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EDITORIAL

Future technology-enabled care for diabetes and hyperglycemia in the hospital setting

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Abstract

Patients with diabetes are increasingly common in hospital settings where optimal glycemic control remains challenging. Inpatient technology-enabled support systems are being designed, adapted and evaluated to meet this challenge. Insulin pump use, increasingly common in outpatients, has been shown to be safe among select inpatients. Dedicated pump protocols and provider training are needed to optimize pump use in the hospital. Continuous glucose monitoring (CGM) has been shown to be comparable to usual care for blood glucose surveillance in intensive care unit (ICU) settings but data on cost effectiveness is lacking. CGM use in non-ICU settings remains investigational and patient use of home CGM in inpatient settings is not recommended due to safety concerns. Compared to unstructured insulin prescription, a continuum of effective electronic medical record-based support for insulin prescription exists from passive order sets to clinical decision support to fully automated electronic Glycemic Management Systems. Relative efficacy and cost among these systems remains unanswered. An array of novel platforms are being evaluated to engage patients in technology-enabled diabetes education in the hospital. These hold tremendous promise in affording universal access to hospitalized patients with diabetes to effective self-management education and its attendant short/long term clinical benefits.

Key words: Diabetes; Inpatients; Continuous subcutaneous insulin infusion; Continuous glucose monitoring; Clinical decision support; Patient education; Self-management

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Core tip: Achieving optimal glycemic control in inpatients with diabetes and hyperglycemia remains a challenge for hospital providers. An array of technology-supported systems are evolving to assist providers and patients in meeting this challenge. Next generation, robust clinical decision support systems embedded in the electronic medical record are well positioned to replace structured order sets in the near term. If demonstrated to be cost effective, fully automated electronic glycemic management systems may become commonplace, in particular in intensive care unit settings. Novel media platforms hold tremendous potential for expanding access to crucial, effective self-management education for all patients with diabetes in hospital settings.

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INTRODUCTION

Adults with diabetes mellitus in the United States account for 7.2 million hospital discharges and 40.3 million hospital days annually[1,2]. Inpatient glycemic control remains suboptimal both in the United States[3] and abroad[4]. Numerous variables impact inpatient glycemic control, including: the pre-admission level of glycemic control[5]; medications prescribed for acute conditions (*e.g.*, steroids)[6]; comorbidities such as acute or worsened renal failure; and nutritional status[7]. Throughout the stay, providers need to identify glycemic trends in the context of multiple dynamic factors to safely and effectively optimize the insulin regimen.

In response to these challenges, technology-enabled systems are being evaluated and adapted for inpatient use. There is significant outpatient experience with diabetes technologies such as continuous subcutaneous insulin infusion (CSII) and continuous glucose monitoring (CGM) systems. Experience with emerging technology systems such as electronic medical record (EMR) based clinical decision support (CDS) for insulin prescription remains limited. Finally, inpatient engagement technology for diabetes education holds the potential to allow access to survival skills education for all inpatients with diabetes.

This editorial will focus on future directions evolving as technology-enabled supports for inpatient diabetes care delivery. For purposes of this discussion, we have grouped these endeavors into three broad categories shown on Table 1.

OUTPATIENT TECHNOLOGIES ADAPTED FOR INPATIENT USE CSII

In 2016 five million persons with diabetes were utilizing CSII pumps[8-10]. Inpatient CSII use is not well characterized, but is likely to grow. CSII for hospital diabetes self-management is considered by the American Diabetes Association (ADA) to be appropriate for select patients[11].

CSII pumps deliver basal insulin (units per hour) to meet insulin requirements in the fasting state and between meals. The pump delivers bolus insulin doses (units) to match nutritional intake and as correction doses when blood glucose (BG) levels are high. Hospital providers need to be cognizant of these basics to safely supervise glycemic management when these patients are under their care. Patient ability to continue pump use in the hospital can be assessed by asking patients to describe essential pump skills such as how to adjust the basal rate, administer a bolus dose, and problem solve correction of an out of target BG[12]. A dedicated insulin pump protocol should address hospital use of CSII, including its use during procedures and in the operating room[13]. Training in pump basics should be provided to nurses and non- endocrinologist inpatient providers, including hospitalists and anesthesiologists, who may be called upon to write CSII orders and oversee glycemic management[14].

Potential CSII safety issues in the hospital include insertion site infections; mechanical pump failure; the need for frequent pump interruptions (*e.g.*, radiology

Table 1 Technology-enabled strategies for inpatient glycemic management and diabetes care

Technology category	Purpose	Technologies
Outpatient technologies adapted for inpatient use	Support insulin management	Personal continuous subcutaneous insulin infusion pumps
		Continuous glucose monitoring sensor systems
Technologies developed for inpatient use	Diabetes and glycemic care management, including care transitions	Electronic medical record based clinical decision support
		Electronic glycemic management systems
Technology-enabled diabetes education	Engagement in diabetes survival skills education	Electronic medical record-generated, printed education content
		"SMART" TVs Web-based education platform

tests involving ionizing radiation); and handoffs for procedures and diagnostic testing. Expert consensus recommends that appropriate patient selection is essential to safe hospital CSII use. Limited retrospective case series suggest a good safety record. The largest series (n = 164 admissions) found no surgical site infections, mechanical failures, or hospital-acquired diabetic ketoacidosis[15,16]. Both retrospective studies and a single, small randomized trial suggest that when compared to usual care, inpatient CSII use is equivalent for hyperglycemia events and possibly superior in hypoglycemia prevention[17,18].

CGM

CGM systems measure and report BG every 5-15 min. CGM technology is estimated to be used by 4%-26% of Americans with type I diabetes[19]. CGM systems use subcutaneously placed sensors that measure BG in interstitial fluids and typically require changing every 10-14 d. Intensive care unit (ICU) CGM use has been studied for over ten years in both observational and prospective randomized studies of varying size. CGM systems accuracy compared to venous/arterial BG performed in the hospital laboratory and efficacy compared to usual care glycemic outcomes have been examined. The accuracy studies have found data generated by CGM systems to be acceptable. With regards to efficacy, a recent systematic review identified five randomized clinical trials. Most reported no significant difference in glycemic control (*i.e.*, mean glucose or time in range) while two found significant reduction in severe hypoglycemia favoring CGM[20,21]. Concerns regarding appropriateness of CGM use when factors which may impact subcutaneous circulation such as hypotension have been raised[22]. Larger randomized studies are needed to confirm benefits in hypoglycemia prevention for CGM in ICU settings and its cost effectiveness when compared to usual care.

Studies assessing routine CGM use in non-ICU settings are limited to small, uncontrolled prospective studies[23-26]. These studies report no difference in mean daily glucose, and CGM identified more hypoglycemic events compared to traditional point of care testing. However, for patients wishing to use their home CGM devices in the hospital, expert consensus has articulated several important potential safety concerns including the accuracy of CGM data when acute physiologic disturbances are present (*i.e.*, hypoxemia, vasoconstriction, and rapidly changing glucose levels in diabetic ketoacidosis) as well as concerns over correct CGM data interpretation by non- Endocrine inpatient care providers[18], and as a result, routine use of patient-generated CGM readings to guide inpatient insulin prescribing is not currently recommended.

Several insulin pumps now utilize CGM data to auto-modify insulin dosing via computerized algorithms. While there have been studies looking at use of "closed loop" insulin delivery systems for inpatients[27-29], to our knowledge, none have used the commercially available pump devices to date.

INPATIENT SPECIFIC TECHNOLOGIES CDS SYSTEMS

Structured insulin order sets are now widely used in hospitals for subcutaneous insulin ordering and have been shown to improve daily average glucose, reduce glycemic extremes, and reduce prevalence of sliding scale only regimens[30-32]. Based on this evidence, current guidelines recommend the use of structured, electronic order sets that include advice for optimal insulin prescription[8].

CDS refers to electronic systems which assist in clinical decision making via provision of recommendations based on processing and presenting patient specific data at an appropriate time. This contrasts with passive order sets that provide advice that is not patient specific. The ubiquity of inpatient EMRs combined with guidelines for the use of insulin to manage most cases with hyperglycemia make inpatient insulin prescribing ideal for incorporation of CDS into workflow. Controlled evidence of the impact of CDS for inpatient insulin prescribing are lacking. However, the safety and acceptability of the Gluco Tab® mobile insulin prescription CDS system[33] has been reported and recently, the creation and implementation of an inpatient insulin prescription CDS module for the Epic EMR system has been described. This utilizes interactive computerized physician order entry elements which prompt the provider to input relevant factors (*e.g.*, indication for insulin - acute hyperglycemia without prior DM *vs* established DM not on insulin *vs* established DM on insulin) while also extracting other relevant factors (*e.g.*, insulin received in last 24 h) in order to process each element into formulating insulin prescription recommendations; the provider then selects one of the provided options[34]. Studies on the efficacy and safety of this CDS module are in progress.

ELECTRONIC GLYCEMIC MANAGEMENT SYSTEMS

While CDS systems rely on user input and chart extraction of key information, more automated CDS systems require minimal provider input and are termed electronic glycemic management systems (eGMS). Several proprietary eGMS systems have been developed for intravenous insulin infusion and subcutaneous administration. Examples include Glytec's GlucommanderTM system[35], GlucoStabilizer®[36] by Medical Decision Networks, and Monarch's EndoTool®[37]. These software systems use multivariate algorithms to continuously recalculate the appropriate insulin dose, adjusting to patient specific variables. Generally, the initial insulin dose is set by the provider based on a weight-based calculation or custom order and the algorithm makes subsequent insulin dosing adjustments. There are several potential advantages to such a system, including reduction in hypoglycemia and hyperglycemia, reduction in the cost of care, improvements in patient safety and provider satisfaction.

Reduction in hypoglycemia rates has been shown in several eGMS studies. Rabinovich *et al*[38] used the Glucommander eGMS to show reduction in BG < 3.9 mmol/L from 21.5% to 1.3% (P < 0.0001) and severe hypoglycemia reduction from 5.4% to 0.01% (P < 0.0001) in a retrospective review of critically ill patients on insulin infusions. A comparison between the eGMS and a computerized basal-bolus order set for non-critically ill patients on subcutaneous insulin also found a difference in glucose < 3.9 mmol/L (1.9% *vs* 2.8%, P = 0.001)[39]. These results may be magnified when an eGMS is implemented where basal-bolus insulin therapy is not prevalent. Newsom *et al*[40] found the rates of use of sliding scale insulin go from 95% to 4% after eGMS implementation, moderate and severe hypoglycemia rates drop by 21% and 50% respectively, reduced length of stay and fewer point of care tests per patient. Although there is limited data demonstrating potential cost savings[41], convincing hospital leadership to invest in them may present a challenge. It remains to be determined where they will fit in the big picture of technology supported inpatient glycemic management as CDS tools evolve and data to support each model accumulates.

TECHNOLOGY-ENABLED DIABETES EDUCATION IN THE HOSPITAL

Deficits in diabetes knowledge and self-care management skills contribute to hospitalizations among persons with diabetes. Hospitalization presents an opportunity to provide education to this population, many of whom may not otherwise have access to this service. An accumulating body of evidence suggests that inpatient diabetes education, improving communication of discharge instructions and involving patients in medication reconciliation may reduce risk for early readmissions[42] and improve outcomes, including hemoglobin A1C and risk of readmission to the Emergency Department[43-46].

The ADA recommends that education be provided during an admission when a need is identified[8]. Content focused on "survival skills" to enable safe self-management until further outpatient instruction, as needed, is recommended. Inpatient diabetes education should also include a discharge plan for continuity of diabetes care as the transition from hospital to home is especially challenging and is associated with a high risk of negative outcomes, including readmissions[8]. Inpatient diabetes education delivery may be supported by both "low-tech" and increasingly by "high-tech" patient engagement strategies as shown on Table 2.

While patient engagement technologies offer the potential to expand the reach of education, in the hospital setting research in this field is emergent and outcomes data is lacking. It is crucial to patient engagement that technology tools are user friendly from a human factors perspective and that support is available to assure patient access and movement through the education content. Finally, if education is to be individualized, data security and privacy need to be assured[47].

Patient education systems are evolving from basic methods to high-tech-enabled systems. Low-tech methods include generic diabetes education sourced from providers such as KRAMES and Healthwise® and delivered *via* "SMART" TVs. These systems offer the advantage availability at every bed in the hospital and delivery through a familiar platform. Reports assessing the impact this type of education are lacking. In addition, whether hospitalized patients would choose to watch health information videos in large numbers remains in question. The Diabetes To Go study explored the effectiveness of video-based inpatient diabetes education in a large urban teaching hospital. Adults with diabetes participated in survival skills education delivered at the bedside *via* DVD player. Significant improvements in diabetes knowledge and medication adherence, as well as a trend towards reduction in hospital admissions in the 3 mo post- intervention were observed[37].

High-tech support for individualized diabetes education can potentially be delivered from the internet *via* tablet computer or smartphone using a web-interface from an education platform or embedded directly onto a tablet computer. Such platforms have ability to administer surveys and subsequently auto-direct the user to content tailored to responses. Staff must deliver the devices to the bedside, if they are not included with each bed, and staff time is often required to familiarize the patient with the platform.

Education delivery *via* personal-use devices also requires attention to infection control, physical device management and ergonomics. While web-based patient education technologies are being studied in the outpatient setting, inpatient studies are needed.

Finally, there are over 5000 technology applications and a wide variety of telehealth coaching programs available for diabetes education support. Among these technologies, very few have reported data or conducted clinical trials to assess impact on outcomes and none to-date has targeted education for inpatients with diabetes[48].

CONCLUSION

Despite the current challenges in achieving optimal glycemic control in the hospitalized patient, there are an array of technology-based systems that have the potential to impact the future of inpatient glycemic management. Of the systems reviewed to-date, EMR-based CDS systems which facilitate insulin management and technology-enabled education would appear to hold the greatest potential for widespread dissemination and impact in a cost-effective fashion. Inpatient use of personal CSII pumps and CGM systems will likely continue to grow making it necessary for hospitals to develop policies and familiarize providers with their use. Electronic Glucose Management systems, whether EMR-based or provided by third parties, will also likely play a role in inpatient glycemic management, particularly in intensive care units. Long after an admission, it is reasonable to believe that technology-enabled diabetes education delivered in the hospital could afford the patient clinical benefit, such as has been documented with traditional outpatient diabetes education approaches. Ongoing research to compare and contrast the potential for impact of each of these technologies in hospital diabetes care management and to develop the business case for their use is needed to help enlighten future use strategies.

Table 2 Inpatient diabetes education delivery - current and future states

Modality	Current state	Future state
1:1 at the bedside	Unit nurse/Physician/educator provides basic education- often skills based, *e.g.*, insulin instruction, and/or printed generic content	Supplemented by printed individualized electronic medical record clinical decision support generated content based on diagnoses, procedures, medications
Low-tech	Generic education content delivered *via* SMART TV or video	Video-based survival skills education content individualized for diabetes medications prescribed at discharge Provider and/or electronic medical record clinical decision support prescribes targeted generic education content
High-Tech	Generic education content prescribed for delivery at bedside on TV or tablet computer from web-based platform	Individualized education delivered via an interactive patient engagement platform Content auto-directed to learner based on embedded survey responses "App" for telehealth coaching prescribed, *e.g.*, BlueStar[49]

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