Curr Diab Rep (2017) 17: 51
DOI 10.1007/s11892-017-0875-2

HOSPITAL MANAGEMENT OF DIABETES (A WALLIA AND JJ SELEY, SECTION EDITORS)

The Case for Diabetes Population Health Improvement: Evidence-Based Programming for Population Outcomes in Diabetes

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Published online: 31 May 2017

Abstract
Purpose of Review The goal of this review is to describe diabetes within a population health improvement framework and to review the evidence for a diabetes population health continuum of intervention approaches, including diabetes prevention and chronic and acute diabetes management, to improve clinical and economic outcomes.
Recent Findings Recent studies have shown that compared to usual care, lifestyle interventions in prediabetes lower diabetes risk at the population-level and that group-based programs have low incremental medial cost effectiveness ratio for health systems. Effective outpatient interventions that improve diabetes control and process outcomes are multi-level, targeting the patient, provider, and healthcare system simultaneously and integrate community health workers as a liaison between the patient and community-based healthcare resources. A multi-faceted approach to diabetes management is also effective in the inpatient setting. Interventions shown to promote safe and effective glycemic control and use of evidence-based glucose management practices include provider reminder and clinical decision support systems, automated computer order entry, provider education, and organizational change.
Summary Future studies should examine the cost-effectiveness of multi-faceted outpatient and inpatient diabetes management programs to determine the best financial models for incorporating them into diabetes population health strategies.

Keywords Diabetes mellitus · Population health · Diabetes prevention · Inpatient diabetes · Multi-level diabetes interventions · Cost-effectiveness

This article is part of the Topical Collection on *Hospital Management of Diabetes*

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Introduction

Diabetes population trends, health outcomes, and healthcare costs make it a priority condition for population health improvement in the USA. An estimated 9.1% of the overall US population has diagnosed diabetes, 5.2% has undiagnosed diabetes, and an additional 38.0% has prediabetes [1•]. Diabetes is the sixth leading cause of disability in the USA [2] and is the seventh leading cause of death, with a 2014 age-adjusted mortality rate of 20.9 per 100,000 population [3]. In the adult US population aged 20 years and older, diabetes ranks highest among all disease categories in healthcare spending, with an estimated $101.4 billion in healthcare spending in 2013 [4]. As a disease of health inequities, racial and ethnic minority groups and persons with lower socioeconomic status experience higher diabetes prevalence, morbidity, and mortality rates [1•, 5, 6]. Over the past decade, evidence has grown for opportunities to impact diabetes and its outcomes across population risk strata and the intervention continuum inclusive of primary prevention, secondary prevention, and tertiary prevention. In this paper, we describe diabetes within a population health improvement framework, review evidence for a diabetes population health continuum of intervention approaches to improve clinical and economic outcomes, and review the intervention continuum within the context of diabetes standards of care and policy advancement.

Diabetes and Population Health

Population health has emerged as a framework to guide comprehensive interventions and policies for improving prevention, health promotion and healthcare outcomes, and addressing the determinants of health that contribute to health inequities [7, 8]. Population health is defined as "the health of a population as measured by health status indicators and as influenced by social, economic, and physical environments; personal health practices; individual capacity and coping skills; human biology; early childhood development; and health services" [9]. Consequently, population health broadens health improvement beyond traditional boundaries of medical care or public health and necessitates community and multi-sector partnerships for intervention implementation outside of healthcare settings, and targeted interventions within the healthcare setting [7, 8]. Population health methods include use of population assessment, risk stratification, targeted interventions to provide population subgroups in different risk strata appropriate and quality care in the right settings, and data to determine outcomes. Figure 1 presents a model for diabetes population health improvement incorporating these concepts.

Within healthcare settings and organizations, national diabetes quality measures are applied to populations with diabetes. The current National Quality Forum ambulatory diabetes metrics that are considered for Healthcare Effectiveness Data and Information Set (HEDIS) accreditation are summarized in Table 1. In our current healthcare model, Accountable Care Organizations are being incentivized for achieving diabetes care metrics in the patient populations in their catchment area, which has required them to develop effective healthcare delivery models that impact not only just individual patients but also the patient population as a whole. In contrast, despite the high costs of acute care of diabetes in the hospital setting, there are no uniformly endorsed inpatient glycemic quality metrics. As we recently reviewed, several professional societies have published guidelines for inpatient glycemic targets, process measures, and pharmacologic management [10]. Tables 2 and 3 summarize the current recommendations from several professional societies as well as the proposed Center for Medicare Services (CMS)/National Quality Forum (NQF) metrics. As seen in Table 3, there are notable differences in the definitions of the inpatient glucometrics, particularly with respect to the patient populations included in the denominator. For the Society of Hospital Medicine (SHM) [14] and Yale [15] metrics, all blood glucose (BG) data, including those obtained from patients who may not have received any glucose-lowering medications, are included in the metrics for normoglycemia, hyperglycemia, and hypoglycemia. The SHM and Yale groups have proposed definitions of normoglycemia that consist of either the percent of all BGs within a target range (70–179 mg/dl for SHM and 70–149 mg/dl for Yale) or the percent of patient days or patient stays in which all BG readings were within the defined target range. CMS has adopted publically endorsed NQF metrics for hypoglycemia and hyperglycemia, but has not proposed a metric for normoglycemia [16]. There is variability with respect to the hyperglycemic metric, with some definitions using a mean BG threshold (≥180 mg/dl) while others use a certain frequency of individual BG readings above a threshold (e.g., any BG >299 mg/dl or 2 or more BG readings >200 mg/dl). Finally, only SHM provides metrics for hypoglycemia management (i.e., time to resolution or time to repeat BG check) [14]. The benchmarking of this metric consists of ranking hospitals against others for performance (i.e., lower response time is better). Since there are agreed upon metrics for other aspects of diabetes population health, including diabetes prevention and ambulatory diabetes management, we will highlight and summarize effective interventions around these metrics, in addition to summarizing the available literature on effective inpatient interventions to improve glycemic control and costs.

Evidence-Based Intervention Programs Across the Population Health Continuum

Diabetes Prevention (Preventive Care)

Prediabetes as a Significant Public Health Issue

Prediabetes is the high-risk state preceding type 2 diabetes and is typically identified by fasting glucose (100–125 mg/dl) or hemoglobin A1c (5.7–6.4%). Prediabetes can also be identified using a 75-g oral glucose tolerance test (2 h glucose, 140–199 mg/dl) [17]. Using these measures, approximately 38% of adults (86 million people)

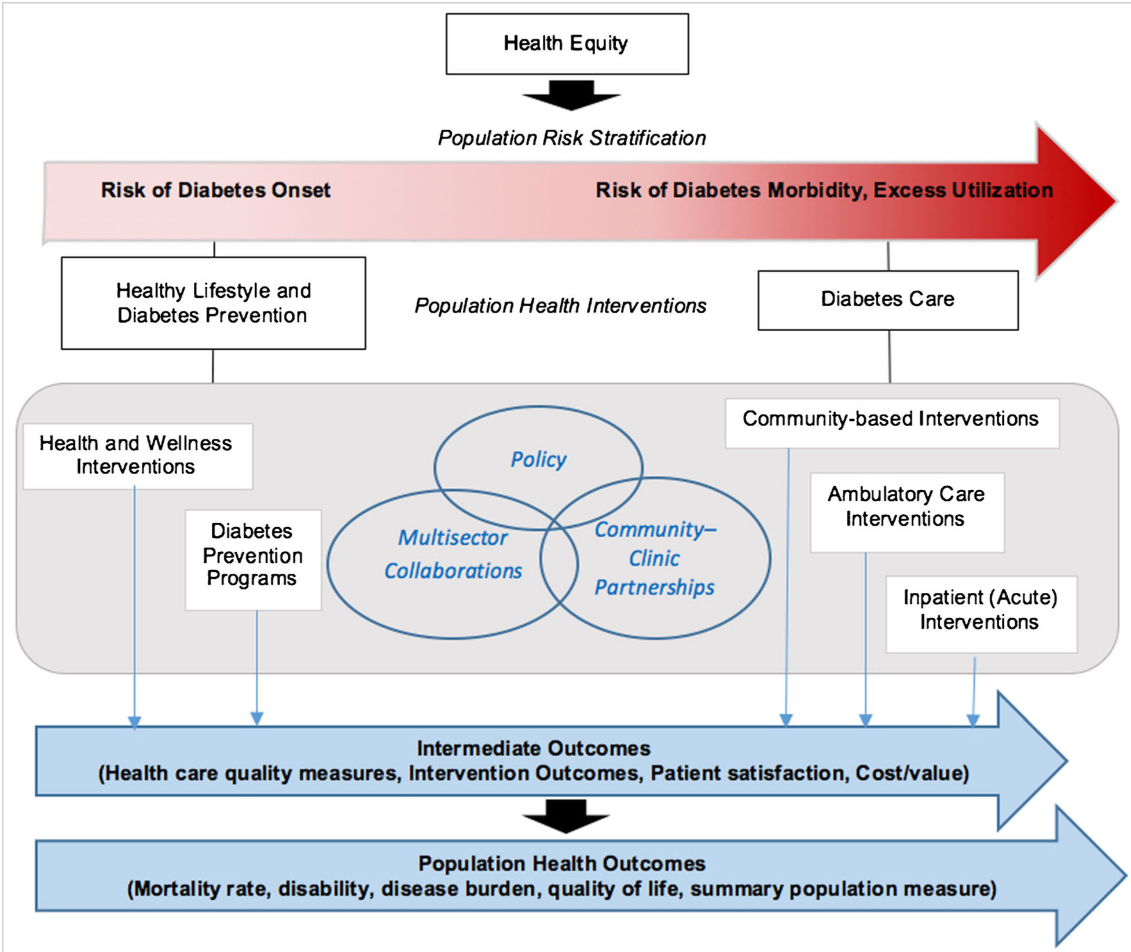

Fig. 1 Diabetes population health improvement framework

without diabetes are estimated to have prediabetes in the USA. Prediabetes is a significant marker of diabetes risk; 15 to 30% of people with prediabetes will develop type 2 diabetes in the next 5 years [18]. Most people with prediabetes (~90%) in the USA are unaware of their prediabetes status [19].

Table 1 National Quality Forum (NQF) ambulatory metrics for HEDIS accreditation

Measure title	NQF number	Description
Diabetes Mellitus: Hemoglobin A1c Control (<8.0%)	NQF 0575	Percentage of patients aged 18 years through 75 years of age with diabetes who had most recent hemoglobin A1c <8.0%
Diabetes Mellitus: Urine Protein Screening	NQF 0062	Percentage of patients aged 18 years through 75 years of age with diabetes who had a nephropathy screening test or evidence of nephropathy during the measurement period
Diabetes Mellitus: Retinal Eye Exam Screening	NQF 0055	Percentage of patients aged 18 years through 75 years of age with diabetes who had a normal retinal eye exam in the past 2 years or a retinal screening in the past year
Diabetes: Hemoglobin A1c Done	NQF 0057	Percentage of patients aged 18 years through 75 years of age with diabetes who received an A1c test during the measurement year
Hypertension (HTN): Controlling High Blood Pressure	NQF 0018	Percentage of patients aged 18 years through 85 years of age who had a diagnosis of hypertension (HTN) and whose blood pressure was adequately controlled (<140/90 mmHg)

HEDIS Healthcare Effectiveness Data and Information Set

Table 2 Glycemic and process metrics for glucose management in the hospital

	AACE/ADA [11] (2009)	ADA [12] (2014)	ENDO [13] (2012)
Outcome measures			
Hypoglycemia	<70	<70	<70
Hyperglycemia	>140	>140	>140
• Premeal	<140	<140	<140
• Random	<180	<180	<180
• Majority of patients	140–180	140–180	N/A
• Select patients	Lower targets may be appropriate, but <110 mg/dl not recommended	110–140	N/A
Process measures			
Documentation of diabetes diagnosis	Absent	Present	Present
BG testing on admission	Absent	Present	Present
A1C on admission	Absent	Present	Present
Insulin delivery method			
• Non-ICU	Basal-bolus	Basal-bolus	Basal-bolus
• ICU	CII	CII	N/A
• Intraoperative	N/A	N/A	N/A
• SSI	Avoid prolonged use	Avoid prolonged use	Avoid prolonged use
BG indication for insulin			
• Non-ICU	>140	>140	>140
• ICU	>180	>180	N/A
• Non-ICU	None	None	High
• ICU	None	Minimal	N/A
Insulin decision support			
• Transition from CII to SC insulin	Moderate	None	High
Non-insulin agents (recommendation)	Avoid in most; may be appropriate in select stable patients	Limited role; may be used in select stable patients	Avoid in most; may be used in select stable patients

(Adapted from: Mathioudakis NM, Golden SH. *Current Diabetes Reports*, 2015;15(3):13) [10]

AACE American Association of Clinical Endocrinologists, *ADA* American Diabetes Association, *CII* continuous insulin infusion, *ENDO* the Endocrine Society, *ICU* intensive care unit, *SSI* sliding scale insulin, *BG* blood glucose, *N/A* not available

Table 3 Comparison of inpatient glucometrics

	Glucometric measures		
Metric	SHM [14]	Yale [15]	CMS/NQF [16]
Hypoglycemia	• % PD or PS with severe hyperglycemia (BG <40 mg/dl) • % PD or PS with hypoglycemia (BG <70 mg/dl)	• % PD or PS with hypoglycemia (BG <70)	• % of PD with severe hypoglycemia (BG <40 mg/dl) attributable to hypoglycemic agents[b] [NQF measure 2361]
Hypoglycemia management	• Mean/median time to next documented BG • Mean/median time to resolution • % of hypoglycemic events with repeat testing within 15 min (or 30 min)	• N/A	• N/A
Normoglycemia	• % of BG readings in goal range (70–179 mg/dl) • % of PD or PS with all readings in range	• % of BG readings in goal range (e.g., 70–149 mg/dl) • % of PD or PS with all readings in range	• N/A
Hyperglycemia	• % of PD or PS with a mean BG above desired range (≥180 mg/dl) • % of PD or PS with any BG >299 mg/dl	• % of PD or PS with any BG >299 mg/dl	• % of PD with hyperglycemia (BG >200 mg/dl)[a] [NQF measure 2362]

PD patient days, *PS* patient stays, *SHM* Society of Hospital Medicine, *CMS* Centers for Medicaid and Medicare Services, *NQF* National Quality Forum, *BG* blood glucose, *N/A* not available

[a] Two or more BG levels >200 mg/dl measured at least 6 h apart or a single BG >200 mg/dl if only one value available that day or no BG measured that day and not preceded by two normoglycemic days

[b] That is, BGs <40 mg/dl that were preceded by administration of a short/rapid-acting insulin within 12 h or an anti-diabetic agent other than a short/rapid-acting insulin within 24 h, were not followed by another glucose value greater than 80 mg/dl within 5 min, and were at least 20 h apart

Type 2 Diabetes Is Preventable Through Lifestyle Change at Population Level

Multiple randomized, controlled trials across the globe have demonstrated the efficacy of lifestyle modification for the prevention or delay of type 2 diabetes [20–22, 23••, 24–29] among those at high risk (Table 4). These trials published in the early 2000s conducted in Europe, India, East Asia, and the USA established that behavioral lifestyle interventions, through modest (5–7%) weight loss and increased physical activity, result in clinically significant reductions in diabetes risk over three to 6 years (relative risk reductions, 28.5 to 67.4%; absolute risk reductions, 6.3 to 21.7%; number needed to treat, 5 to 16). Long-term follow-up of participants in these randomized trials have demonstrated a persistent effect of a lifestyle intervention for reducing diabetes risk over ten or more years in the Diabetes Prevention Program Outcome Study [22, 23••]. Similarly, over 23 years of follow-up in the China Da Qing Diabetes Prevention Study (DPS), the risk of developing diabetes as well as all-cause and cardiovascular disease mortality was lower [29].

In 2008, Ackerman et al. published the results of the Diabetes Education and Prevention with a Lifestyle Intervention Offered at the YMCA (DEPLOY), in which the Diabetes Prevention Program (DPP) lifestyle intervention was adapted for a group setting. Compared to brief counseling alone (−1.8%), weight loss was 4.2 percentage points greater ($P = 0.008$) for the group-based DPP (−6.0%) at 12 months [30]. This landmark study demonstrated that the DPP could be implemented in a community setting at a low cost. In 2015, 16 years after the initial publication of the China Da Qing DPS [27], a comprehensive meta-analysis comparing lifestyle (diet + physical activity) to usual care found that lifestyle interventions [23••] in populations at risk lower weight by an average of 2.5% across settings; higher-intensity programs had larger effects [31].

Economic Evaluation of Lifestyle Interventions for Diabetes Prevention

Economic evaluations of lifestyle intervention for diabetes are promising from a cost effectiveness standpoint. In the DPP Outcomes Study, a within-trial analysis with a payer perspective and time horizon of 10 years demonstrated that lifestyle modification was cost-effective ($10,037 per quality-adjusted life year (QALY)) [32]. In a systematic review in 2015, Li et al., evaluated costs from 16 studies of diet and physical activity programs aimed at reducing diabetes risk and found that from a health system perspective, the median incremental cost-effectiveness ratio (ICER) was $13,761 per QALY with group-based program having much lower median costs ($1819/QALY) than individual-based ($15,846/QALY) programs [33].

Policy, Dissemination, and Implementation The accumulating evidence on the effectiveness of lifestyle interventions targeting 5–7% weight loss and 150 min/week of moderate-intensity physical activity has sparked public health initiatives globally to reduce diabetes risk as reviewed in detail in a recent article [34]. For example, the Finnish National Diabetes Prevention Program (FIN-D2D) identified high-risk individuals using the FINDRISC (Finnish Diabetes Risk Score) for individual- and group-based lifestyle interventions; in this national program, 17.5% of participants lost at least 5% of their baseline weight at 1 year and were 69% less likely to develop diabetes during that time [35]. The Diabetes in Europe—Prevention Using Lifestyle, Physical Activity and Nutritional Intervention (DE-PLAN) was subsequently initiated to evaluate the impact of identifying (using FINDRISC) and intervening upon high-risk individuals across countries in Europe [36].

In the USA, under the Diabetes Prevention Act of 2009, the Centers for Disease Control (CDC) established the National Diabetes Prevention Program (NDPP), a national program intended to raise awareness of diabetes risk and to target those at high risk of diabetes for evidence-based lifestyle change interventions [37, 38]. The NDPP requires risk stratification for determining eligibility for a DPP based on the following: elevated weight for height, biochemical evidence of prediabetes (based on impaired fasting glucose, impaired glucose tolerance, or HbA1c) or history of gestational diabetes, and/or high scores on risk screeners that assess non-laboratory-based risk factors (e.g., age, family history) [39]. The NDPP has established criteria for programs to apply for CDC recognition based on their fidelity with the original DPP approach. Specifically, for a program to apply for CDC recognition status, it must use an approved

Table 4 Randomized, controlled trials demonstrating the efficacy of lifestyle modification for diabetes prevention

Study	Intervention	Control	Number	Follow-up (years)	Diabetes incidence in control arm (%)	RRR (%)	ARR (%)	NNT
Da Qing DPS	Intensive lifestyle	Standard lifestyle advice	577	6	67.7	42	21.7	4.6
Finnish DPS	Intensive lifestyle	Lifestyle advice	523	3.2	23	58	12	8.3
DPP	Intensive lifestyle	Placebo + lifestyle advice	2161	2.8	28.9	58	14.5	6.9
Indian DPP	Lifestyle	Standard lifestyle advice	269	2.5	55	28.5	15.7	6.4
Zensharen study	Intensive lifestyle	Standard lifestyle advice	458	4	9.3	67.4	6.3	15.8

RRR relative risk reduction, *ARR* absolute risk reduction, *NNT* number needed to treat, *DPS* Diabetes Prevention Study, *DPP* Diabetes Prevention Program curriculum that lasts for 12 months and be led by certified lifestyle coaches. These programs must start out with a more intensive phase (e.g., weekly in-person sessions) for the first 6 months followed by a maintenance period of 6 months. In order to attain full recognition, programs must meet specific attendance, physical activity, and weight loss goals (Table 5) at 6 and 12 months [39]. The CDC's Diabetes Prevention Recognition Program (DPRP) requires regular reporting of data to the CDC to assess outcomes. As of January 8, 2017, of 1236 programs participating in the DPRP, 89 (7.2%) had attained full recognition.

The Medicare Diabetes Prevention Program

In March 2016, based on a demonstration among 6874 Medicare beneficiaries, the US Department of Health and Human Services announced its intention to cover the DPP as a benefit for Medicare members [40]. In this demonstration project, eligible Medicare members were recruited to YMCA DPPs: >80% attended at least four in-person group sessions, and of those attending at least four sessions, average weight loss was 4.7% for those attending ≥4 sessions and 5.2% for those attending ≥9 sessions over 24 months. Actuarial analyses demonstrated a cost savings of $2650 per enrollee over 15 months compared to members not in the program.

Diabetes Prevention Program Dissemination and Implementation in the USA

A major challenge to translating the evidence into clinical and public health practice is that the definitions of prediabetes, screening strategies, and treatment recommendations vary across several influential US organizations, including, the US Preventive Services Task Force (USPSTF), the American Diabetes Association (ADA), the American College of Endocrinology (ACE), the American Association of Clinical Endocrinologists (AACE), the American Association of Family Physicians, and the American College of Physicians. A similar challenge exists in assessing the effectiveness of inpatient glucose management programs, where professional societies and regulatory groups have not agreed upon uniform definitions of hypoglycemia, euglycemia, and hyperglycemia (see below, "Inpatient Diabetes Management (Acute Care)" section) The long-term benefit of pharmacologic therapy for diabetes prevention is also unknown. Finally, awareness and knowledge of prediabetes by all stakeholders is limited. Alignment around these issues and further study, particularly in the case of pharmacologic therapy, are needed.

Outpatient Diabetes Management and Patient Self-Management (Chronic Care)

Diabetes Self-Management Education and Support

Patient diabetes self-management education (DSME) is a standard of care, and research examining effectiveness of DSME has led to specific recommendations for the content and quality of DSME [41•, 42]. Several reviews have found evidence that group education, as compared to usual care, results in improvement in glycemic control, with mean changes in HbA1c ranging −0.4 to −1.4% at 6 months following education, −0.5 to −0.8% at 12 months, and −0.9 to −1.0% at 24 months [43, 44]. Studies show that group education also results in improvements in knowledge, self-management behaviors, self-efficacy, and patient satisfaction [44]. There is less evidence that individual education is more effective than usual care for clinical, behavioral, or psychosocial outcomes [43]. Patients with poorer HbA1c at baseline tend to have greater reductions in HbA1c following DSME [43, 45]. A meta-analysis of trials of culturally tailored educational interventions delivered to racial and ethnic minority patient subgroups with type 2 diabetes found a mean reduction in HbA1c of −0.4% at 3 months, −0.5% at 6 months, −0.2% at 12 months, and −0.3% at 24 months [46].

Provider and System Level Interventions to Improve Glycemic Control and Other Outcomes in the Ambulatory Setting [47]

Successful quality improvement strategies for ambulatory diabetes care target several areas—patients (patient education,

Table 5 Diabetes prevention recognition program requirements: goals for recognition

Goal	Metric
Attendance	
Months 1–6	Average of ≥9 sessions attended
Months 7–12	Average of ≥3 sessions attended
Documentation of weight	Weight recorded at ≥80% of sessions attended
Documentation of physical activity	Physical activity recorded at ≥60% of sessions attended
Weight loss[a]	
6 months	Average weight loss of ≥5% from baseline
12 months	Average weight loss of ≥5% from baseline

[a] This applies to participants attending at least four sessions

promotion of self-management, reminder systems), healthcare providers (audit and feedback, clinician education, clinician reminders, financial incentives), and health systems (case management, team changes, electronic patient registry, facilitated relay of information to clinicians, continuous quality improvement [QI]) [48]. Several prior meta-analyses have examined the impact of these intervention approaches on glycemic control and other metabolic control indices in patients with diabetes [48–50].

Shojania et al. performed a systematic review and meta-analysis of 58 studies of 66 distinct trials incorporating these multiple intervention areas. The mean post-intervention HbA1c difference, compared to preintervention, was −0.42% with greater reductions if baseline HbA1c was ≥8% [49]. Strategies associated with at least a 0.5% reduction in HbA1c after controlling for baseline HbA1c ≥8% and study size included team changes (−0.67%) and case management (−0.52%). In comparative analyses, interventions that included case management reduced HbA1c significantly more than interventions that did not include case management and of these types of interventions, the most effective case management interventions were those in which the case managers could make independent medication changes [49]. This was confirmed in a subsequent meta-analysis of randomized controlled trials of disease management programs improving glycemic control in adults with type 1 and type 2 diabetes [50]. Similarly, interventions that included team changes reduced HbA1c significantly more than interventions that did not include team changes, particularly those that included multidisciplinary, interactive teams [50]. Interventions with team changes remained significant after controlling for the presence of case management [49]. In those studies, adding a new team member alone was not effective but rather, adding a team member with shared care between specialists and primary care providers or new team members with an expanded role was most effective.

A more recent meta-analysis expanded on Shojania's prior study by including process outcome measures and additional non-glycemic outcome measures to evaluate the additional impact of multi-component diabetes quality improvement interventions [48]. Overall, interventions resulted in lower HbA1c, LDL-cholesterol, and blood pressure in those receiving compared those not receiving the interventions [48]. These strategies also improved the likelihood that patients received aspirin therapy, anti-hypertensives, and screening for diabetic complications. Statin use, blood pressure control, and smoking cessation were unchanged. For patients with HbA1c ≥8% intervention strategies that lowered HbA1c ≥0.5% included team changes, case management, patient education, and promotion of self-management; however, for patients with HbA1c <8%, facilitated relay was more effective in lowering HbA1c ≥0.5% [48]. The only intervention strategy that was not effective in lowering HbA1c was clinician education alone [48]. These data suggest that greater improvements in HbA1c can be achieved utilizing multi-level QI intervention strategies that target the healthcare system and patient.

Ambulatory Interventions Targeting Underserved and Minority Populations [47]

Glazier et al. conducted a systematic review of 17 studies examining the effectiveness of patient, provider, and health system interventions among patients with type 1 or type 2 diabetes in socially disadvantages populations, defined as those of low socioeconomic status or belonging to an ethnic/racial minority group [51]. Eight of 13 studies showed improvements in HbA1c but less impact on body weight, lipids, and blood pressure. Features of effective interventions that lowered HbA1c included cultural and health literacy tailoring, leading by community educators or lay people, 1:1 (versus group) interventions with individualized assessment/reassessment, incorporation of treatment algorithms, focusing on behavior-related tasks, and providing feedback and high intensity interventions over a long duration [51].

Patient Interventions Within Healthcare Organizations In Peek's review of 17 studies of patient interventions within the healthcare organization that sought to improve dietary habits, physical activity, or self-management activities, those that were culturally tailored were more effective in lowering HbA1c than general QI interventions (−0.69 versus −0.1%) [52]. Also, peer support and 1:1 in-person diabetes self-management and patient education interventions were more effective than online and computer-based delivery modalities for self-management and patient education. In a systematic review and meta-analysis looking exclusively at randomized controlled trials of patient interventions targeting non-Hispanic Blacks (NHBs), most of which were culturally adapted and included peer providers, two of 22 increased patient attendance at screening visits for diabetic eye disease and 20 of 22 promoted improved diabetes self-management behaviors [53]. In a meta-analysis of eight studies, interventions resulted in a significant 0.83% reduction in HbA1c [53].

Community Health Worker Interventions Systematic reviews of community health worker (CHW) interventions in diabetes published between 2006 and 2013 provide evidence of effectiveness of lay health worker interventions on outcomes including knowledge, diabetes self-care behaviors, clinical outcomes, and healthcare utilization and costs, largely for Hispanic and NHB populations [54–56]. Progress in delineating roles of CHWs (e.g., patient care, education, support for care delivery provided by other health professionals, care coordination, and social support) and training in scopes of practice for CHWs have been deemed elements of effective CHW use [54]. In addition to community-based provider service delivery, models of integration of CHW's within healthcare teams [57, 58] have evidence of effectiveness in improving healthcare-related outcomes.

Provider Interventions In Peek's review, provider interventions including education, continuing medical education, computerized decision support, in-person feedback, and problem-based learning improved process measures [52]. The majority of these studies were conducted in NHBs with diabetes. Interventions involving computerized decision support reminders and chart audit and individual feedback resulted in improved HbA1c and treatment modification [59–62].

Healthcare Organization Interventions Healthcare organization interventions in minority populations have included systems for rapid turnaround HbA1c, circumscribed appointments, support staff (e.g., nurse case management, community health worker, pharmacist), and increased follow-up through home visits or telephone/mail contact [52, 63]. In Peek's review, 14 studies with interventions targeting the healthcare organization resulted in a mean HbA1c reduction of 0.34%. Ricci-Cabello et al. included five healthcare system intervention trials in NHBs in their systematic review and meta-analysis and found that the two most highly effective interventions in improving HbA1c and frequency of therapy intensification included rapid turnaround HbA1c [64].

Multi-target Interventions Multi-target interventions target all aspects and components of healthcare delivery, including patients, providers, and the healthcare system. Five of these studies have targeted NHBs with diabetes and used various approaches. Three studies showed an improvement in HbA1c [65–67]. All of these interventions included patient education and self-management support and nurse case management, two included treatment algorithms [65, 66], and two involved collaboration with a physician in treatment decisions [65, 66]. While two additional multi-target interventions showed improvement in process measures and non-glycemic clinical outcomes [57, 68], they did not improve glycemic control. One study involved patient interventions and provider-focused QI interventions focused on system changes surrounding the physician visit [68] and the other involved nurse case management and community health workers using evidence-based clinical algorithms with feedback to primary care physicians [57]. Finally, one study focusing exclusively on Native Americans in the Indian Health Service included provider guidelines, a multi-disciplinary team, diabetes registry/tracking system, and flowsheets [69]. Compared to podiatric screening and patient education, the multi-target intervention resulted in a significant reduction in amputation rate [69].

Cost-Effectiveness of Ambulatory Interventions

Li and colleagues presented a systematic review on cost-effectiveness of diabetes interventions between 1985 and 2008 [70]. The following interventions were considered cost saving: ACE inhibitor therapy (ACEI) or angiotensin receptor blocker (ARB) for intensive hypertension control, ACEI or ARB treatment to prevent end-stage renal disease, and robust foot care to prevent ulcers. A number of other interventions, such as universal screening for diabetes in African-Americans who are 45–54 years old, intensive glycemic control in patients with newly diagnosed type 2 diabetes, intensive statin therapy, and others were found to be very cost-effective [70].

The 2005–2008 Medical Expenditure Panel Survey [71] found that patients with diabetes who received their care at a Community Health Center (CHC) saved payers and individuals up to $1656 in ambulatory care cost, compared to non-users of CHC. The quality of diabetes care was not different, compared to other primary care settings. Another study of four Midwestern CHC found that quality improvement of diabetes care may lead to additional administrative ($6–$22/patient, year 1) and clinical costs, though it varies between the centers [72].

Enhanced diabetes care may save money in the short run [73]. One study showed that improvement in HbA1c levels could potentially save between $685 and $950, mostly due to fewer hospital admissions, and reduced emergency room visits and physician consultations [74]. Ansell showed that improved access to primary care was associated with decreased utilization of non-urgent episodic care services among an indigent population in Chicago, Ill [75]. A 6-month diabetes group initiative at Kaiser Permanente resulted in reduced outpatient and hospital use [76].

In Europe, Nason et al. found that a multi-disciplinary foot protection clinic in Ireland resulted in €114,063 saving per year, as the number of major foot amputations decreased [77]. Schouten and colleagues found that enhanced patient-centered diabetes care in the Netherlands through quality improvement collaborations was modestly cost-effective [78]. While many interventions that intend to control diabetes may be cost-savings or at least cost-effective, a number of studies failed to show cost-effectiveness [79–81].

Inpatient Diabetes Management (Acute Care)

The number and percentage of hospitalized patients with diabetes has increased over the past two decades [82, 83], reflecting the increasing incidence and prevalence of diabetes [84, 85]. While individuals with diabetes represent 8–9% of the US population [86], they account for 23% of hospitalizations (approximately 8.8 million per year) [82]. Diabetes is also a significant source of healthcare expenditures. In 2007, of the projected $430 billion in national expenditures for inpatient hospital care, 23% ($97 billion) was incurred by individuals with diabetes [87]. In addition, admissions for uncontrollable diabetes, which are preventable, accounts for significant hospital costs as well, ranging from $552 million for those without complications to $1821 million for those with ketoacidosis [88]. In addition to having higher rates of hospital admission compared to non-diabetic individuals, those with diabetes also have longer lengths of stay [87]. There is also a cost associated with development of inpatient hypoglycemia. In one study, patients with diabetes who developed hypoglycemia during admission had significantly higher charges, longer length of stay, higher mortality, and greater odds of discharge to a skilled nursing facility [89]. Given the significant costs associated with acute care, there is a huge opportunity for cost savings by developing systems approaches to reducing length of stay and readmissions and preventing hospital admission for ambulatory sensitive conditions.

Because inpatient hypoglycemia and hyperglycemia are associated with negative clinical and economic outcomes, it is critical to devise systems approaches to improving the quality and safety of inpatient management of diabetes. In 2006, the American Association of Clinical Endocrinologists (AACE) and the American Diabetes Association (ADA) released a call to action outlining overarching strategies to successfully implement hospital-wide glucose control efforts to improve care of hospitalized patients with diabetes [90, 91]. The Joint Commission, in partnership with the ADA, bolstered this national movement by establishing key expectations for management of hospitalized patients with diabetes through its Advanced Certification in Inpatient Diabetes Program—(1) specific staff education requirements, (2) written blood glucose monitoring protocols, (3) plans for treatment of hypoglycemia and hyperglycemia, (4) data collection for indices of hypoglycemia, (5) patient education on diabetes self-management, and (6) identified program champion or champion team [92].

To achieve the recommended inpatient glycemic targets and outcomes (Tables 2 and 3), current recommendations include the presence of formal glucose management program infrastructure to facilitate development of standardized order sets, hypoglycemia tracking, and hypoglycemia protocols to deliver safe and high-quality care to hospitalized patients with diabetes [10, 12, 13, 91]. The most commonly employed quality improvement (QI) interventions in inpatient glucose management can be divided broadly into the following categories: (1) provider reminder systems and decision support [15, 93–96], (2) automated computer order entry [93, 97–99], (3) prescriber or nursing education [93, 95, 98, 100], and (4) organizational change [93, 96, 101, 102]. Most QI studies have used a multi-faceted approach as outlined by Draznin et al.'s conceptual model for systems interventions to improve quality and safety of inpatient glucose management (Fig. 2) [103].

Interventions to Improve Glycemic Outcomes

Healthcare provider educational interventions Provider education is an important component in improving diabetes processes of care and intermediary glucose outcomes [103]. Moreover, educating and utilizing existing staff (e.g., nurses, physicians) to implement safe glucose management is critical in settings that are not adequately staffed with endocrine subspecialists. Previous studies have shown that continuing nursing education can be effectively provided through the use of nurse educators, or "superusers", who act as experts on institutional nursing policies and management principles, and are tasked with the peer-to-peer education of their unit-specific nurse colleagues [104, 105]. The advantages of the superuser model are that trained peers are (1) available to support their colleagues outside of traditional hours (since clinical activity occurs around the clock), (2) can be approached more comfortably with questions, and (3) can be available at the point of care [104]. The nursing superuser model has been applied successfully to hospital glycemic management. In one study describing a multi-component educational campaign for hypoglycemia prevention, nursing unit representatives developed expertise in the hypoglycemia protocol and communicated protocol changes back to their unit staff [106]. This intervention resulted in improved compliance with the hypoglycemia protocol and reduced hypoglycemic events [106]. Another program held "Train-the-Trainer" sessions for diabetes liaison nurses who became unit-based experts and clinical resources for the hospital's insulin protocols [107]. This multi-component program resulted in a decline in median glucose for diabetic patients and percentage of patients experiencing hyperglycemia [107]. In our own hospital, we developed a diabetes nursing superuser program that was critical to implementing our hypoglycemia policy nursing interventions, contributing to a sustained reduction in hypoglycemia over 3 years in our Inpatient Glucose Management Program [108]. We are developing a similar diabetes superuser education program for our physicians in order to similarly impact hyperglycemia [109]. In three studies, incorporation of case-based education sessions into a hospital-wide glycemic improvement program resulted in decreased use of sliding scale insulin [98, 110], increased use of basal-bolus correction insulin [98, 110], greater modification of the glycemic regimen in response to severe hyperglycemia [111], and improved glycemic control [98, 110, 111], without an increase in hypoglycemia rates [98, 110, 111].

System-Level Interventions In a large academic center, the combination of provider education and computerized insulin order sets resulted in a modest improvement in hyperglycemia without any significant increase in hypoglycemia [98]. In another example, between January 2006 and December 2009, a Glucose Steering Committee developed and implemented

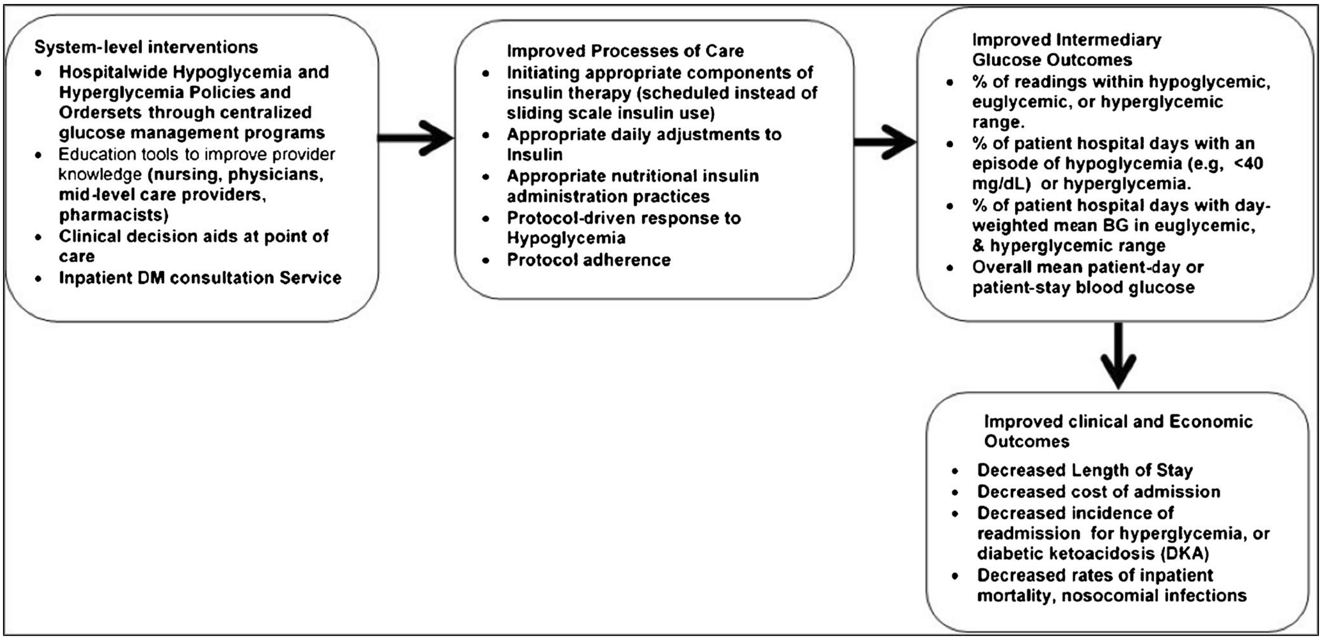

Fig. 2 A conceptual model for systems interventions to improve the quality and safety of inpatient management of hyperglycemia and diabetes. (Adapted with permission from: Draznin et al. Diabetes Care, 2013;36(7):1807–1814; permission conveyed through Copyright Clearance Center, Inc.) [103]

four hospital-wide programs to improve glucose management in patients with diabetes and hyperglycemia—(1) hospital-wide hypoglycemia policy and order set, (2) diabetes nursing superuser program, (3) hospital-wide hyperglycemia policy and order set, and (4) upgraded hyperglycemia order set with medical logic algorithms [112]. Among adult, non-intensive care unit (ICU) patients with diabetes and hyperglycemia, there was a 19% sustained reduction in hypoglycemic events over the course of these interventions [112].

Clinical Decision Support Systems Various types of systems targeting glycemic control are now widely utilized in hospitals throughout the USA. These include computerized provider order entry (CPOE), computerized-based insulin dosing algorithms (CBIA), continuous glucose monitoring (CGM) with closed-loop insulin delivery, and glucose dashboards. A 2011 systematic review by Nirantharakumar summarized the evidence from 14 studies of these systems on glycemic outcomes among hospitalized patients with diabetes in the non-critical care setting. [113] With respect to CPOE-based interventions, most studies found improvements in rates of hyperglycemia with an overall average reduction in patient day-weighted mean blood glucose ranging from 10.8 to 15.6 mg/dl, with only one of the studies showing a significant increase in hypoglycemic events. [113] Since the publication of this meta-analysis, there have been several additional studies evaluating the impact of CPOEs on glycemic outcomes [112, 114, 115]. Most, but not all, of these studies showed similar reductions in hyperglycemia rates without worsening hypoglycemia. In the one recent null study [114], the lack of effect was attributed to low institutional uptake.

Several commercial CBIAs exist that provide automated titration of insulin infusions and subcutaneous insulin regimens in the hospital [116]. In a retrospective cross-over study, a nurse-directed eGlycemic Management System (eGMS) for subcutaneous basal-bolus insulin therapy achieved better glycemic control with less hypoglycemia than basal-bolus insulin therapy managed by providers. [117•] In recent years the use of CGM and closed loop insulin delivery have been considered as advanced methods of clinical decision support for hospitalized patients. A recent randomized parallel-group trial found that this technology improved glycemic control without increasing rates of hypoglycemia among inpatients with type 2 diabetes. [118] Despite the potential of closed loop technology, "widespread adoption of CGM by hospitals is limited by added costs and insufficient outcome data" [119].

Another common IT-based strategy for inpatient glycemic management is the use of glucose dashboards or reports to facilitate "active case finding of in-need patients" [113]. The majority of studies evaluating this intervention showed positive results, with reductions in both hypoglycemia and hyperglycemia rates [111, 120–122]. One study showed no significant improvements in glycemic control with the use of a "multi-component intervention that included an out-of-range glucose report derived electronically" [123]. The financial impact of glucose dashboards for health systems has not been formally studied. However, such tools clearly facilitate tracking of glucometric data at unit, hospital, and health system levels. The Society of Hospital Medicine sponsors a web-based data and reporting center that enables hospitals to compare performance in glycemic control against other hospitals and benchmarks [14]. If, in the future, the quality of inpatient glycemic control becomes a CMS metric tied to reimbursement, health systems will need to be able to readily furnish glucometric data through the use of standardized glucose dashboards.

Considering the complexity of inpatient glucose management, it is not surprising that both IT-based and non-IT-based strategies are often required in combination to achieve significant improvements in glycemic control. Some examples of successful non-IT based interventions include process changes related to timing of meal and insulin delivery [124], restriction of high-dose insulin ordering to endocrine consultants [125], and post-operative algorithms/care bundles [126, 127].

Interventions to Improve Hospital Costs and Length of Stay

Glucose Management Teams Prior studies examining the use of specialized diabetes teams or endocrinologists to manage individual inpatients with diabetes resulted in better glycemic control and decreased length of stay compared to general internists' management [128–130]. Diabetes educational policies targeting nurses, physician assistants, attendings, or patients have been associated with a decrease in length of stay [98, 131, 132].

System-Level Interventions There are limited data about the impact of hospital-wide system-based glucose management programs on length of stay or hospital cost. One study examined the impact of an intensive glucose management protocol on economic outcomes in a mixed medical-surgical adult ICU. Compared to the preintervention period, there was a significant reduction in ICU and ventilator days; total lab, pharmacy, and radiology costs; post-ICU length of stay; and total hospital cost/patient [133]. In one study of a comprehensive inpatient diabetes management program that included diabetes education, a hypoglycemia policy, and computerized insulin order sets, there was a decrease in unadjusted length of stay in critical care and non-critical care patients [134]. In another study [135] of a multi-disciplinary diabetes care management program, there was a decrease in cost/admission. From a financial perspective, glycemic management in the post-operative period has been an area of focus for hospitals in light of the increased costs associated with surgical site infections associated with hyperglycemia. A systematic review and meta-analysis of 8515 patients found that surgical care bundles, of which glycemic control was one component, were associated with a 45% lower odds (95% CI 39–77%) of surgical site infection [127]. While there are presently insufficient economic data regarding the specific impact of glycemic control on surgical site infections [127], one study suggested a significant ROI with care bundles targeting this outcome, with estimated annual costs of $50,000 and savings of $234,261 (achieved mainly through reduction in LOS) [136].

Interventions to Improve Readmissions

Several interventions to reduce readmission risk among patients with diabetes have been explored in mostly small studies of variable quality [137]. One strategy that has been tested in randomized controlled trials (RCTs) is inpatient diabetes care by specialists, for which the data are mixed. One study found that daily rounds by a nurse diabetes educator and an endocrinologist decreased all-cause readmission rates within 3 months from 32 to 15% ($P = 0.01$) [129]. In contrast, however, another study reported that a diabetes specialty nurse decreased length of stay but did not affect readmission rate over 1 year [138]. There is some evidence supporting a beneficial effect of inpatient diabetes education (IDE) on readmission rates. A retrospective cohort study of 2265 hospitalized patients with uncontrolled diabetes reported that IDE was associated with a statistically significantly lower odds of readmission within 30 and 180 days [139]. A single-arm pilot of IDE and follow-up by phone after discharge in 82 patients with uncontrolled diabetes was associated with an 88.5% lower rate of hospitalization for severe hyperglycemia during 6 months of follow-up [140]. An RCT in 65 diabetes patients admitted for hypoglycemia found that IDE, medication adjustment, and discharge planning significantly reduced the risk of readmission for hypoglycemia while also reducing length of stay by more than 2 days [141]. In addition to inpatient diabetes care and education, data from a few retrospective studies suggest that intensifying diabetes therapy upon hospital discharge may reduce readmission risk among poorly controlled patients [142–144]. Another strategy for reducing readmission rates is outpatient diabetes specialty care. A pilot RCT found that follow-up at a diabetes transitional care clinic within 5 days of discharge significantly decreased the incidence of diabetes-related readmissions among patients admitted for diabetes [145]. A non-randomized study of diabetes specialty outpatient support appeared to decrease the risk of readmission for diabetic ketoacidosis over 2 years among patients with type 1 diabetes [146]. Although not formally tested, qualitative data suggest that readmission incidence may be reduced by improving the hospital discharge process with better communication of discharge instructions and involving patients more in discharge planning [147]. Another approach is to utilize CDSS, as was implemented in a health system of 13 hospitals as part of their CME Hospital Readmission Reduction Program and forthcoming bundled payment for patients admitted for coronary artery bypass surgery [148, 149]. They found that the use of an eGMS achieved lower rates of hyperglycemia and hypoglycemia as well as marked reductions in readmission for cardiovascular patients (coronary artery bypass graft, congestive heart failure, acute myocardial infarction) compared to standard care without the CBIA system [148, 150]. Lastly, another approach that has yet to be prospectively tested is to identify hospitalized patients at higher risk for readmission using a predictive model and then focus resources on those patients. One such model, the Diabetes Early Readmission Risk Indicator (DERRI), is to our knowledge the only validated tool developed specifically with diabetes patients [151••]. Whether readmission reduction strategies [137] will reduce overall healthcare costs remains unknown.

Conclusion

Diabetes population health management includes a continuum in patient care from diabetes prevention to chronic outpatient diabetes management to acute diabetes care in the hospital setting. Overall, there are limited data on the cost-effectiveness of multi-level ambulatory diabetes interventions or system-level glucose management intervention programs in the hospital setting, identifying these as important areas for future research. This will inform the best financial models for health systems to incorporate these strategies into diabetes population health programs. From a policy standpoint, professional societies and government organizations need to align around uniform definitions of, screening for, and treatment of prediabetes in order to fully translate research into public health practice. Finally, regulatory agencies should endorse metrics and expectations for hospital management of diabetes, as has been done for ambulatory diabetes management, to incentivize health systems to incorporate acute care into its diabetes population health programs.

Acknowledgments Nisa Maruthur reports grants from the Baltimore City Health Department and from the Maryland Department of Health and Mental Hygiene. Daniel Rubin reports grants from NIH/NIDDK (K23DK102963). Nestoras Mathioudakis reports grant from NIH/NIDDK (K23DK111986-01).

Compliance with Ethical Standards

Conflict of Interest Sherita Hill Golden, Nisa Maruthur, Nestoras Mathioudakis, Elias Spanakis, and Mihail Zilbermint declare that they have no conflict of interest.

Daniel Rubin reports grants from Merck, Boehringer Ingelheim, and AstraZeneca.

Felicia Hill-Briggs is a member of the Board of Directors of the American Diabetes Association.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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