HHS Public Access
Author manuscript
*Int J Clin Endocrinol Metab*. Author manuscript; available in PMC 2019 May 03.

Published in final edited form as:
*Int J Clin Endocrinol Metab*. 2018 ; 4(1): 8–11. doi:10.17352/ijcem.000031.

# Closing the Mortality Gap in Diabetic Ketoacidosis and Hyperosmolar Hyperglycemic State: Implications of a Clinical Decision Support App

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## Keywords

Diabetes; Technology; App; Educational; Clinical Decision Support

## Introduction

Diabetes is a major public health issue affecting millions of people in the United States and worldwide. In the United States alone, about 30.3 million people (9.4% of the population) have diabetes [1]. Worldwide, a staggering 422 million have diabetes according to 2014 estimates [2]. Diabetes complications over years of exposure include cardiovascular disease -- stroke and myocardial infarction -- and microvascular disorders -- kidney failure, blindness and amputation [3]. Acute and potentially fatal complications of diabetes include hyperglycemic crises, specifically diabetic ketoacidosis (DKA) and hyperglycemic hyperosmolar state (HHS) [4].

While overall in-hospital case-fatality rates for hyperglycemic crises have been on the decline in the United States (current estimates of 0.4% mortality rate of DKA) [5,6], HHS still has an unacceptably high mortality rate (ten times that of DKA) [7]. Furthermore, certain geographic locales and certain races have an unacceptably high mortality rate. For example, in one study of 270 patients in India, the mortality rate of DKA was 30% [8]. In a rural regional hospital in South Africa, the mortality rate of DKA was 17.14% [9]. Even within the United States, between 2012–2014, the total number of deaths from diabetes among black children was over twice that of their white counterparts [10]. This is even though incidence and prevalence of diabetes in black children is lower than for their white counterparts [11,12].



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The disparity among different regions and races may be secondary to differences in access to resources, including accessible, up to date clinical guidelines. Despite the wide availability of the American Diabetes Association (ADA) clinical practice guidelines for patients with hyperglycemic crises [13,14] and those of the American Association for Clinical Endocrinologists (AACE) [15], these guidelines do not appear to adequately improve survival among all populations with hyperglycemic crisis. Indeed, the utility of clinical guidelines is only in their practical implementation [16–18]. Even with clinical practice guidelines available, the time, effort and skills needed to access these guidelines are not available to everyone [19].

In this editorial, we introduce a new type of clinical decision support (CDS) tool for DKA/HHS, which provides clinicians a subset of the DKA/HHS guidelines personalized to the clinical features at the point-of-care. In contrast to existing CDS tools that automate decisions or order sets [20,21], we intended that the tool helps clinicians make informed decisions rather than make passive decisions. This allows the clinicians to benefit from individualized education and eventually become independent of the electronic tools. Our app has the potential of improving the mortality of DKA and HHS across all locations and races.

## Framework design: Interactive guideline with participatory design

Our team built an interactive text-based platform in which each paragraph, sentence or summary item is activated or deactivated by triggers based on user inputs. The user chooses among button choices and inputs numeric values on the first screen, and the inputs determine the activation of the triggers. (Figure 1-Left Panel)

We used Google App Script to build a spreadsheet-based tool ('editing app') where the editing experts ('authors') can define data entry elements (e.g., segmented buttons, pickers, numeric or text data field, multiple-item selectors, or multimedia inputs) for the data inputs. The editing authors are allowed to set triggers to each data entry item, allowing branching of questions and the end-users being exposed only to a subset of questions at each usage. The expert authors can name and assign variables to specific questions (e.g., the answer to the question of the presence of symptoms can be saved to a variable named 'symptoms'). The authors can also assign boolean triggers to the text contents as we discussed above.

When the authors finish editing the contents and decide to update a clinical module, the app script packages the contents into multiple CSV files (dashboard, pages, contents of each page, and references) and sends the fi les to Google Firebase, which is Google's real-time database and backend for mobile apps. We developed the front-end side of the app service in XCODE, which is an app development environment for the Apple iOS platform. The entire code is written in Swift.

Seven clinicians without programming skills tested the editing app to build drafts of test apps for several clinical problems and to improve participatory aspects of the framework. A senior endocrinologist reviewed and edited all of the contents of the app for both accuracy and ease of understanding.

## Development of the DKA/HHS module

The ADA consensus guidelines, including the DKA/HHS flowchart, were used as the basis of our decision framework. [13,14] The first step for the user in our framework is to choose DKA or HHS. An info button is provided for clinicians who wish for more information in making this decision. DKA is chosen as a default in case the user is not sure and wishes to proceed to the next question without choosing. Next, the user is asked if fluid resuscitation was started. If it was not, the application prompts the user to begin fluid boluses. The next input is regarding suspected hypovolemia. Here too, if the user chooses shock, the application will recommend to treat shock before proceeding. If the user chooses severe hypovolemia, the application will allow for the rest of the inputs, but will recommend to continue giving 0.9% NaCl boluses (1L/hr). (Figure 1-Middle Panel). The next input fields are for weight, glucose, and electrolytes. The application calculates the anion gap and corrected sodium, and guides the clinician as to the appropriate fluids and rate, the need for potassium repletion, the type and rate of insulin administration (and whether it should even be started), and the need for continued monitoring (Figure 1-Middle and Right Panel).

Emergent inputs, such as choosing “Shock” for the question “Suspected Hypovolemia?” will trigger an emergent response: “Give fluids, start hemodynamic monitoring, and consider pressors if clinically indicated.” A text paragraph is provided to further educate the clinician with additional details. In this case, it would read, “Shock requires rapid treatment with fluid resuscitation (rapid boluses of 0.9% NaCl), hemodynamic monitoring, and pressors if indicated. Stabilize patient first.” References are provided for each of these text paragraphs.

## Discussion and future directions

To our knowledge, there are no currently existing apps that guide clinicians through the process of DKA/HHS management while providing education. Existing systems attempt to use either static informational pages (e.g., guidelines or UpToDate), calculators (e.g., MDCalc), or automatic order sets to help improve access to and implementation of guidelines [22]. Our CDS tool is unique in that it delivers tailored aspects of the management with additional information specific to individual clinical scenarios at the point of care. In doing so, it not only provides clinical decision support, but is a resource for continual education for the clinician. Our app is free to download on the Apple App Store. Since it currently does not link or store any personal patient data, there are no HIPPA concerns. While our app can potentially improve care and decrease mortality, further testing is required for confirmation.

We plan to conduct formal real-world validation by means of measuring the systemic usability scale (SUS), physician satisfaction and decision understanding at the beginning stage of our implementation and using participatory design to build future versions of our app based on input. We will also trial the implementation of our app in a hospital setting and use an interrupted time-series design to assess its effects with each clinician as a target of randomization. Since our app provides easier access to guidelines, rather than a promotion of unique guidelines, the ethical concerns are minimal, similar to existing guideline repositories. If successful, we will spread awareness through physician communities by publishing our usability testing and evaluation results. We will also ask users to rate our app based on ease of use, usefulness of the tool, usefulness of the content, and overall satisfaction. This optional survey will ask for comments, as well, helping us to improve the tool.

Finally, our tool may be applied to a vast array of diseases such as thyroid storm, hypothyroidism and others.

## Conclusion

Elevated mortality in hyperglycemic crisis among various racial groups and across geographic areas is unacceptable and requires novel interventions. We built a clinical decision support tool that systematizes and personalizes the treatment of DKA and HHS by bringing point-of-care access to the guidelines specific to individual cases to the clinician's hands. This is potentially the solution to close the mortality disparity gap for DKA and HHS.

## Acknowledgement

This work is supported, in part, by the efforts of Dr. Moro O. Salifu M.D., M.P.H., M.B.A., M.A.C.P., Professor and Chairman of Medicine through NIH Grant number S21MD012474.

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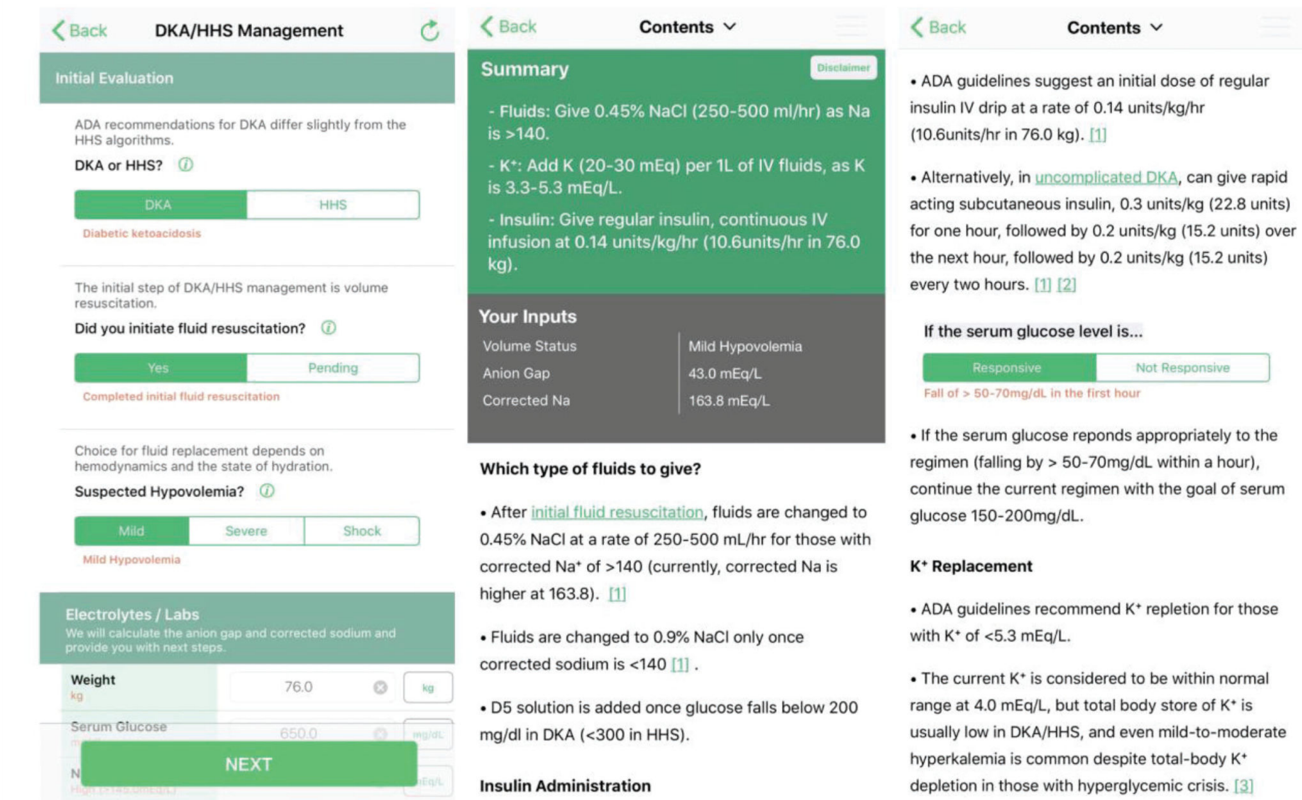


**Figure 1:**

Example of input (Left Panel) and personalizex content (Middle and Right Panel).