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Research Article

Complications of Potassium Infusion in PICU Patients with Diabetic Ketoacidosis: An Observational Study

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ABSTRACT

Background: The most severe complication of type 1 diabetes mellitus is diabetic ketoacidosis (DKA). Hypokalemia, a common electrolyte disturbance in DKA, can be life-threatening and often worsens during treatment. A significant clinical debate exists regarding the optimal route of potassium administration—central versus peripheral lines. Current guidelines recommend aggressive potassium replacement but lack consensus on the safest administration method. This study investigated the safety and complications of high-concentration peripheral potassium administration in pediatric DKA patients within an intensive care setting.

Methods: This observational study, conducted at the PICU of Bahrami Children's Hospital, enrolled 55 pediatric patients with DKA requiring high-concentration potassium supplementation (50, 60, or 70 mEq/L) through peripheral veins. Potassium chloride was administered in normal saline with dosing stratified by serum potassium levels checked every 2 hours. Primary analyses examined associations between infusion-related complications (phlebitis, pain, erythema, burning sensation) and potassium concentration, infusion duration, DKA severity, and patient characteristics.

Results: Among 55 patients (mean age: 8.7 ± 4.1 years; 52.7% male), 32 patients (58.2%) received 50 mEq/L, 21 patients (38.2%) received 60 mEq/L, and 2 patients (3.6%) received 70 mEq/L. Of these, 25 patients (45.5%) required infusion duration exceeding 6 hours. Hypokalemia occurred in 30.9% of patients, with higher prevalence in severe DKA (44.4%). A total of eight patients (14.5%) experienced a total of 10 infusion-related complications. These included one case of phlebitis (1.8%), five cases of injection site pain (9.1%), and four cases of burning sensation (7.3%). Infusion duration exceeding 6 hours significantly increased complication risk (OR: 5.7; 95% CI: 2.01-16.56; p=0.042), with combined high concentration and extended duration showing elevated risk (adjusted OR: 3.1; 95% CI: 1.86-5.24; p=0.003).

Conclusion: In pediatric DKA patients receiving care in the PICU setting, peripheral potassium infusion at concentrations up to 60 mEq/L demonstrates acceptable safety outcomes when administration duration remains under 6 hours and rigorous monitoring protocols are implemented. However, for infusions exceeding 6 hours, our findings suggest careful consideration of alternative approaches may be warranted, particularly at higher concentrations.

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Introduction

Type 1 diabetes mellitus (DM1) is the most common endocrine disease in childhood and adolescence, with approximately 542,000 children affected worldwide and 8,600 new cases identified annually [1]. The most life-threatening complication of DM1 is diabetic ketoacidosis (DKA), which occurs due to severe insulin deficiency and poor glycemic control. Among children with newly diagnosed DM1, the incidence of DKA varies significantly across geographical regions, ranging from 15% to 67%, with mortality rates between 0.15% and 0.31% [2].

DKA is characterized by hyperglycemia (blood glucose >11 mmol/L or 200 mg/dL), acidosis (venous pH <7.3 or serum bicarbonate levels <18 mg/dL), and ketonemia (blood hydroxybutyrate ≥3 mmol/L) or moderate to large ketonuria [3]. DKA severity is categorized by biochemical parameters [4].

A critical aspect of DKA management is maintaining appropriate serum potassium levels. Hypokalemia is a common electrolyte disturbance in diabetic ketoacidosis (DKA), which is less common at presentation but increases significantly to up to 90% during treatment [5]. Multiple factors contribute to potassium depletion in these patients, including insulin therapy, osmotic diuresis, and elevated levels of counter-regulatory hormones such as glucagon and hydrocortisone. Severe hypokalemia can lead to life-threatening complications, including cardiac arrhythmias, respiratory muscle weakness, muscle necrosis, and ascending paralysis [6-7].

Given these risks, both the American Diabetes Association (ADA) and the International Society for Pediatric and Adolescent Diabetes (ISPAD) emphasize the importance of monitoring potassium levels before and during insulin therapy. Current guidelines present clinicians with a therapeutic dilemma: while the 2022 ISPAD and Specialist Pharmacy Service guidelines recommend using central lines for potassium concentrations exceeding 0.5 mEq/kg/hour or 40 mEq/L to prevent phlebitis, they simultaneously advise against central venous access in DKA patients due to increased thrombosis risk, particularly in the setting of hyperosmolar blood [3].

Some evidence suggests that peripheral administration of potassium may be better tolerated when infused in saline rather than sterile water and that the addition of lidocaine might reduce infusion-related discomfort and inflammation [6, 8]. However, comprehensive data regarding the safety and complications of high-concentration potassium administration through peripheral veins in pediatric DKA patients remains limited, particularly in the intensive care setting.

We aimed to investigate the complications associated with peripheral administration of high-concentration potassium (>40 mEq/L) in pediatric DKA patients with hypokalemia admitted to a tertiary care PICU. Our primary objective was to determine the frequency and severity of infusion-related complications across different potassium concentrations. These findings will contribute to establishing evidence-based recommendations for the safe peripheral administration of high-concentration potassium in this vulnerable patient population.

Methods

Study Design

This observational study was conducted at the PICU of Bahrami Children's Hospital, a tertiary care center affiliated with Tehran University of Medical Sciences, from April 2020 to March 2021. The study protocol was approved by the institutional ethics committee of Tehran University of Medical Sciences (approval code: IR.TUMS.CHMC.REC.1400.023).

Setting and Participants

The study enrolled consecutive patients admitted with diabetic ketoacidosis (DKA) who required high-dose potassium supplementation (>40 mEq/L) through peripheral intravenous (IV) lines. Patients were enrolled in the study when they first required potassium supplementation at concentrations exceeding 40 mEq/L based on their serum potassium levels. Patients who initially received lower potassium concentrations (<50 mEq/L) and were later escalated to higher concentrations were included from the point of escalation. Patients with central venous access or those who required central line insertion during the study period, as well as those with incomplete records or withdrawal of consent, were excluded.

The diagnosis of DKA was confirmed by board-certified pediatric intensivists according to the ISPAD criteria, which define DKA as blood glucose >11 mmol/L (≈200 mg/dL), venous pH <7.3, serum bicarbonate <18 mEq/L, and presence of ketonemia or ketonuria. The severity of DKA was categorized based on biochemical parameters: mild (venous pH <7.3, serum bicarbonate <15 mEq/L), moderate (venous pH <7.2, serum bicarbonate <10 mEq/L), or severe (venous pH <7.1, serum bicarbonate <5 mEq/L), in conjunction with mental status assessment [3].

Potassium administration and measurement

DKA management followed the ISPAD 2022 guidelines. Serum potassium levels were measured every two hours, and potassium replacement was administered according to our institutional protocols, which are aligned with ISPAD recommendations. Specifically, potassium

concentrations were selected as follows: 50 mEq/L when serum potassium was 3.5–4.0 mEq/L; 60 mEq/L when serum potassium was 3.0–3.5 mEq/L; and 70 mEq/L when serum potassium was 2.5–3.0 mEq/L. Subsequent treatment with lower potassium concentrations was outside the scope of this study and was not recorded. Based on their potassium concentrations, patients were categorized into three groups (50, 60, and 70 mEq/L), and the duration of potassium administration at each concentration was recorded. Follow-up continued until the potassium requirement decreased to 40 mEq/L or less.

Potassium chloride (KCl) was administered at a maximum rate of 0.5 mEq/kg/hour via infusion pump. Potassium was added directly to the maintenance and deficit fluids, which typically consisted of normal saline during the early phase of resuscitation and transitioned to dextrose-containing solutions when blood glucose levels dropped below 300 mg/dL. In all cases, potassium was infused as part of the primary IV fluid; no separate potassium-only infusions or additional IV lines were used. The number of active IV infusions per patient was limited to one, administered through a single peripheral catheter.

Peripheral venous catheters were placed in the upper extremities (forearm or hand) in all patients. Catheter sizes ranged from 20G to 24G, selected based on patient age, vein caliber, and infusion requirements. Infusion sites were evaluated hourly by trained nursing staff using the standardized Visual Infusion Phlebitis (VIP) score.
If complications such as pain, swelling, erythema, or phlebitis occurred, the findings were promptly documented, and the catheter was immediately replaced to ensure patient safety, in accordance with the institutional treatment protocol.

Data Collection and Outcome Measures

Data collection was performed using a structured questionnaire that gathered information on patient demographics (age, gender), clinical parameters (DKA severity, initial serum potassium level, duration of potassium infusion), and complications. Phlebitis-related complications were assessed using standardized tools, including the VIP score for phlebitis (0-5 scale), measurement of erythema diameter, and age-appropriate pain scales. For verbal children, the Wong-Baker FACES Pain Rating Scale was used, while the FLACC (Face, Legs, Activity, Cry, and Consolability) scale was employed for non-verbal children. All assessments were performed by trained nursing staff and verified by the attending physician every 6 hours.

Sample size was determined based on the formula for estimating a proportion in the population, assuming a prevalence of 5.6% [9], a confidence level of 95%, and a margin of error of 10%. This calculation yielded a minimum required sample size of 21 patients. The study initially screened 61 pediatric patients with diabetic ketoacidosis (DKA). Of these, 6 patients were excluded based on the inclusion and exclusion criteria: 3 patients had central venous lines, and 3 patients had incomplete medical records. The final study population included 55 eligible patients who were followed prospectively for outcomes related to high-concentration potassium infusions.

All collected data were entered into SPSS version 26.0. Continuous variables were expressed as mean ± standard deviation or median (interquartile range) based on their distribution as assessed by the Shapiro-Wilk test. Categorical variables were presented as frequencies and percentages. The relationship between complications and patient characteristics was analyzed using the chi-square or Fisher's exact test for categorical variables and the Student's t-test or Mann-Whitney U test for continuous variables. Logistic regression analysis was performed to identify independent risk factors for phlebitis development. Statistical significance was set at $p< 0.05$. To ensure data quality, all staff received standardized training before study initiation, and data collection processes were monitored regularly. Critical measurements were verified by two independent observers. Missing data were handled using multiple imputation techniques when appropriate.

Results

Demographic and Baseline Characteristics

A total of 55 patients received high-concentration potassium infusions (>40 mEq/L) and were included in the final analysis. The study population ranged in age from 1-18 years, with a mean age of 8.7 years. The gender distribution comprised 26 females (47.3%) and 29 males (52.7%).

In terms of potassium administration, 32 patients (58.2%) received 50 mEq/L, 21 patients (38.2%) received 60 mEq/L, and 2 patients (3.6%) received 70 mEq/L through peripheral veins. Among those receiving 50 mEq/L, the administration duration varied, with 14 patients (25.5%) receiving it for 2 hours, 9 patients (16.4%) for 4 hours, 4 patients (7.3%) for 6 hours, 3 patients (5.5%) for 8 hours, and 2 patients (3.6%) for 10 hours. In the 60 mEq/L group, 14 patients (66.7%) received potassium for 2 hours, 3 patients (5.5%) for 4 hours, 1 patient (1.8%) for 8 hours, 2 patients (3.6%) for 10 hours, and 1 patient (1.8%) for 12 hours. The two patients receiving 70 mEq/L had infusion durations of 6 and 8 hours, respectively (Table 1).

Of the patients receiving more than 40 mEq/L potassium, 17 patients (30.9%) had hypokalemia (serum potassium < 3.5 mEq/L) based on last serum potassium levels before high-dose peripheral administration, while 38 patients (69.1%) had normal potassium levels.

DKA severity distribution showed 12 patients (21.8%) with mild DKA, 16 patients (29.1%) with moderate DKA, and 27 patients (49.1%) with severe DKA.

Hypokalemia was observed in 1 case (8.3%) among mild DKA patients, 4 cases (25%) in moderate DKA, and 12 cases (44.4%) in severe DKA patients. The analytical result was borderline statistically significant (p=0.049), suggesting a near-significant relationship between higher DKA severity and the occurrence of hypokalemia. Patients with severe DKA demonstrated longer mean infusion duration (5.0 hours; 95% CI: 3.9-6.4) compared to mild cases (3.3 hours; 95% CI: 2.3-4.5).

Infusion-Related Complications

A total of eight patients (14.5%) experienced infusion-related complications. The observed complications included one case of phlebitis (1.8%) manifesting as hardness, pain, burning, and redness at the infusion site; five cases of injection site pain (9.1%); and four cases of a burning sensation at the infusion site (7.3%). Notably, two patients experienced both pain and a burning sensation simultaneously, accounting for the overlap in the total number of complications (Table 1).

Of the patients who received 50 mEq/L and experienced complications, two received potassium for 2 hours and one for 8 hours. Among those receiving 60 mEq/L with complications, two patients received it for 12 hours, one for 10 hours, and one for 2 hours. The patient who developed phlebitis had received 70 mEq/L for 6 hours. The patient who developed phlebitis received 70 mEq/L. Notably, two patients experienced both pain and burning sensation simultaneously (Table 1).

Risk Factor Analysis for Complications

Infusion durations exceeding 6 hours were associated with a 5.71-fold increased risk of complications (95% CI: 2.01-16.56; p=0.042). However, there was not found any significant relation between potassium concentrations administered via peripheral line and complication rate (p=0.125).

Multivariate analysis of concentration and duration revealed that the concurrent presence of high concentration (≥60 mEq/L) and infusion duration >6 hours was associated with a 3.1-fold increased risk of complications (95% CI: 1.86-5.24; p=0.003). This relationship remained significant after adjusting for age, gender, and DKA severity.

The incidence of complications was 1/12 (8.3%) in the mild DKA group, 2/16 (12.5%) in the moderate DKA group, and 5/27 (18.5%) in the severe DKA group. No significant association was found between the severity of DKA and the occurrence of complications related to potassium infusion (p=0.681).

Gender analysis of complications revealed that among patients with injection site pain, four were female and one was male. In the group experiencing a burning sensation, there was an equal distribution of two females and two males, while the patient with phlebitis was female. Although female patients showed a higher likelihood of developing complications compared to male patients (OR: 1.80; 95% CI: 1.15-2.88), this association was not statistically significant (p=0.131). Age distribution showed that patients with burning sensation were 7, 10, and 12 years old, while those experiencing pain were 5, 6, 7, 10, and 18 years old. The patient who developed phlebitis was 7 years old. Age demonstrated no significant correlations with complication occurrence (9.6 ± 4.3 years in patients with complications vs. 8.5 ± 4.1 years in the other group; p = p=0.492) (Table 2). Further statistical analysis revealed no significant correlations between severity of DKA and gender (p=0.092) or age (p=0.397).

Table 1- Demographic, Clinical, and Laboratory Status of Patients Based on Administered Potassium Concentration.

Potassium concentration (mEq/L)	N (%)	Age (years)	Gender		[1]DKA severity		
			Male N (%)	Female N (%)	Mild N (%)	Moderate N (%)	Severe N (%)
50	32 (58.2%)	8.8 ± 4.2	16 (50%)	16 (50%)	8 (25%)	11 (34.4%)	13 (40.6%)
60	21 (38.2%)	8.7 ± 4.2	12 (57.1%)	9 (42.9%)	4 (19.0%)	4 (19.0%)	13 (61.9%)
70	2 (3.6%)	7.0 ± 0.0	1 (50.0%)	1 (50.0%)	0 (0.0%)	1 (50.0%)	1 (50.0%)
Total	55 (100%)	8.7 ± 4.1	29 (52.7%)	26 (47.3%)	12 (21.8%)	16 (29.1%)	27 (49.1%)

Potassium concentration (mEq/L)	Hypokalemia N (%)	Infusion duration (hour)	Complication			
			Pain N	Erythema N	Burn sensation N	Phlebitis N
50	5 (15.6%)	4.1 ± 2.5	3	0	3	0
60	10 (47.6%)	4.1 ± 3.3	2	0	1	0
70	2 (100.0%)	7.0 ± 1.4	0	0	0	1
Total	17 (30.9%)	4.2 ± 2.8	5	0	4	1

Note: Values are presented as Number (%) and Mean ± SD. [1]DKA: Diabetic ketoacidosis

Table 2- Univariate Analysis of Factors Associated with Complications in DKA.

Valuable		OR (95% CI)	P value
Age		1.07 (0.89-1.28)	0.492
Gender	Female	1.80 (1.15-2.88)	0.131
DKA Severity	Moderate	1.69 (0.14-21.27)	0.684
	Severe	2.39 (0.25-23.00)	0.450
Potassium Concentration		2.69 (0.76-9.58)	0.125
Duration of Administration	>6 hours	5.71 (2.01-16.56)	0.042

Discussion

This study provides valuable insights into the administration of high-concentration potassium (>40 mEq/L) via peripheral veins in PICU patients with DKA, while simultaneously highlighting the complex challenges in electrolyte management.

The use of potassium concentrations >40 mEq/L is recommended by the current guidelines from the ADA and ISPAD to rapidly correct hypokalemia in DKA. However, these guidelines also advise using central venous access to mitigate the risk of phlebitis with high-concentration infusions. However, the use of central lines introduces risks such as thrombosis, cardiac complications, and procedural challenges, particularly in pediatric patients [10-11]. Carlotti et al. underscored the importance of tailored potassium therapy to minimize complications, including hypokalemia and infusion-related irritation, but also highlighted the risks of prolonged potassium administration [12].

The present findings suggest that peripheral administration above 40 mEq/L can be managed with careful protocols, though not without risks.

Our observed phlebitis rate of 1.8% is notably lower than previous studies, possibly due to our stringent monitoring protocols or our smaller sample size [8]. According to the study by Khalidi et al., phlebitis occurred in 19% of patients who received KCl through peripheral veins. Factors such as age, sex, race, and the dosing and concentration levels of potassium administered did not show a significant correlation with the occurrence of phlebitis. However, phlebitis significantly increased with the duration and rate of infusion [8]. This finding is consistent with the results of this study, which showed that infusion duration, rather than potassium concentration alone, significantly correlates with infusion site complication risk.

Multivariate analysis revealed a critical insight: the concurrent presence of high concentration (≥60 mEq/L) and infusion duration exceeding 6 hours was associated with a 3.1-fold increased complication risk. This finding underscores the importance of not just monitoring potassium concentration but also carefully managing infusion duration.

Hypokalemia, observed in 30.9% of the patients, aligns with Wong et al., who documented hypokalemia in 38% of DKA cases, typically occurring within 2–9 hours of initiating insulin therapy [13]. Importantly, no significant demographic disparities were found, suggesting that adherence to modern guidelines and the use of balanced crystalloids can help mitigate the risk of severe hypokalemia across patient populations [14]. Our findings suggest a borderline significant relationship between DKA severity and hypokalemia (p=0.049), indicating a potential clinical association. Similar results have been reported by Lee et al. and Wong et al., who identified an association between DKA severity and hypokalemia, suggesting that further research is needed to clarify these associations [5, 13].

Studies have proposed practical solutions for minimizing peripheral infusion complications. The addition of lidocaine to high-concentration potassium solutions can delay or alleviate KCl infusion pain, as reported in the Khalidi study [8]. Furthermore, Moulik et al. found that malnutrition exacerbated therapy-induced complications, highlighting the need for nutritional assessments when planning DKA treatment [15].

However, we must explicitly acknowledge the study's significant limitations. The single-center design, relatively small sample size, and particularly limited data for higher potassium concentrations (≥60 mEq/L) substantially restrict the generalizability of our findings. These constraints mean our results should be interpreted as preliminary observations rather than definitive clinical guidelines. Future research should focus on comprehensive, multi-center studies with larger cohorts to validate these initial findings. Researchers should prioritize investigating the detailed mechanisms linking DKA severity to hypokalemia, exploring long-term outcomes of different potassium administration strategies, evaluating the efficacy of adjunctive measures like lidocaine augmentation, and understanding the impact of nutritional status on potassium management.

Conclusion

In pediatric DKA patients receiving care in the PICU setting, peripheral potassium infusion at concentrations up to 60 mEq/L demonstrates acceptable safety outcomes when administration duration remains under 6 hours and

rigorous monitoring protocols are implemented. However, for infusions exceeding 6 hours, our findings suggest careful consideration of alternative approaches may be warranted, particularly at higher concentrations. Future multi-center research should focus on optimizing safety protocols and exploring innovative strategies for prolonged potassium replacement in this vulnerable population.

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Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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