abstract

OBJECTIVE: We sought to create and implement recommendations from an evidence-based pathway for hospital management of pediatric diabetic ketoacidosis (DKA) and to sustain improvement. We hypothesized that development and utilization of standard work for inpatient care of DKA would lead to reduction in hypokalemia and improvement in outcome measures.

METHODS: Development involved systematic review of published literature by a multidisciplinary team. Implementation included multidisciplinary feedback, hospital-wide education, daily team huddles, and development of computer decision support and electronic order sets.

RESULTS: Pathway-based order sets forced clinical pathway adherence; yet, variations in care persisted, requiring ongoing iterative review and pathway tool adjustment. Quality improvement measures have identified barriers and informed subsequent adjustments to interventions. We compared 281 patients treated postimplementation with 172 treated preimplementation. Our most notable findings included the following: (1) monitoring of serum potassium concentrations identified unanticipated hypokalemia episodes, not recognized before standard work implementation, and earlier addition of potassium to fluids resulted in a notable reduction in hypokalemia; (2) improvements in insulin infusion management were associated with reduced duration of ICU stay; and (3) with overall improved DKA management and education, cerebral edema occurrence and bicarbonate use were reduced. We continue to convene quarterly meetings, review cases, and process ongoing issues with system-based elements of implementing the recommendations.

CONCLUSIONS: Our multidisciplinary development and implementation of an evidence-based pathway for DKA have led to overall improvements in care. We continue to monitor quality improvement metric measures to sustain clinical gains while continuing to identify iterative improvement opportunities. Pediatrics 2014;134:e848–e856

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KEY WORDS
pediatric diabetic ketoacidosis, electronic medical record, computerized physician order entry, standardization, quality improvement

ABBREVIATIONS
BOHB—β-hydroxybutyrate
CI—confidence interval
CPOE—computerized provider order entry
D10—Dextrose 10%
DKA—diabetic ketoacidosis
ED—emergency department
ICD-9—International Classification of Diseases, Ninth Revision
IV—intravenous
LOS—length of stay
NS—normal saline
SCH—Seattle Children’s Hospital

Dr Koves drafted, wrote, and submitted the manuscript; developed the design for manuscript and metrics data definitions; interpreted the data; formatted the manuscript; facilitated contributions; developed the figures, tables, references, and reference formatting; and facilitated publication of the final version; she provided oversight for all aspects of the development of the diabetic ketoacidosis (DKA) clinical standard work package; Dr Leu made substantial contributions to the conception and revision of clinical guidelines, architected and updated clinical decision supports used to support the project, reviewed analysis of data, composed a portion of the original manuscript, and edited all of the final manuscript; Ms Spencer performed data analysis and statistical significance testing and contributed writing to the methods of evaluation, results, and analysis sections; Ms Popalisky contributed writing to the methods and discussion sections and assisted with review and revising drafts of the manuscript; Ms Drummond contributed to writing the methods and discussion sections and assisted with review and revising drafts of the manuscript; Ms Beardsley participated in guideline development and implementation, focusing on the emergency department, and contributed to manuscript editing; Ms Klee reviewed the manuscript and developed nursing content and implementation of the DKA pathway in standardization of nursing care of children admitted with DKA; Dr Zimmerman participated in guideline development and implementation, focusing on the PICU; participated in review of electronic decision-support tools and orders; composed a portion of the original manuscript; edited all of the final manuscript; and provided data interpretation; and all authors approved the final manuscript as submitted.

(Continued on last page)
Standardization of clinical practice (clinical standard work) is a prerequisite for continuous performance improvement. Without standardization, it is impossible to determine whether outcomes relate to clinical practice standards, to patient factors, or to variations in practice. The process of developing standard work as a key aspect of quality improvement has been termed “fidelity” of medical advancement delivery. Protocolized care has been demonstrated to be beneficial, as has reducing variability in general. It is important to emphasize that for standard practice to be successful, it must be driven by participants. In this spirit, a multidisciplinary team at Seattle Children’s Hospital (SCH) developed, monitored, and incrementally improved clinical standards for management of diabetic ketoacidosis (DKA).

Before our interventions, there was no consistency in the treatment of children with DKA. There were no standards for when insulin would be started, for the rate of continuous insulin to be used, for which intravenous (IV) fluids to use for fluid resuscitation, or for safe transition to subcutaneous insulin. Many different orders for IV fluids would appear on the electronic medication administration record for individual patients, and the composition of these fluids would differ greatly between patients. If complications such as hypoglycemia developed, there was no uniform management approach applied. Confusion among providers was reinforced by lack of standards and inconsistency.

Given this lack of standard work, high variability in practice, and numerous safety events, the medical director of our PICU created a committee charged with creating an evidence-based clinical standard work pathway for the management of DKA that we hoped would achieve the following: (1) decrease variability in practice, (2) improve stakeholder understanding of the condition and how to manage it, and (3) improve clinical outcomes. After implementation of our clinical pathway, an astute clinician noted that we had a high prevalence of hypokalemia (although similar to pre-guideline data). Accordingly, a follow-up specific aim was to create a new medical standard, to be implemented by our multidisciplinary team, to decrease incidence of clinically significant hypokalemia.

We describe the development and implementation of our clinical standard work pathway. We studied whether implementation of the pathway would affect ICU admission rate, variability in practice, and cerebral edema rates. We also studied whether our improvement efforts successfully reduced episodes of hypokalemia.

**METHODS**

**Setting**

SCH is a 350-bed pediatric hospital affiliated with the University of Washington School of Medicine. Approximately 150 patients are hospitalized at SCH annually for DKA. These patients are most commonly evaluated first in our emergency department (ED; even if referred from other health care facilities), then admitted to our ICU (Pediatric Critical Care Medicine service) or Inpatient Medical Unit (Endocrinology service). Care is provided by teams of residents and medical students supervised by fellows and attending physicians.

Seattle Children’s Hospital was one of the earliest adopters of computerized provider order entry (CPOE), having deployed Cerner PowerChart (Cerner Corporation, North Kansas City, MO) in 2004. In addition to having a robust order catalog, we provide inpatient clinical decision support through CareSets (order sets).

**Planning the Intervention**

**Team Selection**

A multidisciplinary team was selected to review the evidence and to develop and implement a standardized approach to continually improve care for patients with DKA. Committee participation included a critical care physician, an endocrinologist, ED physicians, a clinical pharmacist, ICU and ED clinical nurse specialists, nursing educators, a charge nurse, a laboratory medicine specialist, a pediatric chief resident, endocrinology fellows, and selected pediatric residents with an interest in endocrinology. The committee was supported by a centralized Clinical Effectiveness group including medical librarians, an informatician, a consultant, a project manager, and knowledge management (data expert). Team member responsibility included participation in all aspects of development, implementation of the standard work, and subsequent iterative improvement. These activities included literature review, synthesizing evidence into recommendations, incorporating feedback, training and educating in their respective areas, acting as super users during implementation, and providing guidance on implementation feasibility from their clinical discipline and workflow reality. The multidisciplinary nature of the team proved essential to ensure recommendations were feasible, safe, effective, patient-centered, flow-promoting, and location independent.

**Evidence Basis**

In conjunction with a medical librarian, we identified studies from 1996 through 2012 from the following databases: Medline, Medline in Process, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, Cumulative Index to Nursing and Allied Health, PsycInfo, American College of Physician Journal Club, Database of Abstracts of Reviews and Effects, Health Technology Assessment, National...
Health Service Economic Evaluation Database, Clinical Evidence, AHRQ National Guideline Clearinghouse, TRIP database, Web of Science, Agency for Healthcare Research and Quality, DynaMed, UpToDate, and eMedicine. We systematically evaluated and graded the evidence to support our clinical questions addressing fluid and electrolyte management, insulin strategy, natural and iatrogenic complications, laboratory findings, risk stratification, and disposition (Supplemental Fig 5).

Evidence Synthesis Into Recommendations, Implementation, and Go Live Support

Over 2 years, the multidisciplinary team regularly met to synthesize literature, to create inclusion and exclusion criteria, and to formulate recommendations through evidence-informed consensus. During these meetings, utilizing standard work methods developed by the Clinical Effectiveness team, we also created an executive summary, a clinical algorithm, electronic clinical decision supports (see below), measures that we would be evaluating on an ongoing basis (see below), and an organizational change plan (including communication of change, education/in-depth training, and other implementation issues). We also created an electronic learning module and team room posters to train to our implementation materials.

Clinical Decision Support

We implemented CareSets (order sets) to facilitate ordering. In addition, we created automated clinical rules and clinical calculators to support this project (Supplemental Fig 6). Order sets were designed to contain links to our guideline and other implementation materials. Intravenous fluid orders contained links to the 2-bag system clinical calculator. We created an order for DKA IV fluid administration rate, which contained a link to the fluid rate calculator, and clinical rules for automatic calculation of corrected sodium and serum osmolality from other laboratory values. We also posted an online interactive algorithm containing DKA management recommendations, extensive literature review with graded level of evidence notations, and electronic supporting tools (Supplemental Appendix: Diabetic Ketoacidosis (DKA) v2.1; see also http://www.seattlechildrens.org/pdf/DKA-pathway.pdf).

Go Live

Rollout was supported by a comprehensive communication rollout plan including central and decentralized announcements, notices to community providers, internal and external Web postings, and formal presentations at grand rounds, outreach conferences, and patient safety conferences. Real-time e-mail and phone support by expert users and daily morning huddles were provided for the first few weeks after implementation. As part of “go-live,” all outdated materials related to DKA from involved clinical areas were removed.

Improvement Cycle

The DKA group continued to meet monthly to address safety issues and to fine-tune the clinical pathway. During the first year postimplementation, it was recognized that patients were becoming hypokalemic on our clinical pathway (consistent with historical rates). The improvement team analyzed key drivers (Fig 1) and constructed a multidisciplinary plan to reduce the prevalence of clinically significant hypokalemia. We provided transparency of this finding to the DKA managing teams that strengthened adherence to
the management recommendations relating to potassium management. Furthermore, we “hardwired” additional power plan order elements and added metric measures. The move to power plan ordering included modifying a clinical recommendation so that we would start potassium supplementation in IV fluids together with onset of the insulin infusion, instead of by 4 hours after onset of insulin infusion, and earlier if potassium was <3 mEq/L.

Methods of Evaluation

We used an interrupted time-series design, collecting metric data over multiple time points.

Patient Population

Data were collected retrospectively by using laboratory and medication administration data from Cerner and administrative data from Epic Hyper-space. We defined our DKA population as patients with International Classification of Diseases, Ninth Revision (ICD-9), codes for diabetes (250.xx: 250.00–250.93) who had received a continuous insulin infusion. Cerebral edema case ascertainment was clinical, identified from ICD-9 code and administration of mannitol or hypertonic saline.

Metrics were designed to provide core, outcome-, and process-related DKA relevant measures. Additional balancing measures were focused on safety aspects of DKA management. Reports were updated quarterly and trended over time by using run charts. These metrics (Fig 2) were reviewed quarterly by the DKA committee, along with data from chart review and other sources. All measures were categorized into 3 time periods. Preimplementation included discharges from October 1, 2009, to April 18, 2011 (n = 172); first year postimplementation included discharges from July 18, 2011, to April 17, 2012 (n = 110). The first 3 months immediately after implementation were excluded as a “washout period.” The second year postimplementation included discharges from May 1, 2012, to July 31, 2013 (n = 171). In addition, measures were plotted in run charts. An analysis of patient demographic characteristics (gender, age, payor, language, and race/ethnicity) revealed no significant differences between the discharges in the 3 periods (Table 1).

Analysis

Tests of significance were performed by using Pearson’s χ² tests for categorical variables and t tests for continuous variables.

Human Subjects

Reporting of these findings was approved by the SCH Institutional Review Board.

RESULTS

Guideline Highlights

Some key initial recommendations (in brief) included the following:

- infusion of a 10-mL/kg normal saline (NS) bolus over 1 hour as initial resuscitation;
- utilization of a 2-bag system (Supplemental Figs 7, 8, and 9) to allow for finite control of dextrose delivery;
- initiation of the insulin infusion 1 hour after onset of fluid resuscitation, using fluids based on NS and avoidance of insulin bolus therapy to minimize the risk of cerebral edema;
- transition from NS-based fluids to 1/2 NS-based fluids with potassium salts 4 hours after starting IV infusions, assuming no risk factors for cerebral edema; and
- monitoring of serum β-hydroxybutyrate (BOHB) to inform clinical decision-making including transition to subcutaneous insulin therapy.

<table>
<thead>
<tr>
<th>Core Metrics</th>
<th>Number of DKA patients meeting definition criteria</th>
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<tbody>
<tr>
<td>Inpatient length of stay</td>
<td></td>
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<tr>
<td>Use of pathway by activation of any of the DKA-related order set</td>
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<tr>
<td>Charges per discharge</td>
<td></td>
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<tr>
<td>Readmission within 30 days defined as return visit; planned or unplanned</td>
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</tbody>
</table>

<table>
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<tr>
<th>Outcome Measures</th>
<th>Cerebral edema incidence; defined as received mannitol within DKA population</th>
</tr>
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<tbody>
<tr>
<td>Hypoglycemia incidence: defined as blood glucose ≤70 mg/dL while on insulin infusion</td>
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<tr>
<th>Process Measures</th>
<th>Lead time for insulin start: time from arrival to insulin infusion start</th>
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<tbody>
<tr>
<td>Time from BOHB result &lt;1 mmol/L to subcutaneous insulin given</td>
<td></td>
</tr>
<tr>
<td>Time from BOHB result &lt;3 mmol/L to transfer from ICU to floor</td>
<td></td>
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<tr>
<td>Sodium bicarbonate use</td>
<td></td>
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<tr>
<td>Head CT rate</td>
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<tr>
<th>Balancing Measures</th>
<th>ICU admission rate</th>
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<tbody>
<tr>
<td>ICU length of stay</td>
<td></td>
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<tr>
<td>Hyperchloremia rate; any chloride level ≥110 mEq/L</td>
<td></td>
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<tr>
<td>Hyperkalemia rate; any potassium level ≥5.6 mEq/L</td>
<td></td>
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<tr>
<td>Hypokalemia rate; any potassium level ≤3 mEq/L</td>
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FIGURE 2

Metrics. BOHB, beta-hydroxybutyrate; CT, computed tomography; DKA, diabetic ketoacidosis; ICU, intensive care unit.
**Implementation Highlights**

**Resource Utilization**

Diabetic ketoacidosis pathway activation as measured by order set use was 99% in the first year, with 108 activations of 110 opportunities (Table 2). These results were sustained in the second year, with 170 activations of 171 opportunities. We noticed that ICU admission percentages increased slightly, 34%, 51%, and 39%, but ICU length of stay in days decreased (Fig 3) by 1.06 (95% confidence interval [CI]: 0.81–1.30), 0.69 (95% CI: 0.59–0.79), and 0.68 (95% CI: 0.61–0.75) days, respectively, for each of the study intervals (Table 2). In addition, implementation of the DKA standard work was associated with more consistent ICU length of stay, as evidenced by narrower CIs.

**Cerebral Edema**

The proportion of patients with cerebral edema decreased to 2.9% (95% CI: 0.9%–6.6%), 1.8% (95% CI: 0.2%–6.4%), and 1.2% (95% CI: 0.1%–4.1%) during each of the 3 intervals. The decrease was not statistically significant per χ² analysis; however, the decrease in size of the CI indicates a decrease in variation.

**Improvement Highlights**

After noting the frequent occurrence of hypokalemia (Fig 4A), we modified the third recommendation above to initially use fluids based on NS with potassium salts, with a goal of starting potassium simultaneously with the insulin infusion unless hyperkalemia was present. Lag time in minutes between start of insulin infusion and addition of potassium salts was essentially eliminated with the change in order sets (Fig 4B). The preimplementation mean was 90 (95% CI: 51–129) minutes.

<table>
<thead>
<tr>
<th>TABLE 1 Demographic Characteristics</th>
<th>Preimplmentation (N = 172)</th>
<th>First Year Postimplementation (N = 110)</th>
<th>Second Year Postimplementation (N = 171)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female gender, n (%)</td>
<td>89 (52)</td>
<td>44 (40)</td>
<td>89 (52)</td>
</tr>
<tr>
<td>Age, mean ± SD, y</td>
<td>10.9 ± 4.47</td>
<td>10.4 ± 4.6</td>
<td>11.1 ± 4.6</td>
</tr>
<tr>
<td>Payor, n (%)</td>
<td></td>
<td></td>
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<tr>
<td>Commercial</td>
<td>99 (57)</td>
<td>62 (56)</td>
<td>91 (53)</td>
</tr>
<tr>
<td>Public</td>
<td>73 (43)</td>
<td>48 (44)</td>
<td>79 (47)</td>
</tr>
<tr>
<td>Language, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>161 (94)</td>
<td>96 (87)</td>
<td>157 (92)</td>
</tr>
<tr>
<td>Spanish</td>
<td>5 (3)</td>
<td>12 (10)</td>
<td>7 (4)</td>
</tr>
<tr>
<td>Other</td>
<td>6 (3)</td>
<td>2 (3)</td>
<td>6 (4)</td>
</tr>
<tr>
<td>Race/ethnicity, n (%)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>White</td>
<td>119 (69)</td>
<td>67 (61)</td>
<td>104 (61)</td>
</tr>
<tr>
<td>Black</td>
<td>24 (14)</td>
<td>11 (10)</td>
<td>25 (15)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>5 (3)</td>
<td>14 (13)</td>
<td>13 (13)</td>
</tr>
<tr>
<td>Asian</td>
<td>5 (3)</td>
<td>4 (4)</td>
<td>8 (5)</td>
</tr>
<tr>
<td>Other</td>
<td>11 (6)</td>
<td>6 (5)</td>
<td>11 (6)</td>
</tr>
<tr>
<td>Unknown</td>
<td>8 (5)</td>
<td>8 (7)</td>
<td>10 (6)</td>
</tr>
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</table>

<table>
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<tr>
<th>TABLE 2 Results by Implementation Time Interval</th>
<th>Preimplmentation (N = 172)</th>
<th>First Year Postimplementation (N = 110)</th>
<th>Second Year Postimplementation (N = 171)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order set activation, n (%)</td>
<td>NA</td>
<td>108 (98.1)</td>
<td>NA</td>
</tr>
<tr>
<td>Cerebral edema incidence, n (%)</td>
<td>5 (2.9)</td>
<td>2 (1.8)</td>
<td>70</td>
</tr>
<tr>
<td>ICU admission rate, n (%)</td>
<td>59 (34.3)</td>
<td>56 (50.9)</td>
<td>0.006</td>
</tr>
<tr>
<td>ICU length of stay, mean (95% CI), d</td>
<td>1.05 (0.8–1.3)</td>
<td>0.7 (0.6–0.8)</td>
<td>0.007</td>
</tr>
<tr>
<td>Time from arrival to insulin infusion start, mean (95% CI), min</td>
<td>131 (100–162)</td>
<td>153 (108–197)</td>
<td>0.42</td>
</tr>
<tr>
<td>Hypokalemia rate, n (%)</td>
<td>39 (22.6)</td>
<td>26 (23.6)</td>
<td>.85</td>
</tr>
<tr>
<td>Hypokalemia results per patient, mean (95% CI)</td>
<td>4.8 (3.4–6.3)</td>
<td>4.9 (2.3–7.5)</td>
<td>.97</td>
</tr>
<tr>
<td>Potassium management results, mean (95% CI), min</td>
<td>First period (N = 152)</td>
<td>90 (51–129)</td>
<td>188 (149–228)</td>
</tr>
<tr>
<td>Time from insulin infusion start to Potassium-containing fluids start</td>
<td>90 (51–129)</td>
<td>188 (149–228)</td>
<td>.001</td>
</tr>
<tr>
<td>Time from arrival to start of potassium-containing fluids</td>
<td>223 (169–277)</td>
<td>361 (306–417)</td>
<td>.001</td>
</tr>
</tbody>
</table>

NA, not applicable.

* First year compared with preimplementation.

Second year compared with preimplementation.

Potassium management results time periods changed to coincide with changes in recommendations to manage potassium: first period is from July 2011 to July 2012 (N = 152); second period is from August 2012 to July 2013 (N = 128).
We then noted a significantly increased lag time (mean: 188 minutes; 95% CI: 149–226 minutes; \( P < .001 \)) during the first year postimplementation. However, after the iterative change (Fig 4B, arrow), the mean lag time was 19 minutes (95% CI: −3 to 40 minutes; \( P < .004 \)), when compared with preimplementation.

The effects of DKA standard work implementation on rates of hypokalemia are summarized in Table 2. The percentage of patients with hypokalemia remained steady in the first year as compared with preimplementation (22% vs 23%); after the introduction of this metric measure in the second year, hypokalemia decreased significantly to 13.4% (\( P = .025 \)). The average number of hypokalemia occurrences per patient also remained steady (\( P = .97 \)) in the first year, but then significantly decreased by 50% (\( P = .005 \)) by the second year coincident with adjusted potassium replacement plan, linked to initiation of the insulin infusion (Fig 4A and B).

**DISCUSSION**

Our expected outcomes for the DKA pathway were to create safer, standardized care for the patient with DKA that was not dependent on the patient’s location. We reasoned that hardwiring the pathway would make compliance with the pathway easier, that faculty and staff would be trained in the pathway, and that nursing advancement of DKA care would result in staff confidence and engagement in the care of patients. With pathway implementation we expected fewer adverse events and resource utilization attributable to DKA. Finally, we expected use of serial BOHB testing \(^{9–12} \) to improve quantification of the clinical trajectory of DKA, particularly its resolution.

Increased patient safety and improved patient outcomes are an expectation of the health care consumer. The prevalence of type 1 diabetes \(^ {13} \) and DKA \(^ {13–15} \) are increasing. The Institute of Medicine and the Institute for Healthcare Improvement have released a number of reports highlighting methods to improve the quality and safety of health care. Recommendations for improvement include implementation of evidence-based practice to reduce variation in care to improve efficiency \(^ {16} \) (Institute of Medicine, http://iom.edu; Institute for Healthcare Improvement, www.ihi.org; retrieved July 7, 2012). The plan requires clinical experts with knowledge of the disease, who understand the system within which the pathway is to be implemented, and other experts who are able to facilitate learning and champion change. \(^ {17,18} \) Development of the DKA pathway achieved these goals through the collaboration of nurses, physicians, and other health care professionals. This pathway was the first developed at SCH; hence, the longer, 2-year, process. Subsequent pathway development using similar methodology for other pediatric conditions within our institution has required development time frames of 3 to 6 months.
Implementation of standard work for DKA has resulted in the following: (1) education of our care staff regarding contemporary management of DKA; (2) composition of a standard electronic DKA order set that forces compliance with the guidelines; (3) reduction in the risk of hypokalemia by adding potassium salts to IV fluids at the time of insulin initiation; (4) recognition of the trajectory and resolution of DKA per serial BOHB measurements resulting in shorter, more consistent use of ICU resources; (5) possible reduction in the risk of cerebral edema; and (6) recognition of the requirement for ongoing system monitoring to identify unintended consequences and to facilitate iterative improvement and sustainability.

FIGURE 4
A, Percentage of patients with hypokalemia and the mean number of hypokalemia results per patient. B, Time from arrival to start of insulin infusion and time from arrival to start of potassium-containing fluids. Dark gray lines: mean minutes from arrival to start of insulin infusion. Light gray lines: mean minutes from arrival to start of potassium-containing fluids.
Implementation of DKA standard work using our tools would be difficult at institutions that do not use CPOE. Although most of our effort to develop DKA standard work involved intricacies of electronic orders, the forcing function of CPOE in terms of compliance is at once complex but powerful. An important limitation of this report revolves around lack of statistical power for events that occur rarely (eg, overt cerebral edema). We found no changes in the incidence of cerebral edema within the relatively short time interval of 16 months post–pathway implementation, during a time period of iterative changes. Because of the relatively rare occurrence of cerebral edema, longer term data collection is needed for meaningful interpretation of this adverse event. The introduction of the 2-bag system constituted a large change in practice, although it may be commonly used at many institutions, perhaps not in an electronic format and less rigorously standardized.

Multidisciplinary, electronic pathway management is time consuming and costly. However, the DKA pathway appears to be cost-efficient while ensuring safer management of patients with DKA. Further studies are needed with health economist oversight to gauge the actual cost savings on the overall health care system.

Key steps to further improve performance and adherence to guidelines include continuing to address the fundamentals of “why” (understanding the evidence and pathophysiology of DKA) before the “how” (electronic medical record resources) and “what” (standardized guidelines). Continued provider education of basic pathophysiology is essential to sustain engagement and safe medical practice, the most difficult task in development of standard work. In addition, community outreach and education are required to achieve a shared mental model of pediatric DKA care among regional community hospitals and adult ED settings.

Case ascertainment using only ICD-9 codes for DKA resulted in inclusion of all patients with hyperglycemia and ketosis without acidosis per code definition. Hence, we decided to add insulin infusion to better define the population with a true DKA diagnosis. Other studies have used only the 250.1 ICD-9 code that likely included patients who were not undergoing DKA, which might explain the relatively large “DKA” patient populations and conclusions confounded by selection bias due to poor case ascertainment, a common pitfall with electronic medicine data collection. Similarly, our cerebral edema case ascertainment is based on both ICD-9 code as well as having received mannitol or hypertonic saline as therapy to avoid such pitfalls. Additional detailed individual patient chart review by a pediatric endocrinologist included all patients with an ICD-9 code of cerebral edema (348.5), and case ascertainment was found to be consistent with the above.

Specific criteria for admitting patients with DKA to the ICU were in place at the initiation of this study, but criteria for transfer out of the ICU were vague and likely influenced the longer baseline ICU length of stay. As part of iterative improvements, we formulated ICU DKA discharge criteria on the basis of BHOB trajectory, which resulted in significant reduction in ICU length of stay.

CONCLUSIONS
Practice variability and patient safety issues in DKA management prompted development of, implementation of, and improvement in our DKA clinical standard work. Electronic clinical decision support facilitated the implementation of clinical change by hardwiring desired clinical decision-making. Even with these resources, continual surveillance and iterative improvements are necessary to ensure sustainability of clinical improvements and prompt resolution of safety issues.

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