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ORIGINAL ARTICLE

Evaluation of Point-of-Care Blood Glucose Measurements in Patients with Diabetic Ketoacidosis or Hyperglycemic Hyperosmolar Syndrome Admitted to a Critical Care Unit

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Abstract

Background:

Point-of-care (POC) blood glucose (BG) measurement is currently not recommended in the treatment of patients presenting with diabetic ketoacidosis (DKA) or hyperglycemic hyperosmolar syndrome (HHS).

Methods:

We prospectively evaluated and compared capillary and venous POC BG values with laboratory venous glucose in patients with DKA or HHS admitted to one critical care unit over 8 months.

Results:

Venous laboratory glucose was strongly correlated with venous (r = 0.98) and capillary (r = 0.96) POC glucose values, though POC glucose values were higher than venous laboratory values (venous POC 21 ± 3 mg/dl, capillary POC 30 ± 4 mg/dl; both $p < .001$). Increased plasma osmolality had no effect on glucose meter error, while acidemia (pH < 7.3) was associated with greater glucose meter error ($p = .04$) independent of glucose levels. Comparing hypothetical insulin infusion rates based on laboratory venous glucose to actual infusion rates based on POC glucose values showed that 33/61 insulin infusion rates would have been unchanged, while 28 out of 61 rates were on average 7% ± 2% higher. There were no instances of hypoglycemia in any of the patients.

Conclusions:

Overall, both venous and capillary POC BG values were safe for the purpose of titrating insulin infusions in patients with severe hyperglycemia. Acidemia, but not hyperosmolality, increased POC BG value errors.

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Abbreviations: (BG) blood glucose, (DKA) diabetic ketoacidosis, (ED) emergency department, (FDA) Food and Drug Administration, (HHS) hyperglycemic hyperosmolar syndrome, (ICU) intensive care unit, (ISO) International Standards Organization, (MCICU) medical cardiac intensive care unit, (POC) point of care

Keywords: accuracy, blood glucose, hyperglycemic hyperosmolar syndrome, ketoacidosis, point of care

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Introduction

Diabetic ketoacidosis (DKA) and hyperglycemic hyperosmolar syndrome (HHS) are common hyperglycemic emergencies that require hospitalization. While some hospitals, including our own, have protocols that allow some patients with DKA to be admitted to acute care units,[1,2] the majority of DKA and HHS patients require admission to an intensive care unit (ICU) for management, including intravenous insulin administration. Simulation modeling of medical errors based on current quality specifications for point-of-care (POC) blood glucose (BG) meters suggests that using POC rather than venous laboratory glucose to determine insulin infusion rates can cause differences >50% in the administered insulin doses.[3] These estimates are based on previous studies that demonstrated increased POC glucose meter error relative to laboratory glucose measurement among critically ill patients.[4–7] Accordingly, the U.S. Food and Drug Administration (FDA) has requested that all hospital glucose meters include a limitation of use statement indicating that the device is not intended to be used in critically ill patients. This would not disallow use of POC glucose meters in ICU patients but does make measuring POC BG in ICU patients an off-label use. Importantly, similar to other ICU patients, patients with DKA/HHS frequently have comorbid conditions that could decrease the accuracy of POC plasma glucose estimation from whole blood, including dehydration, hypoperfusion, acidosis, and hyperosmolality.[8,9] This institution's current glucose meter manufacturer guidelines recommend not using Accu-Chek POC BG meters in patients presenting with DKA or in critically ill patients with HHS.[10] One small study has shown a good correlation between POC and venous BG in pediatric DKA patients,[11] while an emergency room study in patients with suspected DKA showed that an Abbott glucose meter systematically underestimated BG values (on average by ~115 mg/dl).[12] Importantly, counter to manufacturers' guidelines, in practice, POC glucose results are commonly used to adjust insulin infusion rates in critically ill patients,[13] including those with hyperglycemia, DKA, and HHS. Accordingly, this study investigated the accuracy of capillary and venous POC glucose in comparison with laboratory BG results among adult DKA/HHS patients admitted to the ICU. Additionally insulin infusion errors due to POC glucose meter use were evaluated.

Methods

A prospective, cross-sectional study was conducted on all nonpregnant adult subjects admitted from the emergency department (ED) to the Harborview Medical Center medical cardiac intensive care unit (MCICU) from February 2011 through November 2011 with a primary diagnosis of DKA or HHS. All subjects received standard-of-care treatment both in the ED and in the MCICU. DKA/HHS Critical Care Orders and study procedures were reviewed with the registered nurses working on this unit. The admitting registered nurse obtained venous blood for laboratory testing per DKA/HHS Critical Care Orders (see **Appendix A**) on admission and again 2 and 4 h postadmission. At each time point, one drop of the venous blood was applied to the study Accu-Chek test strip lot (lot 551388) and measured using a single designated ROCHE Inform meter (uj67005478) used exclusively for the study to reduce lot-to-lot and interinstrument variability.[14] Levels 1 and 2 quality control testing (lot 900) were performed on the study meter no more than 24 h prior to use. A capillary POC glucose measure was obtained from the patient using the study test strip lot and glucose meter within 15 min of each laboratory draw. Blood laboratory glucose was collected in a lime green PST tube containing lithium heparin without a metabolic inhibitor. Proximate arterial or venous pH, plasma osmolality, hematocrit, and insulin infusion rates, when available, were obtained by chart review. Using the DKA/HHS critical care orders and decision tree/algorithms (see **Appendix B and C**), the difference between actual insulin infusion rates based on capillary POC glucose and hypothetical insulin infusion rates based on laboratory venous glucose values was calculated. At our institution, patients are converted from a DKA/HHS protocol to a standard intravenous insulin protocol when BG values have stabilized at the 200–300 mg/dl range for 4 h. Clinical outcomes for all subjects in our study, including hypoglycemia <70 mg/dl and venous laboratory values that decreased >75 mg/dl (maximum ideal decrease per the DKA/HHS protocol) were evaluated. Data presented are means ± standard error of the mean unless otherwise indicated. Null hypothesis was rejected at a p value < .05 determined by Student's t-test, chi square test, or Fischer's exact test as indicated in the following section. This study was approved by the University of Washington, Human Subjects Division (IRB 616-2345).

Results

Study Subjects and Glucose Data

A total of 84 potential time points were obtained from 28 patients with a maximum of three time points included per patient. Eliminating all capillary and venous POC results beyond the 15 min cutoff, as well as missing venous or capillary POC results, yielded 66 glucose pairs (laboratory versus venous POC) and 61 glucose pairs (laboratory versus capillary POC) analyzed further in the following. Of these, 45 time points contributed all three glucose values. The mean laboratory glucose was 340 ± 25 mg/dl (range 88–1186 mg/dl). The mean hematocrit was 36.6% ± 6.4% with a range of 23–52%, meaning that none of the 28 patients had a hematocrit value outside the Accu-Chek reference range of 20–55% for BG > 200 mg/dl.[10]

Timing of Point-of-Care and Laboratory Sampling and Reporting

Venous POC BG was performed at the same time that the venous blood sample was drawn for measuring laboratory BG. The mean time elapsed between the venous POC BG and the time stamp on the laboratory blood sample was 4.0 ± 0.4 min, suggesting that this was mean time elapsed for samples to be transported from the ICU to the clinical laboratory. The time interval from when venous blood arrives in the laboratory until glucose values are reported in the electronic medical record is significant. Fifty percent of stat laboratory glucose values are reported within 27 min, while 95% of values are reported within 48 min. The mean time difference between the blood draw (venous POC) and the capillary POC was also 4.0 ± 0.4 min.

Correlation of Venous Laboratory and Venous Point-of-Care Glucose Values

Venous laboratory and POC glucose values were strongly correlated (**Figure 1A**; $r = 0.98$, $p < .001$). Excluding POC readings of "HI" (>600 mg/dl; **Figure 1A**, open squares), 40 out of 56 POC glucose values were greater than the matched laboratory values. Mean divergence of venous POC glucose was 21 ± 3 mg/dl higher than the laboratory glucose, while the mean percentage deviation was 7.4% ± 0.7% and did not differ between laboratory glucose values <200 mg/dl (6.4% ± 0.9%) and laboratory glucose values ≥200 mg/dl (7.9% ± 1.0%; $p = .32$). The International Standards Organization (ISO) standard 15197 for glucose meters adopted by the FDA requires that 95% of POC glucose results must be within 20% of the paired laboratory glucose value.[15] In our study, only 2 of the 56 (4%) venous POC glucose pairs diverged by >20%, thus meeting the ISO standard 15197. Laboratory glucose values were >500 mg/dl for all 10 HI venous POC glucose readings.

Correlation of Venous Laboratory and Capillary Point-of-Care Glucose Values

Venous laboratory and capillary POC glucose values were also strongly correlated (**Figure 1B**; $r = 0.97$, $p < .001$), with the exception of two outliers described in the following. Excluding POC readings of HI, 46 of 50 POC glucose values were greater than matched laboratory values, and mean divergence of capillary POC glucose was 30 ± 4 mg/dl from laboratory glucose, exceeding the divergence of the venous POC glucose values ($p = .04$ versus venous POC BG difference from laboratory glucose by Student's *t*-test). Ten out of 50 (20%) glucose pairs diverged by >20%, exceeding the ISO standard 15197 and exceeding divergence in the venous POC group ($p < .001$ versus venous POC, by Fischer's exact test). For 2 of the 11 HI capillary POC glucoses (**Figure 1B**, open squares), the laboratory glucose values were <500 mg/dl (447 and 365 mg/dl). In addition, there were two (3%) low outliers for capillary POC glucose, one with a POC value of 445 mg/dl when the laboratory glucose was 1186 mg/dl and one with a POC value of 213 mg/dl when the laboratory glucose was 476 mg/dl (**Figure 1B**, diamond symbols), which were not included in the correlation analysis. Only one of these two patients showed a consistent large divergence between the capillary POC and laboratory venous BG values. Importantly, divergence between venous POC and laboratory BG was similar to other subjects, suggesting a peripheral, rather than systemic, factor, but the patient's blood pressure was normal and the physical exam did not mention edema or cyanosis. As expected based on published data,[16] the capillary POC glucose meter error was higher (+38 ± 6 mg/dl) for laboratory glucose values between 200 and 400 mg/dl (mean 292 ± 12 mg/dl) compared with laboratory glucose values <200 mg/dl (mean 148 ± 12 mg/dl) for which the divergence between capillary POC and laboratory venous glucose was only +16 ± 3 mg/dl ($p < .001$ by Student's *t*-test), causing a divergence between the regression line (**Figure 1B**, black line) and the line of identity (**Figure 1B**,

dashed line). However, the mean percentage deviation of capillary POC glucose values was not different for laboratory glucose values <200 mg/dl (12.1% ± 2.8%) compared with laboratory glucose values between 200 and 400 mg/dl (11.6% ± 1.5%; $p = .86$) or laboratory glucose values >400 mg/dl (15.2% ± 5.5%; $p = .56$). The mean percentage deviation from laboratory glucose was higher for capillary POC BG values than for venous POC BG values ($p < .001$).

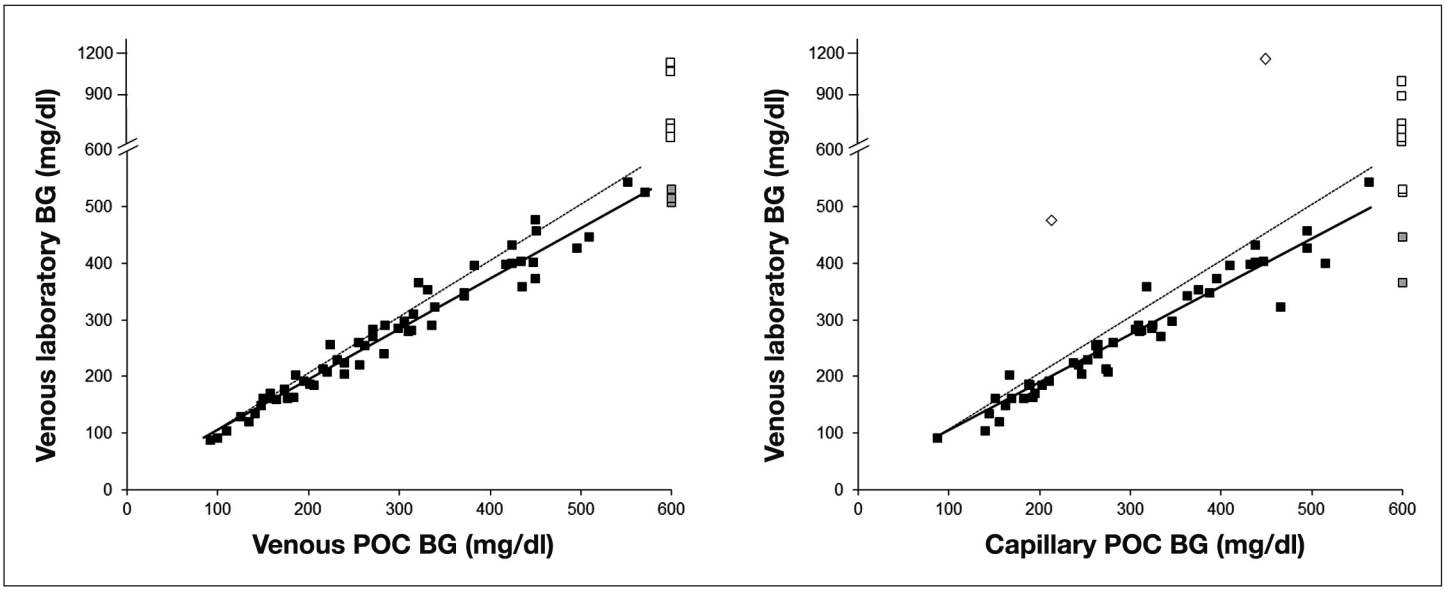

Figure 1. (**A**) Correlation between venous laboratory BG values and venous POC BG values in patients with DKA/HHS. Regression line is shown for 56 pairs from 29 patients ($r^2 = 0.96$; $p < .001$). Blood glucose pairs with glucose meter readings of HI are shown as open squares ($n = 10$) and are not included in the correlation. (**B**) Correlation between venous laboratory BG values and capillary POC BG values in patients with DKA/HHS. Regression line is shown for 49 pairs from 29 patients ($r^2 = 0.93$; $p < .001$). Blood glucose pairs with glucose meter readings of HI are shown as squares ($n = 11$) and are not included in the correlation. Gray squares indicate two of the glucose pairs for which the glucose meter reading of HI corresponded to laboratory glucose value <500 mg/dl. Open diamonds indicate two outlier glucose pairs for which the capillary POC BG value was much lower than the laboratory glucose value, and these outliers were not included in the correlation. For both graphs, the solid line is the regression line and the dashed line is the line of identity between the two tests.

The Effect of pH and Osmolality on Glucose Meter Error

We subsequently evaluated the effect of blood pH and osmolality on the difference between capillary POC and laboratory venous glucose values. A total of 33 capillary POC and laboratory glucose pairs were identified with a proximate plasma osmolality measure (less than 15 min). Osmolality was >315 mOsm/liter for 14 pairs (mean 325 ± 2 mOsm/liter) and ≤315 mOsm/liter for 19 pairs (mean 305 ± 1 mOsm/liter; $p < .001$). The divergence between capillary POC and venous laboratory glucose was not different between the two osmolality groups: 53 ± 18 mg/dl for >315 mOsm/liter and 31 ± 10 mg/dl for pairs ≤315 mOsm/liter, $p = .22$. There was a significant difference in mean plasma glucose between the two groups (>315 mOsm/liter, 375 ± 22 mg/dl, versus ≤315 mOsm/liter, 222 ± 22 mg/dl; $p < .001$).

In contrast, plasma pH did affect glucose meter error. A total of 31 capillary POC and laboratory glucose pairs were identified with a proximate plasma pH (less than 15 min). When plasma pH was less than 7.3, the difference between capillary POC and venous laboratory glucose values was 56 ± 20 mg/dl ($n = 13$), while for samples with plasma pH ≥ 7.3 ($n = 18$), the glucose difference was only 24 ± 4 mg/dl (**Figure 2**; $p = .03$). Importantly, there was no significant difference in mean venous glucose values between the two groups (pH < 7.3, 284 ± 40 mg/dl, versus pH ≥ 7.3, 278 ± 21 mg/dl; $p = .6$). This finding was also present when examining the difference between venous POC glucose and laboratory venous glucose, which was 27 ± 6 mg/dl when pH was <7.3 and only 11 ± 2 mg/dl when pH was ≥7.3 (**Figure 2**; $p = .03$).

Evaluation of Insulin Infusion Rates Based on Capillary Point-of-Care versus Laboratory Glucose Values

Insulin infusion rates would not have changed for 33 of the 61 (54%) time points. Of the remaining 28 time points, rates would have been higher for 24 of the 61 (39%) time points and lower for only 4 of the 61 (7%) time points. On average,

the diverging insulin infusion rates were only 7% ± 2% higher using capillary POC glucose than would have occurred using laboratory glucose values (i.e., 3.2 U/h (POC) instead of 3 U/h (laboratory)). Of the insulin infusion rates that would have been different using laboratory glucose values, 18 of the 28 had a difference of ≤1.0 U/h, 8 of the 28 demonstrated a difference of 1.2–2.0 U/h, and 2 of the 28 had a rate difference of 3–4 U/h. Examining clinical outcomes, we found no instances of hypoglycemia (glucose <70 mg/dl). Evaluating the glucose difference between consecutive laboratory samples 2 h apart identified 35 intervals for which we could calculate a mean hourly glucose decrease. Of these, 6 resulted in a decrease of >75 mg/dl/h (ideal BG decrease is 50–75 mg/dl/h). In all 6 instances, the insulin infusion rate based on the capillary POC glucose was identical to the hypothetical insulin infusion rate based on the laboratory glucose. None of the remaining 29 time intervals resulted in excessive BG decreases, even when the hypothetical laboratory adjusted insulin infusion rate would have been less than the actual capillary POC adjusted rate. The mean BG decrease in the first 4 h of treatment was 45 ± 9 mg/dl/h.

Discussion

Per FDA "limitation of use" guidelines, some manufacturers no longer recommend using POC glucose meters in critically ill patients and have plans to make POC glucose meter use in the ICU "off label." While some patients with mild DKA can be safely managed outside of the ICU,[1] the majority of DKA and HHS patients are admitted to an ICU, are treated with intravenous insulin, and require frequent BG evaluation. Some manufacturers of hospital POC glucose recommend against using POC BG results to make insulin administration decisions for patients with DKA and HHS but provide little evidence to support this recommendation.[10] Relying on laboratory glucose values can result in increased cost and long delays before insulin infusion rates are changed, which could result in patient harm. Currently, therefore, in clinical practice, POC glucose values are used to adjust intravenous insulin. In this study of patients with DKA/HHS, the correlation between both capillary and venous POC glucose and laboratory glucose values is similar to that in the healthy outpatient population.[16] Importantly, the correlation was high even though, in contrast to many other POC glucose studies, our study involved actual staff nurse operators rather than designated study personnel.

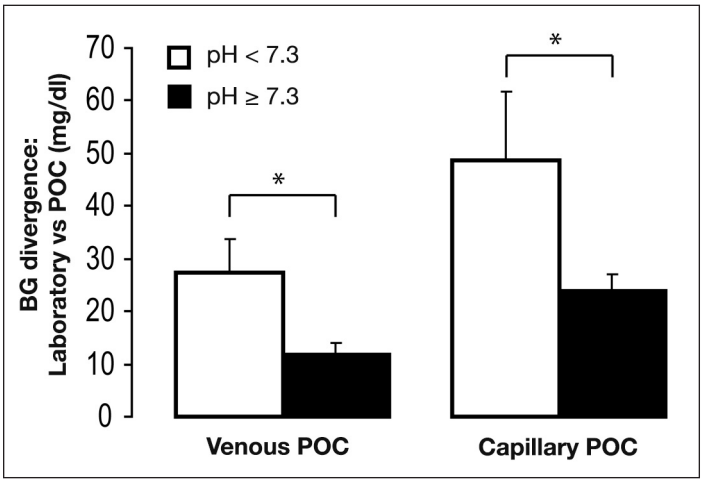

Figure 2. The effect of acidemia on POC BG error. The divergence (mg/dl) between POC and laboratory BG pairs is shown for pairs at plasma pH < 7.3 (white bars) and pH ≥ 7.3 (black bars) for both venous POC and capillary POC values. Data are means ± standard error of the mean, with the asterisks representing $p < .05$ by unpaired Student's *t*-test.

Several studies have called into question the accuracy of POC glucose results in hospitalized and critically ill patients,[4–7] leading to significant agreement that POC BG meters should have tighter standards (e.g., less than 10% difference between POC and laboratory glucose results).[17] One study found that 15% of capillary and 7% of venous POC glucose values differed >20% from laboratory values (range 45–650mg/dl),[7] exceeding the ISO standard 15197,[15] similar to our data (20% capillary and 4% venous POC values differ >20% from laboratory glucose) and that of others.[8] A second study in ICU patients[5] demonstrated systematic overestimation of glucose by POC glucose meters similar to our study. However, venous POC error was not considered clinically significant (using Parke's error grid[18]), consistent with our finding in patients with DKA/HHS. In addition, similar to our study, 3% of capillary POC glucose values severely underestimated plasma glucose.[5] While underestimated BG is unlikely to cause hypoglycemia from excess insulin administration, patient harm could occur by delaying correction of metabolic disturbances in patients with DKA/HHS. Our study demonstrated no difference in hourly glucose decreases >75 mg/dl when insulin infusion rates based on capillary or laboratory glucose values would have diverged, and no hypoglycemia occurred. Previous studies have suggested that, while very low or high hematocrit, hypotension, and edema contribute to POC error in critically ill patients,[5–7] these factors are less common, especially in patients with DKA. In our study, greater POC error was associated with higher BG levels, as demonstrated previously. However, the clinical impact of greater POC error at high

glucose levels in hyperglycemic patients with DKA/HHS remains uncertain. While previous studies have concluded that POC glucose values should not be used in critically ill patients,[5–7] our study does not suggest that use of POC glucose values causes clinically significant error in patients with DKA/HHS. One reason for this difference may be that, while DKA/HHS patients have many of the same clinical characteristics as critically ill patients in previous studies (acidosis, dehydration, severe hyperglycemia), they often have much lower medical acuity. DKA/HHS tends to resolve relatively quickly, and ICU admission is often brief and based on the need for monitoring rather than cardiac, pulmonary, or other organ failure, and thus, the impact of POC error may differ between DKA/HHS patients and a general ICU population.[1,2] In addition, previous studies focused on DKA/HHS patients evaluated potential clinical harm based on measured POC error but did not evaluate actual hypoglycemic events or patient harm.

An *in vitro* study using ROCHE Inform meter (which uses glucose dehydrogenase pyrroloquinoline quinine technology) showed no interference in estimating plasma glucose between pH 6.7 and 9.8,[19] and a review suggested that pH between 6.8 and 7.55 does not cause significant POC glucose error.[4] One previous study using Abbott Precision QID meters (glucose oxidase technology) suggests POC error related to varying pH.[12] Our *in vivo* study suggested that pH < 7.3 increases POC error independent of BG levels, and future studies will be needed to identify the role of acidemia in contributing to POC error using a variety of commonly used hospital glucose meters. In contrast, plasma osmolality >315 mOsm/liter did not increase POC error, demonstrating that hyperosmolality related to free water deficits and dehydration is not a major confounder for POC glucose estimates as had been previously suggested.[4]

Limitations

Our study was performed at one institution in a single ICU. Our conclusions are limited to one commonly used hospital glucose meter—the ROCHE Inform meter—and importantly, our findings are consistent with a study in critically ill patients on a tight glycemic control protocol using the same type of meter.[5] In contrast to these findings with the ROCHE meter, a study using Abbott Precision QID glucose meters in patients with suspected DKA in an ED demonstrated that the Abbott meter consistently underestimated glucose compared with laboratory glucose values.[12] Thus, our findings cannot be generalized to all glucose meters currently in clinical use, and further studies are needed to evaluate different meters in the DKA/HHS patient population. This study protocol reduced some of the known variability of POC BG results by using a single designated study meter and a single lot of test strips.[14] This may not always be feasible in clinical situations, and thus, in real clinical scenarios, POC error rates—or at least the divergence between consecutive POC BG values using different meters or test strip lots—may be greater than demonstrated in this study.

Our study sample was modest; however, the strong correlations we observed would unlikely be altered by enrolling additional subjects. Our study took place in the ICU after patients had received initial stabilization in the ED; however, we obtained sufficient numbers of samples from acidotic and hyperosmolar patients to determine the effect of these variables on divergence between POC and laboratory BG values. However, our study was not primarily designed to determine the effect of pH and osmolality on accuracy of POC BG meters, and more definitive studies regarding POC glucose and acidosis are warranted. Because our sample included only four "pure" HHS patients, our findings need to be confirmed by larger studies examining POC error in patients with HHS.

Conclusions

In patients with DKA/HHS, capillary and venous POC glucose values are highly correlated with laboratory glucose values. While POC error systematically overestimates plasma glucose and insulin infusion rates are higher using POC glucose values than would have occurred using laboratory glucose values, our study did not demonstrate hypoglycemia or excessive hourly glucose decreases due to capillary POC adjusted insulin infusion rates. Our study suggests that venous POC glucose, and potentially capillary POC glucose, values are safe to use in ICU patients with DKA/HHS, with hourly BG monitoring using a single meter and test strip lot per patient, for adjusting insulin infusion rates per this institution's DKA/HHS protocol. Further study is needed to determine if this finding can be replicated in larger multicenter investigations.

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Appendix A

Diabetic Ketoacidosis (DKA) & Hyperglycemic Hyperosmolar (HHS) Critical Care Orders

Admit to Critical Care Unit if patient meets Critical Care Admit Criteria. This order set for adult patients > 40Kg only
See *DKA/HHS Management Guidelines* for critical care admit criteria, differential diagnosis, and clinical reference

Diagnosis: (Check one box): ☐ DKA | Type 1 diabetes ☐ DKA | Type 2 diabetes ☐ HHS | Type 2 diabetes

NOTE: **These orders are an adjunct to Medicine ICU Routine orders**

Blood Glucose Monitoring		☒ Blood glucose monitoring as instructed in the DKA/HHS Algorithm Decision Tree (see back)
Initial work-up		☒ If not obtained in ED: ABG or VBG, iCa, lactate, HbA1c, serum BHOB (ketones), serum osmolality, troponin-I, blood culture x 2, urinalysis, 12 lead ECG
Additional work-up		☒ Every 1 hour ABG until pH > 7.0, then ABG/VBG every 2 hours ☒ Basic Metabolic Panel (BMP), Mg, Phosphate, iCa & osmolality every 2 hrs x 2, then every 4 hrs ☒ Call HO with lab results to adjust fluid orders & frequency of monitoring ☐ Other_____
IV Fluid Resuscitation or Repletion		**1. Resuscitation: Either** ☐ NS: _____ mL/hr for ___ hrs ***OR*** ☐ LR: _____ mL/hr for ___ hrs After resuscitation is complete, start fluid repletion: **2. Repletion:** see equation for Na^+ corrected (serum) and free water deficit in ORCA calculator Aim to replete free water gradually, decreasing serum Na^+ ~0.5mEq/L per hour **Order:** ☐ NS: ____ mL/hr ***OR*** ☐ 0.45NS: ____ mL/hr ***AND*** ☐ Add KCl ____ mEq/L to IV fluids ☒ When blood glucose < 250 mg/dL, call HO to add dextrose to IV Fluids
Electrolytes		• See *DKA/HHS Management Guidelines* for electrolyte management details. • **Prior to giving insulin**, K^+ must be ≥ 3.3 mEq/L, if not, replace to ≥ 3.3 mEq/L. Continue fluid replacement while replacing K^+. Add K^+ to IV fluids as indicated by lab results. • **Please refer to Medicine ICU Routine Orders for electrolyte replacement except phosphate.** In DKA/HHS, phosphate usually self corrects but may be replaced if <1.0
Insulin	**Initial Phase BG Goal Range: 200-300 mg/dL**	☒ 100 units regular insulin/ 100 mL 0.9%NS IV infusion (started in ED prior to transfer) ☒ Change to **DKA/HHS Decision Tree and DKA/HHS Algorithm (Alg) Table** (See back) • Start **DKA/HHS Alg 1** if pt weight is 40-80 Kg OR **DKA/HHS Alg 2**: if pt weight > 80 Kg ☒ Adjust rate until BG is 200-300 mg/dL for 4 consecutive hours AND anion gap is decreasing OR osmolality is <330. Move to intermediate phase.
	Intermediate Phase BG Goal Range: 100-180 mg/dL	☒ Continue to adjust rate until BG goal of 100-180 mg/dL for 4 consecutive hours and patient is ready to eat. Move to resolution phase
	Resolution Phase BG Goal Range: 100-180 mg/dL	☒ Notify HO to order SubQ insulin. Transition to SubQ insulin prior to patient eating. • www.uwmedres.org/resources can be used for SubQ insulin dosing guidance. ☒ Continue insulin infusion for 2 hours after SubQ dose administered, then discontinue infusion.
	All phases	☒ NPO except medications, water and ice chips while receiving insulin infusion. ☒ Utilize the decision tree and algorithm table (see back) for adjusting insulin infusion rates ☒ **Hypoglycemia treatment** ½ to 1 amp 50% dextrose IV (see decision tree on back) ☒ Notify provider for BG decrease >100mg/dL per hour in Alg 1 OR failure of Alg 4
Consults and Follow-up		• Consider Endocrine consult it not responding to treatment: Contact via paging operator • Consider insulin management assistance by Glycemic Team ARNP: Call pager 540-6713 • Consider diabetic education by Diabetes CNS: Call pager 559-7192

PROVIDER SIGNATURE	PRINT NAME	PAGER	UPIN/NPI	DATE	TIME

PT.NO

NAME

DOB

UW Medicine
Harborview Medical Center – UW Medical Center
University of Washington Physicians
Seattle, Washington

DKA AND HHS CRITICAL CARE ORDERS

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WHITE – MEDICAL RECORD

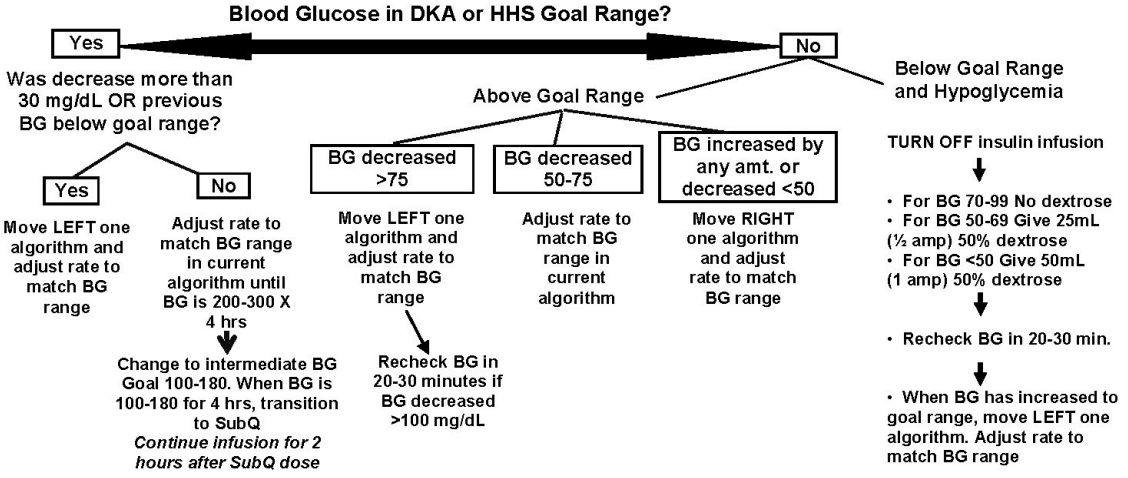
Appendix B

DKA / HHS Insulin Infusion Guidelines

Initial Phase BG Goal Range: 200—300 mg/dL
Intermediate Phase BG Goal Range: 100—180 mg/dL

Blood Glucose Every 1hr until BG reaches goal of 100-180 mg/dL X 4 consecutive hours, then every 2 hours.
Recheck BG in 20-30 minutes for BG decrease >100 mg/dL/hr

Insulin Infusion DKA / HHS Algorithm Decision Tree



Insulin Infusion DKA / HHS Algorithms Table

See Front for orders to start on DKA/HHS Algorithm 1 or DKA/HHS Algorithm 2.
DKA/HHS Algorithm 3 and 4: NO PATIENTS START HERE.

DKA/HHS Algorithm 1		DKA/HHS Algorithm 2		DKA/HHS Algorithm 3		DKA/HHS Algorithm 4	
BG	Units/hr	BG	Units/hr	BG	Units/hr	BG	Units/hr
<70 = Hypoglycemia (See decision tree for treatment)							
70-99: Off x 20-30 minutes & recheck BG							
100-110 Recheck BG in 20-30 minutes, consider moving left one Algorithm							
100-120	**0.5**	100-120	**1**	100-120	**1.5**	100-120	**2**
121-140	**0.8**	121-140	**1.5**	121-140	**2.5**	121-140	**3.5**
141-160	**1.2**	141-160	**2**	141-160	**3**	141-160	**4.5**
161-180	**1.5**	161-180	**2.5**	161-180	**4**	161-180	**6**
181-210	**2**	181-210	**3**	181-210	**5**	181-210	**7.5**
211-240	**2.5**	211-240	**4**	211-240	**6.5**	211-240	**9.5**
241-270	**3**	241-270	**5**	241-270	**8**	241-270	**11.5**
271-300	**3.5**	271-300	**6**	271-300	**9**	271-300	**13.5**
301-330	**4**	301-330	**6.5**	301-330	**10.5**	301-330	**15**
331-360	**4.5**	331-360	**7.5**	331-360	**12**	331-360	**17**
>360	**5**	>360	**8.5**	>360	**14**	>360	**19**

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Appendix C

DKA/HHS Management Guidelines

Criteria for Critical Care Admit:
(any one of the following or per clinical judgment)

- pH < 7.2 (or initial pH <7.0)
- HCO3 ≤ 9
- Osmolarity > 330
- Altered Mental Status
- Persistent Hypotension
- Age > 65
- Comorbidities: including:
  - Acute MI or Stroke
  - Acute renal failure
  - Heart failure/ ESLD/ Anasarca
  - Immunosuppression
  - Pregnancy

Diabetic Ketoacidosis (DKA):	**DKA – Usual Causes:**	**Hyperglycemic Hyperosmolar Syndrome (HHS):**	**HHS – Usual Causes:**
• Type 1 or Type 2 DM • Abdominal pain, N/V • Altered mental status • Severe dehydration • BG >250mg/dl, serum ketones present, pH <7.3, bicarb <15mEq/ml, anion gap >20	• Newly diagnosed T1DM or T2DM • Acute infection • Not taking or improper use of medications • Degraded insulin • Insulin pump occlusion • MI or CVA	• Uncontrolled Type 2DM • Dehydration, polyuria, polydipsia, polyphagia • Altered mental status • BG >600mg/dl, serum Osm. 300 – 400 mOsm/L, lactic acidosis, pH >7.3, low serum ketones	• Uncontrolled T2DM • Acute infection or recent acute illness • Not taking or improper use of medications • Degraded insulin • MI or CVA

General Management Guidelines:	
Initial Phase *Occurs within 1st 24 hours*	• Determine cause & address treatment • Hourly ABG until pH >7.0 • Assess renal function & electrolytes every 2 hrs x 2 then every 4 hrs if improving. • Ensure adequate fluid resuscitation and potassium replacement. • Initial BG goal 200-300mg/dL. Correct BG at a rate of 50-75 per hour. Assess BG hourly until BG reaches 200-300 x 4 consecutive hrs.
Intermediate Phase *BG in goal range of 200-300 X 4 consecutive hours AND anion gap decreasing OR osmolality <330mEq/L*	• Maintain BG 100-180mg/dL, HCO_3 15-21 mEq/L, Serum osmo <330 mEq/L • Assess BG hourly until BG reaches 100-180 x4 consecutive hrs, then every 2 hrs • Continue fluid repletion with dextrose added to IVF • Electrolyte replacement (assess BMP + Osm every 4 hours until WNL) • If admitted to critical care, consider transfer to acute care unit
Resolution Phase *BG in goal range of 100-180 X 4 consecutive hours AND patient is ready to eat*	• Transition to SubQ Insulin: Calculate basal, prandial, correction. Use www.uwmedres.org/resources • Discontinue IV fluids and check BMP daily • Diet: Carbohydrate managed as tolerated

Electrolyte replacement guidelines:

Potassium
- Hyperkalemia is common in patients with DKA, despite total body hypokalemia
- Initial bolus of insulin and fluid replacement reduce serum potassium, therefore close monitoring is advised
- In rare cases of patients in DKA presenting with hypokalemia, start potassium replacement concurrently with fluid. Start insulin infusion when potassium is >3.3

Phosphate
- Phosphate replacement is generally not recommended
- Phosphate replacement can result in hypocalcemia and has not shown in randomized trials to be of clinical benefit in the treatment of DKA
- Correction in DKA patients may be indicated in those with a serum phosphate concentration <1.0

Bicarbonate
- No clinical benefit has been shown for bicarbonate replacement in patients with a pH of 6.9 - 7.1.
- Replacement in patients with a pH <6.9 may be indicated. Ionized calcium should be monitored to prevent hypocalcemia from rapid pH increase
- The pH should be assessed every hour until pH is >7.0, when replacement should be stopped, to prevent risk of cerebral edema in young DKA patients

Fluid Resuscitation and Repletion:

1. In pure DKA, *resuscitation* to restore circulating volume and tissue perfusion should be accomplished with 1 or 2L of NS (or LR). If the resuscitation takes more volume than 2L, seek additional causes of hypotension or hypoperfusion.
2. Start fluid *repletion* once resuscitation is complete. The goal is to reduce the hyperosmolality and hyperglycemia. Calculate the free water deficit and start with either 0.45NS (or sometimes NS if the patient is very hyperosmolar/ hypernatremic). Switch to D5/0.45NS when the BG is < 250mg/dL.

Corrected Sodium & Volume Repletion Equations: (See ORCA Calculator)

Na^+ corrected (serum)=((BG - 100)/100) x 1.6 (add this # to actual Na^+ value)

Free water deficit in liters = Weight in Kg x 0.6 x (corrected Na^+/140 minus 1)

EXAMPLE -- BG 554, Na^+ 125, Wt 100 Kg

554-100=454/100x1.6=7.3+125=132.3 corrected Na^+

100Kg x 0.6 x (132.3/140=.95-1)
60 x -0.05= -3L free water deficit

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