled nurses to independently obtain POC testing in patients presenting with concern for DKA before a provider order occurred.

Measures

The primary outcome measure, DKA determination time, was measured as time from ED arrival to first bicarbonate measurement (obtained by POC test, blood gas, or basic metabolic panel) in any patient presenting with concern for DKA. Per local treatment guidelines, bicarbonate $<18$ confirmed DKA, and bicarbonate $\geq 18$ ruled out DKA. Secondary indicators of DKA included pH level and patient status.

Secondary outcomes included the proportion of patients undergoing IV placement and ED LOS measured from ED arrival to ED disposition. IV placement rates were calculated on the subgroup of patients without DKA who were discharged from the hospital because these patients did not require IV therapies for DKA. The decision for IV placement was left to the discretion of the provider. Process measures included the proportion of patients undergoing POC testing and using DKA provider or nursing order panels. Balancing measures included admission rates, time to IV placement in patients with confirmed DKA, and 72-hour ED return rates.

Analysis

Descriptive statistics were used to describe the patient population. Statistical process control charts were used to measure the impact of our
interventions in real time, and control limits were set at ±3 SDs. The center line and control limits were revised when special cause was noted, as defined by 8 consecutive points above or below the mean or a single data point lying outside of the control limits. Additionally, a pre-post analysis was conducted, and differences in percentage, time, and average values were measured by using χ², Mann-Whitney U, and unpaired t tests as appropriate. These statistical analyses compared the preintervention period of January 2015 to October 2015 to the postintervention period unique to each measure, as is noted in each figure.

**Ethical Considerations**

Our institutional review board reviewed the project and considered it to be a quality-improvement (QI) project. The project was determined to be exempt from informed consent. There were no identified conflicts of interest.

**RESULTS**

Patient demographics and clinical characteristics for the entire cohort are listed in Table 1. Figure 2 demonstrates modifications to the 4 key interventions over time. The use rate of POC testing and provider and nursing DKA order panels increased from 0% preintervention to 98% and 90%, respectively, during the postintervention period (Figs 3 and 4). The DKA determination time improved after each of the interventions from a mean of 86 minutes preintervention to 26 minutes postintervention in any patient presenting with concern for DKA (P < .001; Fig 5). Since March 2017, 80% of patients evaluated for DKA had a bicarbonate level measured within 30 minutes of arrival. The center line and control limits were revised when special cause was noted in Figs 3 through 5, as defined by 8 consecutive points above or below the mean. In the subset of patients who did not meet laboratory criteria for DKA and were discharged from the hospital, the proportion of IV placements decreased from a mean of 85% preintervention to 36% postintervention (P < .001; Fig 6). Special cause was detected in Fig 6 by a single data point lying below the lower confidence interval as well as 8 points below the mean. ED LOS in any patient evaluated for DKA showed no significant improvements; therefore, we assessed ED LOS in a subset of patients evaluated for DKA and discharged from the ED because we anticipated the greatest impact.

**FIGURE 5**

DKA determination time (average arrival time to initial bicarbonate value) each month in any patient evaluated for DKA (X-bar chart). LCL, lower control limit; UCL, upper control limit.
in this population. ED LOS in any patient discharged from the ED improved from 206 minutes preintervention to 186 minutes postintervention ($P = .009$) after conversion of the DKA nursing guideline into a protocol (Fig 7), and the centerline was revised when 8 points were detected below the mean. Balancing measures in the postintervention period revealed no change in admission rates or time to IV placement in patients with DKA; however, 72-hour ED return rates decreased from 13% to 7% ($P = .009$) in any patient presenting with concern for DKA.

**DISCUSSION**

Before this project, the DKA determination time at our institution was 86 minutes and IV placement occurred in 85% of patients without DKA because of laboratory-related delays in diagnosis and the importance of IV therapy when treating DKA. Implementation of POC testing and optimization of provider and nursing workflows led to consistent evaluation of DKA within 30 minutes of arrival in 80% of patients. The more rapid ascertainment of DKA safely allowed a 49% reduction in IV placements in patients without DKA. Furthermore, ED LOS improved 20 minutes in discharged patients after we protocolized rapid DKA evaluation in triage.

Like many EDs new to QI methodology, our team met initial resistance to change when attempting PDSA cycles in a dynamic ED. This barrier was overcome by working closely with nursing leadership and frontline providers. We improved nursing engagement by presenting the rationale behind using POC testing at quarterly nursing staff meetings. Frequent announcements of upcoming PDSA cycles minimized confusion, and dissemination of results showing reduction in IV placements fueled nursing buy-in. Because of these efforts, there was a shift toward a culture of improvement. Frontline providers joined the QI initiative and contributed to the refinement and protocolization of the nursing DKA guideline. The nursing DKA guideline became the standard of care despite an expected 10-month process in converting it to an official hospital protocol.

FIGURE 6
Percentage of patients receiving IV placement each month in patients who did not meet DKA criteria and were discharged from the ED (p-chart). LCL, lower control limit; UCL, upper control limit.
sustained improvement in DKA determination time, IV placements, and ED LOS.

With the nursing guideline and additional QI interventions, the team demonstrated a 49% reduction in IV placements for patients with diabetes who present with concerns for DKA. This translates to the annual prevention of 52 painful and distressing IVs at our institution. Previous research efforts have focused on implementing pharmacologic and nonpharmacologic interventions to limit pain and emotional distress in patients and their caregivers in the ED. However, this is the first study to reduce resource use and painful procedures by more appropriately triaging which patients needed an IV.

Given the significant reduction in IV placement and DKA determination time, we had anticipated a similar improvement in ED LOS; however, we were surprised to find that ED LOS showed only a modest improvement. In theory, POC testing leads to rapid diagnostic evaluation and reduced ED LOS. However, previous studies examining ED LOS after POC implementation have shown conflicting results. Our findings support the belief that POC testing alone is not enough to improve ED LOS. Kankaanpää et al demonstrated reduced ED LOS by combining POC testing with an early-assessment-team model; however, this required a provider and nurse to evaluate the patient in triage. Although early provider assessment in triage may reduce ED LOS, this solution is resource and cost intensive. Our study is unique in that we accomplished rapid patient assessment and improved ED LOS via nursing protocols. We capitalized on nursing medical knowledge and achieved early patient evaluation without an additional provider in triage. Our findings suggest nursing protocols that incorporate POC testing could serve as an adjunct in triage to facilitate early diagnosis and lead to more appropriate distribution of resources in a busy ED.

Given the significant decrease in resource use via reduced interventions, we would expect cost savings for the hospital. Further studies are necessary to perform a formal cost analysis that compares the benefits of reduced interventions and ED LOS with the cost of implementing POC testing. Additionally, the decrease in 72-hour ED return rates was an unintentional observation noted in this study. ED return rate was used as a balancing measure to ensure that our interventions did not lead to

--- Postintervention ---

FIGURE 7
ED LOS (average arrival time to disposition) each month in any patient evaluated for DKA and discharged from the ED (X-bar chart). LCL, lower control limit; UCL, upper control limit.
premature discharge and subsequent ED return for recurrent DKA or dehydration. None of the interventions in this study targeted 72-hour ED returns, and there were no additional efforts to reduce return visits during this time frame. Therefore, further evaluation is necessary to illicit the source of decreased 72-hour ED return visits.

This project did have limitations. To simplify the DKA guidelines and expedite care, a calculated bicarbonate value was used as the primary determinant of DKA, and pH level and patient status secondarily informed decision-making. Although agreement between calculated bicarbonate and measured total carbon dioxide is generally clinically adequate, discrepancies can occur; therefore, generalizability could be limited because other institutions may use different determinants of DKA.\textsuperscript{29,30} In addition, institutions that lack POC testing capabilities for bicarbonate and pH values will require alternative interventions to reduce DKA determination time. To avoid selection bias, we did not exclude patients with additional chief complaints because DKA can present with a multitude of symptoms; however, additional chief complaints may confound ED LOS results. Finally, in the summer of 2017, a multidisciplinary team tasked with standardizing DKA management was developed, and further QI efforts were initiated February 2018. These efforts may have contributed to the sustained improvements in DKA management.

Although this study was performed at a single tertiary-care pediatric ED, it can be generalized to any ED where rapid diagnostic confirmation through POC testing can assist with the decision to initiate or withhold treatment, especially in the case of patients in need of time-sensitive interventions.

CONCLUSIONS

By using QI methodology, a reliable system was implemented to rapidly evaluate DKA and limit IV placement. These successes have been sustained for 8 months. In the future, we plan to spread the use of POC testing to primary care clinics where rapid exclusion of DKA can reduce the need for ED evaluation, leading to improved patient satisfaction, cost savings, and more appropriate use of resources.

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ABBREVIATIONS

DKA: diabetic ketoacidosis
DM: diabetes mellitus
ED: emergency department
IV: intravenous
LOS: length of stay
PDSA: plan-do-study-act
PEM: pediatric emergency medicine
POC: pediatric emergency medicine
QI: quality improvement

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