



Social Determinants of Health and Diabetes: A Scientific Review

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Decades of research have demonstrated that diabetes affects racial and ethnic minority and low-income adult populations in the U.S. disproportionately, with relatively intractable patterns seen in these populations' higher risk of diabetes and rates of diabetes complications and mortality (1). With a health care shift toward greater emphasis on population health outcomes and value-based care, social determinants of health (SDOH) have risen to the forefront as essential intervention targets to achieve health equity (2–4). Most recently, the COVID-19 pandemic has highlighted unequal vulnerabilities borne by racial and ethnic minority groups and by disadvantaged communities. In the wake of concurrent pandemic and racial injustice events in the U.S., the American College of Physicians, American Academy of Pediatrics, Society of General Internal Medicine, National Academy of Medicine, and other professional organizations have published statements on SDOH (5–8), and calls to action focus on amelioration of these determinants at individual, organizational, and policy levels (9–11).

In diabetes, understanding and mitigating the impact of SDOH are priorities due to disease prevalence, economic costs, and disproportionate population burden (12–14). In 2013, the American Diabetes Association (ADA) published a scientific statement on socioecological determinants of prediabetes and type 2 diabetes (15). Toward the goal of understanding and advancing opportunities for health improvement among the population with diabetes through addressing SDOH, ADA convened the current SDOH and diabetes writing committee, prepandemic, to review the literature on 1) associations of SDOH with diabetes risk and outcomes and 2) impact of interventions targeting amelioration of SDOH on diabetes outcomes. This article begins with an overview of key definitions and SDOH frameworks. The literature review focuses primarily on U.S.-based studies of adults with diabetes and on five SDOH: socioeconomic status (education, income, occupation); neighborhood and physical environment (housing, built environment, toxic environmental exposures); food environment (food insecurity, food access); health care (access, affordability, quality); and social context (social cohesion, social capital, social support). This review concludes with recommendations for linkages across health care and community sectors from national advisory committees, recommendations for diabetes research, and recommendations for research to inform practice.

DEFINITIONS OF HEALTH DISPARITIES, HEALTH EQUITY, AND SDOH

Table 1 displays definitions of key terms. Differences in diabetes risk and outcomes can result from multiple contributors, including biological, clinical, and nonclinical factors (1). A substantial body of scientific literature demonstrates the adverse impact of a particular type of difference, health disparities (16) in diabetes (1,17,18). A preponderance of health disparities research in the U.S. has examined disparities by race and ethnicity (3,19). Internationally, the term health equity has traditionally been used to encompass the range of population inequalities resulting from demographic and economic characteristics, and this term is used increasingly in the U.S. (20–24). Addressing healthy equity necessitates an understanding of social and environmental factors that combined account for 50% to 60% of health outcomes (22,25). These social and environmental factors collectively are known as SDOH (21,26,27).

SDOH NOMENCLATURES AND CONTEXTUAL FACTORS

The writing committee reviewed the following commonly referenced SDOH frameworks for classifications and terminology: the World Health Organization (WHO) Commission on Social Determinants of Health (28), Healthy People 2020 (29,30), the

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See accompanying articles, pp. 1, 8, 11, and 188.

Table 1—Definitions

Term	Definition
Health disparities	A particular type of health difference that is closely linked with social, economic, and/or environmental disadvantage. Health disparities adversely affect groups of people who have systematically experienced greater obstacles to health based on their racial or ethnic group; religion; socioeconomic status; sex; age; mental health; cognitive, sensory, or physical disability; sexual orientation or gender identity; geographic location; or other characteristics historically linked to discrimination or exclusion (16).
Health equity	Equity is the absence of avoidable, unfair, or remediable differences among groups of people, whether those groups are defined socially, economically, demographically, or geographically or by other means of stratification. “Health equity” or “equity in health” implies that ideally everyone should have a fair opportunity to attain their full health potential and that no one should be disadvantaged from achieving this potential (24). Health equity is attainment of the highest level of health for all people. Achieving health equity requires valuing everyone equally with focused and ongoing societal efforts to address avoidable inequalities, historical and contemporary injustices, and the elimination of health and health care disparities (23).
Social determinants of health (SDOH)	The social determinants of health are the conditions in which people are born, grow, live, work, and age. These circumstances are shaped by the distribution of money, power, and resources at global, national, and local levels. The social determinants of health are mostly responsible for health inequities—the unfair and avoidable differences in health status seen within and between countries (26).

County Health Rankings Model (31,32), and Kaiser Family Foundation Social Determinants of Health factors (33).

No single consensus set of factors define SDOH. Nomenclatures used by each framework, for shared SDOH factors, are depicted in Fig. 1. Common among the frameworks is placement of economic and socioeconomic determinants as foremost. Food SDOH factors (e.g., insecurity and access) are classified as economic stability (29), neighborhood and built environment (29), material circumstances (28), or as an independent category (33). Housing is classified as material circumstances (28), economic stability (29), or neighborhood and built environment (33). Environmental exposures (i.e., toxins, air pollution, and water quality) are classified as neighborhood and physical environment (31) or built environment (29). Social environment is represented as community and societal context (29,33), social cohesion and social capital (28), or social factors (31). Health care is a SDOH in the WHO, Healthy People 2020, and County Health Rankings models, with access factors as primary, with or without quality of care factors.

Each framework posits complex interactions among SDOH factors. WHO additionally maps causal priority among the determinants. For example, the upstream sociopolitical context and resulting socioeconomic position are root cause, structural determinants of health

inequities that work through intermediary sets of determinants to cause health inequities. WHO positions the health system as an SDOH that plays a role in mediating impact of intermediary determinants on health outcomes (28).

REVIEW OF SDOH AND DIABETES

SDOH inclusion in this review was determined by representation within one or more existing SDOH frameworks and presence of a sufficient body of literature to demonstrate influence of the determinant on diabetes. The reviewed SDOH are shown in Table 2. Studies of primarily adult populations are described, and the terms type 2 diabetes mellitus (T2DM), type 1 diabetes mellitus (T1DM), and “diabetes” (indicating either a mixed T2DM and T1DM sample or diabetes case ascertainment methods that do not enable specifying clinical diagnostic type) are used in accordance with the terminology used in the respective studies.

Socioeconomic Status and Diabetes

Socioeconomic status (SES) is a multidimensional construct that includes educational, economic, and occupational status (34–36). SES is a consistently strong predictor of disease onset and progression at all levels of SES for many diseases, including diabetes (37). SES is linked to virtually all of the established SDOH. It is associated with the extent to which individuals and communities can access material resources including health care,

housing, transportation, and nutritious food and social resources such as political power, social engagement, and control.

The three components of SES are intercorrelated (38), but each aspect has unique implications for health. Each component can be assessed at the individual or population level (39). For example, economic status is often measured by determining a person’s own income. However, it is also assessed by the income of the household in which the person resides and by the income level of the community (e.g., mean household income of the census tract in which a person resides) as a proxy for the individual’s household income. Census-level household income also operates as a contextual variable, reflecting the composition and available resources in a defined area.

Educational status can be quantified either in years of schooling or highest degree earned. It may be assessed at the level of the individual (e.g., the person’s own educational attainment), the household (the highest grade completed by anyone in the household), or the community (e.g., percent of high school or college graduates in a census tract). Quantity of education does not capture differences in quality of education that may be relevant to SES measurement (38). Literacy has emerged as a measure of educational quality and as potentially more reflective of SES than years of schooling among African Americans and

World Health Organization (2010)	Socioeconomic and Political Context <ul style="list-style-type: none"> Governance Macroeconomic policies Social policies (labor housing, land) Public policies (Education, health, social protection) Culture and societal values 	Socioeconomic Position <ul style="list-style-type: none"> Social class Gender Ethnicity (racism) Education Occupation Income 	Social Cohesion and Social Capital	Material Circumstances <ul style="list-style-type: none"> Housing and neighborhood quality Consumption potential (means to buy healthy food, warm clothes) Physical work environment 	Health Care <ul style="list-style-type: none"> Access 	
Healthy People 2020	Economic Stability <ul style="list-style-type: none"> Employment Food insecurity Housing instability Poverty 	Education <ul style="list-style-type: none"> Early childhood education and development Enrollment in higher education High school graduation Language and literacy 	Social and Community Context <ul style="list-style-type: none"> Civic participation Discrimination Incarceration Social cohesion 	Neighborhood and Built Environment <ul style="list-style-type: none"> Access to foods that support healthy eating patterns Crime and violence Environmental conditions Quality of housing 	Health and Health Care <ul style="list-style-type: none"> Access to health care Access to primary care Health literacy 	
County Health Rankings Model (2014)	Economic Factors <ul style="list-style-type: none"> Education Employment Income 		Social Factors <ul style="list-style-type: none"> Family and social support Community safety 	Physical Environment <ul style="list-style-type: none"> Air and water quality Housing and transit 		
Kaiser Family Foundation (2018)	Economic Stability <ul style="list-style-type: none"> Employment Income Expenses Debt Medical bills Support 	Education <ul style="list-style-type: none"> Literacy Language Early childhood education Vocational training Higher education 	Community and Social Context <ul style="list-style-type: none"> Social integration Support systems Community engagement Discrimination Stress 	Neighborhood and Physical Environment <ul style="list-style-type: none"> Housing Transportation Safety Parks, playgrounds Walkability Zip codes/geography 	Health and System <ul style="list-style-type: none"> Health coverage Provider availability Provider linguistic and cultural competency Quality of care 	Food Environment <ul style="list-style-type: none"> Hunger Access to healthy options

Figure 1—Nomenclatures for shared determinants among four social determinants of health frameworks, the World Health Organization Commission on the Social Determinants of Health, the U.S. Department of Health and Human Services Healthy People 2020, the County Health Rankings Model, and the Kaiser Family Foundation Social Determinants of Health framework.

low-income Whites (40,41). Health literacy, which is directly associated with literacy and is context specific (42–44), and literacy are included as SDOH in Healthy People 2020 (29).

Occupation is itself multidimensional. It has been measured as employment status (e.g., employed vs. unemployed), stability (e.g., job insecurity), job type (e.g., manual vs. nonmanual, prestige of the occupation), and working conditions (e.g., shift work, number of hours worked, job demands, and control) (39,45). For members of large organizations, occupational hierarchies of job titles capture work conditions as well as qualifications and pay (e.g., civil service grades).

Associations of SES With Diabetes Incidence, Prevalence, and Outcomes

Income, education, and occupation show a graded association with diabetes prevalence and complications across all levels of SES, up to the very top. Those lower on

the SES ladder are more likely to develop T2DM, experience more complications, and die sooner than those higher up on the SES ladder (46,47). The higher a person’s income, the greater their educational attainment, and the higher their occupational grade, the less likely they are to develop T2DM or to experience its complications. The gradient is steeper at the bottom, however, and research has focused primarily on those with the lowest levels of income and education.

Income. Prevalence of diabetes increases on a gradient from highest to lowest income (48,49). In data from the National Health Interview Survey (NHIS) covering 2011–2014, Beckles and Chou (50) found increasing diabetes prevalence at lower levels of income as reflected in the levels of ratio of income to poverty level. Compared with those with high income, the relative percentage difference in prevalence of diabetes for those classified as

middle income, near poor, and poor, was 40.0%, 74.1%, and 100.4%, respectively. The difference in diabetes prevalence by income was greater during this time period than it had been in a prior period (1999–2002), pointing to widening disparities in diabetes prevalence associated with income.

At the neighborhood level, differences in diabetes prevalence by census tract are attributable to SES (51,52). For example, in a recent study by Kolak et al. (52), rate of T2DM was found to be significantly higher and concentrated in census tracts characterized by factors including lower incomes, lower high school graduation rates, more single-parent households, and crowded housing. Living in neighborhood census tracts with lower educational attainment, lower annual income, and larger percentage of households receiving Supplemental Nutrition Assistance Program benefits has been

Table 2—SDOH and component factors included in the diabetes review

Socioeconomic status	Neighborhood and physical environment	Food environment	Health care	Social context
Education	Housing	Food security	Access	Social cohesion
Income	Built environment	Food access	Affordability	Social capital
Occupation	Toxic environmental exposures	Food availability	Quality	Social support

associated with higher risk of progression to T2DM among adults with pre-diabetes (53).

Gaskin et al. (49) examined the interaction of individual poverty with neighborhood poverty and found that, compared with nonpoor adults living in nonpoor neighborhoods, poor adults living in nonpoor neighborhoods have increased odds of having diabetes, and poor adults living in poor neighborhoods have two-fold higher odds of having diabetes. In addition, a race-poverty-place gradient was observed. Compared with nonpoor Whites in nonpoor neighborhoods, odds of diabetes were highest for poor Whites in poor neighborhoods (odds ratio [OR] 2.51, 95% CI = 1.31–4.81), followed by poor Blacks in poor neighborhoods and nonpoor Blacks in poor neighborhoods (OR 2.45, 95% CI 1.50–4.01, and OR 2.49, 95% CI 1.48–4.19), and finally poor Whites in nonpoor neighborhoods (OR 1.73, 95% CI 1.16–2.57) (49).

Adults with T2DM who have a family income below the federal poverty level have a twofold higher risk of diabetes-related mortality compared with their counterparts in the highest family income levels (54). This pattern of diabetes-related mortality has been observed specifically in adults with T1DM as well (55). A meta-analysis by Bijlsma-Rutte et al. (56) observed an inverse association between income and HbA_{1c} levels in people with T2DM, with a pooled mean difference in HbA_{1c} of 0.20% (95% CI –0.05 to 0.46) between people with low and high income. Low income is associated with a higher risk of experiencing diabetic ketoacidosis among youth and adults with T1DM (57) and with higher HbA_{1c} levels, particularly among racial/ethnic minority youth with lower SES (58,59).

Education. Age-adjusted incidence of diagnosed diabetes in adults is associated also with educational level in a stepwise pattern. Diabetes incidence is highest (10.4 per 1,000 persons) for adults with less than a high school education, 7.8 per 1,000 persons for those with a terminal high school education, and 5.3 per 1,000 persons for those with more than a high school education (60). Diabetes prevalence in the adult U.S. population is similarly inversely associated with educational level in a stepwise pattern. In the U.S., the age-adjusted prevalence of diagnosed diabetes is 12.6% for those with less than a high school

education, 9.5% for those with a high school education, and 7.2% for those with more than a high school education (61). Having a college education or more is associated with the lowest odds of diabetes (62). Mirroring findings on income, temporal trends in diabetes prevalence at different levels of education show increasing disparities in prevalence associated with educational attainment (50).

The risk of diabetes-related mortality demonstrates a gradient from lowest to highest education level. Compared with adults with a college degree or higher, having less than high school education is associated with a twofold higher mortality from diabetes (relative hazard 2.05, 95% CI 1.78–2.35) (54). In adults with T1DM, not having a college degree is associated with a threefold higher mortality from diabetes compared with counterparts with a college degree (63). Lower educational level is associated with higher HbA_{1c}, with a meta-analysis (56) reporting a pooled mean difference in HbA_{1c} of 0.26% (95% CI, 0.09–0.43) between people with low and high educational levels. Regarding literacy/health literacy as a SDOH, Marciano et al. (64) conducted a meta-analysis of 61 studies of 18,905 adults with T1DM or T2DM to determine associations of health literacy with several diabetes outcomes and found that higher levels of health literacy were significantly associated with lower HbA_{1c} levels and better diabetes knowledge, but not with more frequent self-management activities.

Occupation. Systematic reviews and meta-analyses have examined several aspects of occupation in relation to diabetes risk, although most of this research has been conducted outside of the U.S. Ferrie et al. (65) conducted a meta-analysis of associations of job insecurity with incident diabetes and found an association of high job insecurity with higher risk of incident diabetes (OR 1.19, 95% CI 1.09–1.30). A meta-analysis by Varanka-Ruuska et al. (66) found that unemployment was associated with increased odds of both prediabetes (OR 1.58, 95% CI 1.07–2.35) and T2DM (OR 1.72, 95% CI 1.14–2.58). Exposure to shift work is associated with higher risk of diabetes than working normal daytime schedules (67). A meta-analysis by Kivimäki et al. (68) reported an association of long work hours (≥ 55 h per week) as compared

with standard work hours (35–40 h per week) with higher incident diabetes in adults with low SES but not in adults with high SES. A U.S. population-based survey on diabetes and occupation found highest prevalence of diabetes among transportation workers and lowest prevalence of diabetes among physicians (69,70).

SES Interventions and Diabetes Outcomes

To date, there is no body of literature describing impact of change in income, change to higher educational status, or different employment/occupational status on diabetes outcomes, although income and wage changes, and job changes and loss, do occur naturalistically. Similarly, no diabetes outcomes have been reported from interventions directly targeting living wages, early childhood education, educational quality, or educational access for poor children and families. Studies have examined diabetes self-management interventions in the setting of low literacy/health literacy, particularly among racial/ethnic minority adults with T2DM and have demonstrated effectiveness of low-literacy adaptations (71) and health literacy and numeracy tools in improving diabetes knowledge and self-care (72–74). A meta-analysis of nine intervention trials with 1,874 adults with T2DM found that literacy-sensitive interventions were associated with a small but statistically significant decrease in HbA_{1c} (–0.18%; 95% CI –0.36 to –0.004) in comparison with usual clinical care (75) in patients regardless of health literacy status. Literacy-adapted education and tools may need to be combined with more comprehensive evidence-based behavioral self-management intervention approaches to achieve substantive clinical improvements in racial/ethnic minority populations with T2DM and low literacy/health literacy (76,77). In conclusion, despite the long-standing evidence for SES as a key determinant both of diabetes risk and outcomes, systematic investigation of impact on diabetes of change in SES remains a gap in the literature.

Neighborhood and Physical Environment and Diabetes

The neighborhood environment in which one lives has been of major interest as a setting in which to understand contextual and multilevel influences on health (78). Diez Roux and Mair (78) have described the role of historical and contemporary

residential segregation by race, ethnicity, and SES as the socioeconomic and political context that produced the patterns of unequal resource distribution resulting in neighborhood environments that maintain health inequities. Tung et al. (79) also discuss the multiple intricacies associated with how race, place, and poverty converge in a dynamic way across various spatial contexts and circumstances to influence health and propose that understanding the intersection of these contextual influences is needed to prevent diabetes inequities. Neighborhood and physical environment factors of housing, built environment, and environmental exposures are reviewed.

Housing

Stable housing is a key indicator of economic stability (80) and a core SDOH (80). Housing instability refers to a spectrum of situations that can range from living in one's car, staying with relatives or friends, having trouble paying rent, suffering evictions or frequent moves, paying more than 50% of income in rent, and living in crowded conditions (historically defined as having more than one person per room) to homelessness—the most extreme form of unstable housing (81–85). Homelessness is defined as “lacking a regular nighttime residence or having a primary nighttime residence that is a temporary shelter or other place not designed for sleeping” (86). As of 2020, the U.S. government reported 567,715 or 17 of 10,000 people in the country are homeless; African Americans accounted for 40% of people experiencing homelessness, while those identifying as Hispanic or Latino comprised 22% of the homeless population (87). A common theme in conceptual models linking housing instability to poor health is that the instability inherent to the situation makes it difficult to attend to preventive services and self-care (83,88–90), leading to worse control of chronic conditions, higher use of acute-care services like emergency departments, and higher likelihood of complications (91–93).

Associations of Housing Instability With Diabetes Incidence, Prevalence, and Outcomes. The prevalence of diabetes among those with housing instability in the U.S., and whether it differs from that among those without housing instability, is not known. A key limitation for the field is that there is no single, accepted definition of housing

instability or a commonly used assessment instrument. Further, because housing instability is more likely to occur among individuals with lower SES—which is independently associated with higher diabetes prevalence—it is unclear whether housing instability is causally related to developing diabetes. One systematic review did not find higher diabetes prevalence than in the general population among persons experiencing homelessness, estimating approximately 8% prevalence in adults who do and do not experience homelessness (94). A recent study using nationally representative data from individuals seen in community health centers found that approximately 37% of individuals with diabetes reported housing instability. This study also found that individuals with diabetes and housing instability were more likely to self-report having an emergency department visit or hospitalization for their diabetes (adjusted OR 5.17, 95% CI 2.08–12.87) (82). A cross-sectional study in a single health care system found that housing instability among individuals with diabetes was associated with higher outpatient utilization (incident rate ratio 1.31, 95% CI 1.14–1.51) (95). Though not specific to diabetes, additional work has linked housing instability to poor health outcomes and reduced health care access (91,96–100). A longitudinal study in the Department of Veterans Affairs (VA) health care system found that experiencing homelessness was associated with higher adjusted odds of having an HbA_{1c} >8.0% and >9.0%. Vijayaraghavan et al. (84) identified unstable housing as a key barrier to diabetes care among low-income individuals. There was an observed linear decrease in diabetes self-efficacy as housing instability increased (β -coefficient -0.94 , 95% CI -1.88 to -0.01 , $P < 0.01$), which was partially mediated by food insecurity. Qualitative work has found that unstable housing makes it more difficult to engage in self-care, follow self-management routines, afford diabetes medications and supplies, and eat healthy foods (91,92). Choice of medication is important, and considerations should include medication cost and the ability to store medication and diabetes care supplies safely. Brooks et al. provide a narrative review of considerations for diabetes treatment among individuals experiencing homelessness (101).

Housing Instability Interventions and Diabetes Outcomes. Given its expense, housing is one of the most difficult health-related social needs to intervene upon. Housing intervention studies reporting diabetes outcomes are few; however, there is some high-quality evidence for housing interventions. The Moving To Opportunity for Fair Housing Demonstration Project (MTO), a randomized social experiment conducted through the Department of Housing and Urban Development, in partnership with behavioral scientists and other federal agencies, was designed to determine what impact moving from a high-poverty to a low-poverty census tract would have on multiple outcomes (102,103). In 1994–1998, MTO randomized 4,498 women with children living in public housing within high-poverty census tracts in five cities to one of three study arms. The 1,788 women in the experimental arm received Section 8 vouchers usable only in low-poverty areas (census tracts with <10% of the population below the poverty line) along with counseling and assistance in finding a private rental unit. The 1,312 women in the Section 8 arm received traditional unrestricted vouchers and the usual briefing the local Section 8 program provided. The 1,398 women in the control arm received no vouchers but continued to receive MTO project-based assistance. Those who received vouchers could choose whether to use the vouchers or not. Findings from the follow-up survey in 2008 through 2010 found a 21.6% relative reduction in prevalence of an elevated HbA_{1c} (>6.5%) in the group that moved to low-poverty census tracts compared with the control group, with an absolute difference of 4.31 percentage points (95% CI -7.82 to -0.80). The low-poverty group also had relative reductions of 13.0% in prevalence of BMI ≥ 35 and relative reduction of 19.1% in BMI ≥ 40 kg/m², with absolute differences of 4.61 percentage points (95% CI -8.54 to -0.69) and 3.38 percentage points (95% CI -6.39 to -0.36), respectively (102). The usual vouchers and control arms did not differ. Other MTO outcomes among the group randomized to low-poverty census tracts included higher housing quality, education, employment, and earnings as well as multiple additional improvements to child and adult health (103). A 10–15 year follow-up study found substantial and sustained reductions in diabetes prevalence, rates

of extreme obesity, and improvement in mental health outcomes among the adults who received vouchers to move to low-poverty neighborhoods and reduction in extreme obesity among the adults who received Section 8 vouchers (104). While not specific to diabetes, a meta-analysis of randomized trials that provided low-barrier housing support for individuals experiencing homelessness found significant reductions in health care utilization (105).

Housing interventions may facilitate access to diabetes care. The Collaborative Initiative to End Chronic Homelessness provided adults who were chronically homeless with permanent housing and supportive primary health care and mental health services (106). Placed persons were more likely to receive evaluation and management services (relative risk [RR] 1.03, 95% CI 1.01–1.04) than unplaced persons (107). Placed persons were more likely to receive HbA_{1c} tests (RR 1.10, 95% CI 1.02–1.19) and lipid tests (RR 1.09, 95% CI 1.02–1.17), while for those without baseline diabetes placement was associated with lower risk of new diabetes diagnoses (RR 0.87, 95% CI 0.76–0.99). Keene et al. (91) suggest the relationship of stable housing to diabetes management is due to its role as a foundation for prioritizing care and allowing for the routinization of diabetes management, critical to disease control. This suggests the benefits of supportive and stable housing may be extended to diabetes care and prevention. A naturalistic qualitative study of the impact of transitioning to rental-assisted housing among low-income, housing-insecure adults with T2DM reported that rental assistance afforded individuals more environmental and financial control over life circumstances, thereby enabling diabetes routines and allocation of financial resources to diabetes care (108).

Built Environment

The built environment, as defined by the U.S. Centers for Disease Control and Prevention (CDC), includes the physical parts of where people live and work, such as infrastructure, buildings, streets, and open spaces (109). Here, built environment factors of walkability and green-space are reviewed.

Associations of Built Environment with Diabetes Incidence, Prevalence, and Outcomes. A robust literature has demonstrated associations of the built environment with

obesity-related outcomes (110–113). However, a smaller body of research has examined associations of the built environment with diabetes specifically. Smalls et al. (114) reported significant associations of both walking environment ($\beta = -0.040$) and neighborhood activities ($\beta = -0.104$) with exercise in a southeastern U.S. population with diabetes. A recent U.S. review and meta-analysis by Chandrabose et al. (113) examined longitudinal studies of the built environment and cardiometabolic health. Results showed strong evidence for impact of walkability on T2DM outcomes, with four of seven studies (57%) showing significant findings in the aggregated analyses using objective and perceived measures of walkability. Although the methods to determine mediation by physical activity in most studies were ineffective to make conclusions, one study tested the indirect effect of walkability on 10-year change in HbA_{1c} and found a partial mediation effect for self-reported physical activity using structural equation modeling. For other measures of built environment, such as neighborhood recreational facilities or destinations/routes, there was insufficient data to examine the relationship with T2DM outcomes. A larger body of research on built environment and diabetes has been conducted in countries outside of the U.S (110–112). In these studies, neighborhood physical activity (PA) environments, specifically better walkability of neighborhoods and access to greenspace, have been consistently associated with lower risk of T2DM and better outcomes (115,116). Numerous studies have been conducted on walkability measured by macroscale aspects of the neighborhood, including higher population density, land use mix, and aesthetics, to microscale aspects, including sidewalks, street connectivity, and street safety. A review by Bilal et al. (115) on walkability and diabetes incidence and prevalence found that more walkable neighborhoods are associated with a lower incidence and prevalence of T2DM. Similarly, Twohig-Bennett and Jones (117) conducted a systematic review and meta-analysis examining the relationship to diabetes outcomes of “high” and “low” exposure to greenspace in neighborhoods (defined as open, undeveloped land with natural vegetation and/or spaces such as parks

and tree-lined areas). The meta-analysis, representing 462,220 participants, showed an association of high exposure with reductions in the incidence of T2DM (OR 0.71, 95% CI 0.61–0.85) (117). After decades of research, many built environment factors related to PA and obesity risk have been identified for consideration in urban planning (118).

Neighborhood-Level Interventions on the Built Environment and Diabetes Outcomes.

Because it is often not feasible or ethical to randomize neighborhoods to receive certain structural interventions, natural experiment designs are used in which the researcher does not control or withhold intervention allocation to particular areas; rather, natural or predetermined variation in allocation occurs, often as a result of policy intervention (119). Several review articles of natural experiments summarize the benefits of policy and built environment changes on obesity-related outcomes (112) and diet and PA outcomes (120,121). The strongest diet-related studies were those that evaluated regulations to the food environment, and the strongest PA-related studies were those that improved infrastructure for active transport. Although this literature does not directly address diabetes outcomes, improvements in obesity and diet and PA behaviors are relevant to populations with diabetes and warrant rigorous evaluation (122).

Toxic Environmental Exposures

Toxic environmental exposures can be naturally occurring (e.g., arsenic in private wells, radon) or introduced into the environment through human activity (e.g., pollution, synthetic pesticides) (123). Marginalized communities in the U.S. are disproportionately exposed to environmental agents that have evidence of an association with diabetes, including air pollution, environmental toxicants, and ambient noise (124–129), and subgroups that generate the least pollution have highest exposures (130).

Factors contributing to inequities in toxic environmental exposures include residential segregation and inequity in goods and services, due in part to systemic racism in environmental regulation and opportunities (128,130–133). Explanatory factors are closer proximity of underserved neighborhoods to nearby pollution sources, poor enforcement of regulations, and inadequate response to

Table 3—SDOH intervention recommendations from international and national (U.S.) committees

Committee	Recommended actions	Description
Commission on the Social Determinants of Health, WHO (2008) (27)	<p>Improve daily living conditions</p> <p>Tackle the inequitable distribution of power, money, and resources</p> <p>Measure and understand the problem and assess the impact of action</p>	<p>Put major emphasis on early childhood education and development. Improve living and working conditions. Create social protection policy supportive of all.</p> <p>Create a strong public sector that is committed, capable, and adequately financed. Ensure legitimacy, space, and support for civil society, for an accountable private sector, and for the public to agree to reinvestment in collective action.</p> <p>Acknowledge there is a problem. Ensure that health inequity is measured. Develop national and global health equity surveillance systems for routine monitoring of health inequity and the social determinants of health. Evaluate the health equity impact of policy and action. Ensure stronger focus on social determinants in public health research.</p>
Committee on Recommended Social and Behavioral Domains and Measures for Electronic Health Records, Institute of Medicine, NASEM (2014) (80)	<p>Standardize data collection and measurement to facilitate the critical use and exchange of information on social and behavioral determinants of health</p>	<p>Office of the National Coordinator for Health Information Technology and the CMS should include the recommended standardized measures in the certification and meaningful use regulations. Commonly used measures: race and ethnicity, * residential address, * alcohol use, tobacco use</p> <p><u>Additional recommended measures:</u> census tract-median income, * education, * financial resource strain, * social connections and social isolation, * depression, intimate partner violence, physical activity, stress</p>
Committee on Educating Health Professionals to Address the Social Determinants of Health, NASEM (2016) (301)	<p>Create a learning environment for health professionals to foster community collaborations</p> <p>Prepare health professionals to take action on SDOH</p> <p>Integrate SDOH into organizational mission and values</p> <p>Build the evidence base for SDOH learning, intervention, and evaluation approaches</p>	<p>Health professional educators should create lifelong learners who appreciate the value of relationships and collaborations for understanding and addressing community-identified needs and for strengthening community assets.</p> <p>To prepare health professionals to take action on the social determinants of health in, with, and across communities, health professional and educational associations and organizations at the global, regional, and national levels should apply [frameworks for] partnering with communities to increase the inclusivity and diversity of the health professional student body and faculty.</p> <p>Governments and individual ministries (e.g., signatories of the Rio Declaration), health professional and educational associations and organizations, and community groups should foster an enabling environment that supports and values the integration of the social determinants framework principles into their mission, culture, and work.</p> <p>Governments, health professional and educational associations and organizations, and community organizations should use [a social determinants] framework and model to guide and support evaluation research aimed at identifying and illustrating effective approaches for learning about the social determinants of health in and with communities while improving health outcomes, thereby building the evidence base.</p>
Committee on Integrating Social Needs Care into the Delivery of Health Care to Improve the Nation's Health, NASEM (2019) (5)	<p>Design health care delivery to integrate social care into health care, guided by the five health care system activities—awareness, adjustment, assistance, alignment, and advocacy</p> <p>Build a workforce to integrate social care into health care delivery</p>	<p>Establish organizational commitment to addressing disparities and health-related social needs. Incorporate strategies for screening and assessing for social risk factors and needs. Incorporate social risk into care decisions using patient-centered care. Establish linkages between health care and social service providers. Include social care workers in team care. Develop infrastructure for care integration, including financing of referral relationships with select social providers.</p> <p>Social workers and other social care workforces should be providers eligible for reimbursement from payers. Integrate SDOH competencies in medical and health professional credentialing.</p>

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Table 3—Continued
Committee

Recommended actions	Description
Develop a digital infrastructure that is interoperable between health care and social care organizations	Establish ACA-recommended digital infrastructure for social care. The Office of the National Coordinator should support identification of interoperable, secure, platforms for use across health and social care communities. The Federal Health Information Technology Coordinating Committee should facilitate data sharing across domains (e.g., health care, housing, and education). Analytic and technology implementation must have an explicit focus on equity to avoid unintended consequences such as perpetuation or aggravation of discrimination, bias, and marginalization.
Finance the integration of health care and social care	CMS should define and use flexibility in what social care constitutes Medicaid-covered services. Health systems, payers, and governments should consider collective financing to spread risk and create shared returns on investments in social care. Health systems subject to community benefit regulations should comply with those regulations and should align their hospital licensing requirements and public reporting with community benefits regulations and should link their community benefits providing social care.
Fund, conduct, and translate research and evaluation on the effectiveness and implementation of social care practices in health care settings	Federal (e.g., NIH, AHRQ, PCORI) and state agencies, payers, providers, delivery systems, and foundations should contribute to advancing research and evaluation of social care through funding opportunities, researcher support (i.e., cultivate health services, social sciences, and cross-disciplinary researchers), and use of experimental trials, rapid learning cycles, and dissemination of learnings. CMS should fully finance independent state waiver evaluations to ensure robust evaluation of social care and health care integration pilot programs and dissemination.

AHRQ, Agency for Healthcare Research and Quality; NASEM, National Academies of Sciences, Engineering, and Medicine; NIH, National Institutes of Health; CMS, Centers for Medicare & Medicaid Services; PCORI, Patient-Centered Outcomes Research Institute. *SDOH measures.

community complaints (134–138). In rural and suburban communities, including Native American Indian communities, unregulated private wells are a source of water contaminants including arsenic and other metals/metalloids, pesticides, and hazardous chemicals, affecting millions of people (139–141). Both food packaging and fast-food consumption, which can be high in low-income neighborhoods, can expose people to chemicals known to be endocrine disruptors (142–145). Examples include chemicals released from plastic packaging during microwave heating (142), higher urinary phthalate levels associated with fast food (145), and higher urinary bisphenol A levels from canned foods (146). Certain personal care and cosmetic products, which are a source of phthalates and metals (e.g., skin-lightening products, which are high in mercury), are disproportionately marketed to marginalized population subgroups (147).

Associations of Environmental Risk Factors With Diabetes Incidence, Prevalence, and Outcomes. In 2011, the National Toxicology Program at the National Institute of Environmental Health Sciences convened an international workshop to evaluate the experimental and epidemiologic evidence on the relationship of environmental chemicals with obesity, diabetes, and metabolic syndrome (148–150). Evidence was deemed strongest for arsenic, with relative risks of diabetes found to range from 1.11 to 10.05 in different studies (median 2.69) at high arsenic exposure levels. More recent systematic reviews and meta-analyses present the growing literature examining multiple groups of chemicals (148,151) or specific groups of chemicals (152–154). Overall, the evidence supports an increased risk of diabetes in populations exposed to environmental chemicals including arsenic, persistent organic pollutants, phthalates, and possibly bisphenol.

In 11 prospective studies of air pollution exposure and incident diabetes in adults, the pooled hazard ratio (HR) (95% CI) per 10 $\mu\text{g}/\text{m}^3$ increment particulate matter of $<2.5 \mu\text{m}$ aerodynamic diameter was 1.10 (1.04–1.17) (155). Other reviews have reached conclusions consistent with this increased diabetes risk finding (156–158). The epidemiologic evidence is also supported by animal experiments showing that air pollution exposure can increase susceptibility to

insulin resistance and T2DM (159–161). These findings highlight that populations more exposed to air pollution are also disproportionately at risk for developing diabetes.

There is epidemiologic and experimental evidence that environmental exposures increase susceptibility to cardiovascular disease (CVD) in people with diabetes. The evidence is extensive for air pollution exposures (162,163). For example, in Medicare patients, a daily increase of 10 $\mu\text{g}/\text{m}^3$ in particulate matter $<10 \mu\text{m}$ of aerodynamic diameter was associated with 2.01% increase in CVD hospitalizations for those with diabetes compared with 0.94% increase among those without diabetes (162). Short-term increases in air pollution exposure are also related to higher risk of stroke mortality in patients with diabetes compared with those without (164). In an experimental model, mice with diabetes exposed to diesel exhaust particles showed increased cardiovascular susceptibility compared with mice without diabetes (165). In natural experiments in human populations, air pollution exposure also resulted in increased vascular reactivity (166) and inflammation in patients with diabetes compared with those without (167). In addition to air pollution, some evidence is also available for metals. In the Strong Heart Study of American Indian adults followed since 1989–1991, the risk of CVD associated with higher exposure to arsenic and cadmium was higher among participants with diabetes compared with those without diabetes (168,169). In a clinical trial in patients with a previous myocardial infarction (Trial to Assess Chelation Therapy [TACT]), the beneficial effects of repeated chelation with disodium edetate on cardiovascular outcomes were greater in patients with diabetes (170).

Environmental Exposures Interventions and Diabetes. Few studies have evaluated the effect of population-based or clinical interventions related to environmental exposures and diabetes prevention or control. The increased risk of diabetes in populations exposed to environmental chemicals and the increased susceptibility for diabetes complications in individuals with diabetes exposed to air pollution potentially provides an opportunity for prevention and treatment that can be particularly relevant for the most vulnerable populations. For example, a

comparison of preterm births among four studies in different countries, before and after the implementation of smoke-free legislation, has shown reductions in diabetes risk (pooled risk change -18.4% , 95% CI -18.8 to -2), although the long-term benefits have not yet been evaluated (171).

Because individuals generally have limited control over environmental agents, the most effective interventions will be at the population level, through policy and regulation, with a particular focus on protecting marginalized and underserved populations. There is evidence that declines in air pollution levels and metal exposures have contributed to improvements in CVD development (172,173); benefits for diabetes development are pending. Research is also needed to test intermediate strategies at the clinical level, such as exposure screening (e.g., asking about living near highways or using private wells for drinking water) and recommendations to test air or water, reduce known sources of exposure (e.g., minimize packaged foods, avoid heating food in plastic containers, and minimize use of certain cosmetic products), and make home interventions (e.g., install filters for air or water contaminants) (174–176).

Food Environment and Diabetes

The food environment can be defined as the physical presence of food that affects a person's diet; a person's proximity to food store locations; the distribution of food stores, food service, and any physical entity by which food may be obtained; or a connected system that allows access to food (177). It is the "collective physical, economic, policy and sociocultural surroundings, opportunities and conditions that influence people's food and beverage choices and nutritional status" (178). It is also referred to as the community food environment (e.g., number, type, location, and accessibility of food outlets such as food stores, markets, or both) and the consumer-level environment (e.g., healthful, affordable foods in stores, markets, or both), which interact to affect food choices and diet quality (179,180). Key dimensions of the food environment include accessibility, availability, affordability, and quality (181–184). These factors, which define the quality of the food environment, are of particular

Table 4—Examples of resources on SDOH available for health care organizations and health care professionals

Organization	Resource
Centers for Disease Control and Prevention (CDC)	Tools for Putting Social Determinants of Health Into Action (https://www.cdc.gov/socialdeterminants/tools/index.htm)
National Academies of Science, Engineering, and Medicine	Questions for conducting social and behavioral determinant assessment and frequencies for assessing Adler NE, Stead WW. Patients in context—EHR capture of social and behavioral determinants of health. <i>N Engl J Med</i> 2015;372:698–701. DOI: 10.1056/NEJMp1413945
National Institutes of Health (NIH) Division of Extramural Affairs	The Neighborhood Atlas—Free social determinants of health data for all! Kind AJH, Buckingham W. Making neighborhood disadvantage metrics accessible: the neighborhood atlas. <i>N Engl J Med</i> 2018;378:2456–2458. PMID: PMC6051533
American Academy of Family Physicians	The EveryONE Project's Neighborhood Navigator Toolkit (https://www.aafp.org/patient-care/social-determinants-of-health/everyone-project/neighborhood-navigator/training-videos.html)
American College of Physicians	Addressing Social Determinants to Improve Patient Care and Promote Health Equity: An American College of Physicians Position Paper. DOI: 10.7326/M17-2441
American Medical Association	Podcast: Social determinants of health: What they are and what they aren't (https://www.ama-assn.org/delivering-care/patient-support-advocacy/social-determinants-health-what-they-are-what-they-arent)
Nonprofit services	211: A service of the United Way that continuously identifies links for all "211" health and human services referral services in the U.S. HealthLeads: A nonprofit offering tools, training and resources for integrating SDOH into accountable care Aunt Bertha: A service that provides links to hundreds of programs serving every U.S. zip code. Free basic use.

importance in marginalized communities, which may have poor access to supermarkets and healthy foods but abundant access to fast-food outlets and energy-dense foods and are often disproportionately impacted by physical hazards (e.g., vacant houses, traffic, and crime) (78). At their root, differences in the food environment can be caused by government policies and incentives, and the legacy of such policies as redlining and segregation.

Associations of Food Environment With Diabetes Incidence, Prevalence, and Outcomes

Food Access and Availability. Cross-sectional studies have shown associations between food access, availability, geographic characteristics, and T2DM prevalence. Ahern et al. (185) examined 3,128 counties across the U.S. for food access (assessed as percent of households with no car living more than one mile from a grocery store) and food availability (assessed as number of fast-food restaurants, full-service restaurants, grocery stores, convenience stores, and per capita sales in dollars from local farms made directly to consumers). Higher access to food was associated with lower T2DM rates in metro and nonmetro counties, and higher availability of full-service restaurants and grocery stores and lower availability of fast-food and convenience stores were associated with lower

diabetes rates (185). Haynes-Maslow and Leone (186) similarly found availability of full-service restaurants to be associated with lower prevalence of diabetes in adults and availability of fast-food restaurants generally to be associated with higher diabetes prevalence. However, the study reported variability in associations among numerous food environment characteristics based on county composition (low poverty/low minority, low poverty/medium minority, high poverty/low minority), highlighting complexities in understanding patterns among variables of county socioeconomic status, demographics, food availability, and diabetes prevalence (186).

Several observational, longitudinal studies report neighborhood resources in general, and access and availability of the food environment in particular, as associated with diabetes prevalence and incidence (187). A systematic review by den Braver et al. (188) found availability of fast-food outlets and convenience stores to be associated with higher T2DM risk/prevalence and perceived healthfulness of the food environment to be associated with lower diabetes risk/prevalence, but no association was found between density of grocery stores and T2DM risk/prevalence. Heterogeneity across the studies prevented the conduct of meta-analyses. Gabreab et al. (189)

examined neighborhood, social, and physical environments and T2DM in 3,700 African Americans through the Jackson Heart Study and found higher density of unfavorable food stores was associated with a 34% higher T2DM incidence after adjusting for individual-level risk factors. In a longitudinal employee cohort, Herrick et al. (190) found that living in a zip code with higher supermarket density was associated with a reduction in T2DM risk, while zip codes with a higher percentage of poverty and zip codes with higher walkability scores were both associated with higher diabetes risk. Christine et al. (191) reported long-term exposure to residential environments that offer resources to support healthy diets and PA was associated with a lower incidence of T2DM, although results varied by measurement method.

Studies have also examined both food and PA environments in combination and diabetes risk. Meyer et al. (192) combined measures of neighborhood food and PA environments and weight-related outcomes ($N = 14,379$) of the Coronary Artery Risk Development in Young Adults (CARDIA) study, examining population density-specific (less than vs. greater than 1,750 people per square kilometer) clusters of neighborhood indicators: road connectivity, parks and PA facilities,

Table 5—SDOH and diabetes research recommendations

Research recommendation 1 Establish consensus core SDOH definitions and metrics	Consensus is needed around language and metrics associated with SDOH and diabetes care that move beyond health care and capture the impact of social advantage and disadvantage in population settings. Clarity and consistency in measurement, evaluation, and reporting of progress will allow for appropriate planning of interventions, allocation of resources, and analysis of impact in achieving equity goals.
Research recommendation 2 Examine specificities in SDOH pathways and impacts among different populations with diabetes	Examinations of potential differences in pathways or impacts of SDOH based on characteristics including diabetes type or diagnostic category (e.g., T1DM vs. T2DM, gestational diabetes mellitus, prediabetes), age group (e.g., children and youth, adults, older adults), and different SES (wealthy vs. middle class vs. poor) are needed. In addition, complexities of SDOH pathways and impacts for different racial/ethnic groups, based on historical drivers and policies, warrant elucidation to inform intervention and mitigation strategies.
Research recommendation 3 Prioritize a next generation of research that targets SDOH as the root cause of diabetes inequities	Multisector partnerships, comprising academic institutions, government sectors (e.g., housing, education, justice), and public health entities are required in order to design and test observational and intervention studies to better understand and intervene on SDOH as root causes of diabetes disparities. Priorities need to move from compensatory to the next-generation of research that will be larger in scope, addressing foundational causes of disparities (e.g., policy, systems change), and tested over time across sectors. Complex studies, examining the interactive effects of multifaceted systems that influence SDOH, will also transform and move translational efforts toward large-scale solutions that promote equity for all populations and mitigate the influence of SDOH on diabetes outcomes.
Research recommendation 4 Use dissemination and implementation science to ensure SDOH considerations are embedded within diabetes research and evaluation studies	For clinical research programs, dissemination and implementation methods will shorten the translation gap from discovery to impact of evidence-based interventions by addressing the complexity of integrating and adapting evidence-based practices to real-world community and clinical settings. This will assure all populations benefit from the billions of U.S. tax dollars spent on research to prevent diabetes and to improve diabetes population health. Research studies must also consider the potential influence of either positive or negative SDOH (e.g., wealth or economic security vs. poverty, food security vs. insecurity, stable vs. unstable housing) on intervention appropriateness and outcomes, on study recruitment and participation, and on study outcomes and conclusions.
Research recommendation 5 Train researchers in methodologies and experimental techniques for multisector and next generation SDOH intervention studies	Training on SDOH and their influence on diabetes prevention and treatment is needed. Training priorities include interdisciplinary science, multisector collaboration research approaches, and methods to advance root cause research on SDOH. Additionally, increasing diversity among research workforces, and fostering educational experiences encompassing multisector partners will develop a workforce that is congruent with promoting diabetes health equity.

and food stores/restaurants. In lower-population density areas, higher food and PA resource diversity relative to other clusters was significantly associated with higher diet quality (192). In higher-population density areas, a cluster with relatively more natural food/specialty stores, fewer convenience stores, and more PA resources was associated with higher diet quality. Neighborhood clusters were inconsistently associated with BMI or insulin resistance and not associated with fast-food consumption, or walking, biking, or running (192). Tabaei et al. (193) examined associations of residential socioeconomic, food, and

built environments with glycemic control in adults with diabetes ascertained from the New York City A1C Registry from 2007 to 2013. Individuals who lived continuously in the most advantaged residential areas, including greater ratio of healthy food outlets to unhealthy food outlets and residential walkability, achieved increased glycemic control and took less time to achieve glycemic control compared with the individuals who lived continuously in the least advantaged residential areas (193).

Food Affordability. Kern et al. (194) note that it is reasonable to expect that large differences in price between healthy and

unhealthy foods would lead to differences in purchasing patterns and resulting diets and that those differences would be more prominent for individuals of lower SES. In a longitudinal study, they examined food affordability and neighborhood price of healthier food relative to unhealthy food and its association with T2DM and insulin resistance. Higher prices of healthy foods relative to unhealthy foods were found to be associated with lower odds of having a high-quality diet; however, there was no association with diabetes incidence or prevalence (194). More studies are needed in this area.

Food Insecurity. Food insecurity is defined as not having adequate quantity and quality of food at all times for all household members to have an active, healthy life (195,196). Approximately 20% of diabetes patients report household food insecurity (197), and food insecurity is a risk factor for poor diabetes management (196). Researchers have investigated several pathways through which food insecurity may worsen T2DM outcomes (198–200). First, in the *nutritional pathway*, food insecurity is associated with lower diet quality (201), which in turn associated with higher HbA_{1c}. Food insecurity incentivizes more affordable, energy-dense foods that can directly raise serum glucose (e.g., refined carbohydrates, processed snacks and sweets, sugar-sweetened beverages, etc.) and may lead to greater insulin resistance (202,203). Conversely, low or inconsistent food availability can increase risk of hypoglycemia. Second, via a *compensatory pathway*, behavioral strategies necessary to cope with the immediate problem of food insecurity can inadvertently undermine T2DM management. For example, financial resources that might otherwise have been used for medications or diabetes care supplies are diverted to meet dietary needs (197,204–206). Third, through the *psychological pathway*, the state of food insecurity, in which meeting basic needs is outside an individual's control, undermines self-efficacy and increases depressive symptoms and diabetes distress (207–210). Several studies have reported a relationship between food insecurity and adverse diabetes outcomes (211,212), and a review by Barnard et al. (213) has suggested that food insecurity among patients with and at high risk for T2DM may be particularly toxic because, in addition to issues of accessing sufficient calories overall, the dietary quality of the foods eaten is even more important than for the general population. Several cross-sectional studies report a relationship between food insecurity and T2DM diabetes outcomes (214–216), including poor metabolic control (217,218), experience of severe hypoglycemia in low-income and low-education samples (218), lower diabetes self-management behavioral adherence and worse glycemic control (219), and increased outpatient visits but not increased emergency department/inpatient visits (95,212).

Food Environment Interventions and Diabetes

Three studies reported food bank and pantry interventions with food insecure clients with T2DM (196,220,221). Seligman et al. (196) conducted a pilot program in Texas, California, and Ohio with a pre/post design, encompassing provision of diabetes-appropriate food, blood glucose monitoring, self-management support, and primary care referrals. The study resulted in improvements in HbA_{1c}, fruit and vegetable consumption, self-efficacy, and medication adherence. In a randomized controlled trial of the intervention, Seligman et al. (220) found improvements in nutritional consumption, food security, and distress but no clinical changes. Palar et al. (221) found reduction in BMI but not HbA_{1c} and better nutritional and psychosocial outcomes.

Studies have examined effect of supermarket gain or loss on T2DM outcomes. A study conducted within the setting of the Kaiser Permanente Northern California Diabetes Registry linked clinical measures to metrics from a geographic information system based on participants' residential addresses (115,222,223). Results over 4 years of tracking supermarket change in low-income neighborhoods showed that relative to no change in supermarket presence, supermarket loss was associated with worse HbA_{1c} trajectories, especially among those with highest HbA_{1c}. Supermarket gain in neighborhoods was associated with marginally better HbA_{1c} outcomes, but only for those with near-normal HbA_{1c} baseline values (223). In a natural experiment design, the Pittsburgh Hill/Homewood Study on Eating, Shopping, and Health (PHRESH) tested the effects of adding a supermarket, along with other neighborhood investments, on cardiometabolic risk factors among a randomly selected cohort of residents from two low-income, urban, and predominately African American matched neighborhoods (222,224). Results for the intervention neighborhood (receiving the supermarket) showed improved perceived access to healthy food (225), and the prevalence of diabetes increased less in the neighborhood with the supermarket than in the comparison neighborhood. Since the initiation of the supermarket, many other investments including greenspace, housing, and commercial spaces have been implemented in the intervention neighborhood (226).

Results of these neighborhood investments on measured BMI, blood pressure, HbA_{1c}, and HDL cholesterol will be forthcoming. In sum, food environment factors of food unavailability, inaccessibility, and insecurity each demonstrate associations with worse diabetes risk and outcomes, and interventions including diabetes-targeted food and self-management care at food banks and pantries and increasing grocery store presence in low-income neighborhoods are few, but collectively they demonstrate the potential to impact diabetes risk, clinical outcomes, and psychosocial outcomes.

Health Care and Diabetes

Health care as a SDOH includes access, affordability, and quality of care factors. In the U.S., these factors are highly correlated with race/ethnicity, SES, and place/geographic region (19).

Associations of Health Care With Diabetes Incidence, Prevalence, and Outcomes

Access. In population-based studies, having health insurance is the strongest predictor of whether adults with diabetes have access to diabetes screenings and care (227). Uninsured adults in the U.S. population have a higher likelihood of having undiagnosed diabetes than adults with insurance (228). Compared with insured adults with diabetes, the uninsured have 60% fewer office visits with a physician, are prescribed 52% fewer medications, and have 168% more emergency department visits (229). Liese et al. (230) found that, among adolescents and young adults with T1DM or T2DM, compared with having private insurance, having state or federal health insurance was associated with higher HbA_{1c} values by 0.68%, and having no insurance was associated with higher HbA_{1c} by 1.34%. Having insurance has also been found to attenuate associations of financial barriers with higher HbA_{1c} (231).

Geographic access to adult and pediatric endocrinologists varies substantially by state and county in the U.S (232), with disparities in access in many of the geographic regions with highest diabetes prevalence and socioeconomic disadvantage (232,233). Similarly, factors that increase odds of having a diabetes self-management education program in a geographic area include a higher percentage of the population with at least a high school education, a higher percentage of

insured individuals, and a lower rate of unemployment (234). DeVoe et al. (235) found that among adults with diabetes, having both insurance and a usual source of care, rather than one or the other, conferred the greatest odds of receiving at least minimum diabetes health care. Being uninsured and without a usual source of care was associated with three to five times lower odds of adults receiving an HbA_{1c} screen, blood pressure check, or access to urgent care when needed (235). Among adolescents and young adults with diabetes who had state or federal health insurance, not having any usual source of provider (primary care or diabetes specialist) was associated with higher HbA_{1c} than having a usual source of provider, and HbA_{1c} was similar whether in primary care or specialist care (230).

Affordability. On average, health care costs of people with diabetes are 2.3 times those of people without diabetes (229). Approximately 14% to 20% of adults with diabetes report reducing or delaying medications due to cost (236–238). Among adults with diabetes who are prescribed insulin, rates may be >25% (236,239). Cost-related or cost-reducing nonadherence (CRN) is associated with income, insured status, and type of insurance. Adults with diabetes with an annual household income of <\$50,000 are more likely to engage in CRN than their counterparts with income ≥\$50,000, and uninsured adults with diabetes are more likely to engage in CRN than those with insurance (236). Within a diabetes clinic population of adults with T1DM or T2DM prescribed insulin, odds of CRN were three times higher for those with Medicaid or no insurance compared with those with Medicare (239). Piette et al. (240) found differences based on health system model. Compared with VA patients with diabetes, risk of CRN was found to be almost three times higher for privately insured patients and four to eight times higher for patients with Medicare, Medicaid, or no health insurance (240). Higher financial stress, financial insecurity, and financial barriers are associated with likelihood of CRN (231,238). People with CRN experience poorer diabetes management, higher HbA_{1c}, and decreased functional status (231,240). Deaths have been reported from insulin CRN among youth and adults with T1DM (241).

Quality. Having insurance is the strongest single predictor of whether adults with diabetes are likely to meet individual quality measures of diabetes care (242). Sociodemographic disparities in care quality are well documented in national reports and recommendations (2) and appear to remain consistent over time (243). In a U.S. population-based study of achievement of a composite diabetes treatment goal from 2005 to 2016, data from 2013 to 2016 showed that non-Hispanic Blacks had lower odds of achieving a composite diabetes quality measure than non-Hispanic Whites (adjusted OR 0.57, 95% CI 0.39–0.83), and women had lower odds than men (adjusted OR 0.60, 95% CI 0.45–0.80), with no improvement in diabetes treatment gaps from prior time periods (2005–2008 and 2009–2012), especially for minorities, women, and younger adults (227). Within insured settings, disparities have been reported among Blacks as compared with Whites—in measures including dilated eye exam taken; LDL test taken; LDL, blood pressure, or HbA_{1c} control; and statin therapy (244–246). A study of 21 VA facilities found Blacks with diabetes were more likely than Whites with diabetes to receive care at lower-performing facilities overall, which explained some racial differences in diabetes quality measures (246).

Health Care Interventions and Diabetes

Community Health Workers. Several systematic reviews have concluded that community health worker (CHW) interventions using trained lay workforces are effective for multiple outcomes in underserved African American and Hispanic adults with T2DM and comorbid conditions (247–250). CHWs have been integrated into care delivery (251,252) with reimbursement in some states (253). Roles of CHWs include patient navigation, appointment scheduling, visit attendance, patient education, home-based monitoring, assessment of social needs and connection with social services, social support, and advocacy (252,254). Reported outcomes include better diabetes knowledge and self-care behaviors, increased quality of life, reduced emergency visits and hospitalizations, reduced costs, and modest improvements in glycemic control (247–250,255), using home-based or integrated health team delivery models (252,256). A majority of the CHW interventions designed for adult

populations with diabetes have been diabetes-focused in content and goals and have utilized structured curricula (254); however, one series of studies reported use of a standardized, all-condition CHW intervention and found modest gain in diabetes outcomes along with additional health benefits (257,258).

Organizational Interventions. Systematic reviews report improvements in quality of diabetes care among racial/ethnic minorities resulting from quality improvement employing health information technology (i.e., patient registries in the electronic health record, computerized decision support for providers, reminders, centralized outreach for diabetes patients overdue for specific services) (245,259,260). There is also evidence of effectiveness of self-management interventions delivered directly to underserved patients with diabetes when interventions are designed to overcome barriers. For example, the Centers for Medicare & Medicaid Services (CMS)-sponsored National Diabetes Prevention Program (DPP) Medicaid demonstration found CDC-recognized DPP lifestyle change programs were effective in achieving performance measures among Medicaid recipients in Maryland and Oregon, and additional strategies (i.e., transportation assistance and child care) facilitated the high retention reported over the 12 months of DPP visits (261). In a series of studies, a problem-based self-management training addressing multiple life barriers to care in low-income and minority populations was adapted for low literacy and prevalent diabetes-related functional limitations (e.g., low vision, physical disability, and mild cognitive impairment) that impede self-management education (73,262). The approach has proven effective in improving clinical outcomes (HbA_{1c}, blood pressure), self-care behaviors, and self-management knowledge and problem-solving skills in low-income, racial/ethnic minority, and rural populations (76,263,264).

Policy. Studies have examined the impact of the Affordable Care Act (ACA) on insurance coverage and health care access for patients with diabetes (265). Analyses of NHIS data from 2009 and 2016 found an increase nationwide of 770,000 more adults with diabetes aged 18 to 64 years with health insurance coverage in 2016, with a significant increase in coverage seen among Whites, Blacks, and Hispanics, people with family

income <\$35,000, and people across educational attainment strata (less than high school and more than high school) (266). Among people with diabetes in the lowest income strata, the proportion of income spent on health costs decreased significantly from 6.3% to 4.8% (266). Other studies found increased access to care, diabetes management, and health status among people with diabetes in Medicaid expansion states as compared with their counterparts in non-Medicaid expansion states (267); increased rates of diabetes detection and diagnosis among Medicaid patients with undiagnosed diabetes in states with Medicaid expansion (268); and reduction in cost-related medication nonadherence rates and uninsured rates among people with diabetes following ACA (269).

Social Context and Diabetes

Several multidimensional factors shape the social environment as a determinant of health (270), including social capital, social cohesion, and social support (28,29). Social capital is defined as the features of social structures that serve as resources for collective action (e.g., interpersonal trust, reciprocity norms, and mutual aid) (271–273). Bonding social capital refers to trusting and co-operative relations between members of a network who see themselves as being similar in terms of their shared social identity; by contrast, bridging social capital refers to aspects of respect and mutuality between people who do not share social identities (e.g., differing by race/ethnicity, social class, age) (274–276). Racism, discrimination, and inclusion versus exclusion are macro-level social capital factors that impact health (28).

Social cohesion refers to the extent of connectedness and solidarity among groups in a community (271,277) and has two dimensions: reduction of inequalities and patterns of social exclusion of population subgroups from full participation in society (278) and strengthening of social relationships and interactions (279–281). Social cohesion actions facilitate the goal of keeping the society united, not only through social relations, community ties, and intergroup harmony but also through reducing bias and discrimination toward economically disadvantaged groups within a society, such as women and ethnic minorities (28).

Social support describes experiences in individuals' formal and informal personal

relationships as well as their perceptions of those relationships. Categories include emotional support, tangible support, informational support, and companionship (282–285). Social support is theorized to operate by either buffering the effects of poor health or by directly impacting health (285,286).

Associations of Social Context With Diabetes Incidence, Prevalence, and Outcomes

A systematic review by Flôr et al. (287) concluded that social capital was positively associated with diabetes control among different populations, independent of the quality or quantity of social capital. However, the few studies available and variations among populations and measures limit the ability to draw firm conclusions related to dimensions of social capital and whether the association is the same at the individual or neighborhood level (272,288–290). Gebreab et al. (189), using data from the Jackson Heart Study, examined social cohesion, measured as trust in neighbors, shared values with neighbors, willingness to help neighbors, and extent to which neighbors get along. The study revealed higher neighborhood social cohesion was associated with a 22% lower incidence of T2DM (189). Studies demonstrating the relationship between social support and diabetes have associated increased social support with better glycemic control and improved quality of life (291–295), while lack of social support has been associated with increased mortality and diabetes-related complications (291).

A number of studies suggest social cohesion, social capital, and social support may influence—or be influenced by—racism and discrimination (296). Racism interacts with other social entities, creating a set of dynamic, interdependent components that reinforce each other, sustaining racial inequities and promoting both institutional- and individual-level discrimination across various sectors of society impacting diabetes incidence (296,297). For example, Whitaker et al. (298) documented associations of major and everyday discrimination experiences with incident diabetes among a diverse sample of 5,310 middle-aged to older adults from the Multi-Ethnic Study of Atherosclerosis. The Black Women's Health Study found that, when compared with women in the lowest quartile of

exposure, those in the highest quartile of exposure to everyday racism had a 31% increased risk of diabetes (HR 1.31, 95% CI 1.20–1.42), and women with the highest exposure to lifetime racism had a 16% increased risk (HR 1.16, 95% CI 1.05–1.27); both associations were mediated by BMI (298,299). Further work is needed to understand the multiple ways that the social environment influences inequities in diabetes outcomes.

Social Context Interventions and Diabetes Outcomes

To our knowledge, there is no empirical research on social capital or social cohesion interventions and impact on diabetes outcomes, but a body of literature has examined effects of social support. The systematic review by Strom and Egede (284) of 18 observational studies of adults with T2DM found that higher levels of social support were associated with outcomes including better glycemic control, knowledge, treatment adherence, quality of life, diagnosis awareness and acceptance, and stress reduction (284). Lack of social support has been linked with increased mortality and diabetes-related complications in T2DM (291,295). Strom and Egede's review of 16 social support intervention studies demonstrated improved diabetes-related outcomes (clinical, psychosocial, and/or self-management behavior change) in adults with T2DM, and improvements in clinical outcomes (HbA_{1c}, blood pressure, lipids) appeared to be unrelated to the source or delivery (i.e., peer support, couples/spouse, or nurse manager).

With regard to preferences—in a study conducted before the coronavirus disease 2019 pandemic—Sarkar et al. (300) found that, compared with White adults with diabetes, Hispanics with diabetes preferred telephone-based and group support (including *promotoras*), while African Americans demonstrated more variability in their preferences (i.e., telephone, group, internet). Reliance on support from family and community tended to be higher in minority populations, while Whites relied more on media and health care professionals (300).

LINKAGES ACROSS HEALTH CARE AND COMMUNITY SECTORS TO ADDRESS SDOH

International and U.S. national committees have convened to provide guidance

on SDOH intervention approaches. These expert committee recommendations are not specific to any disease; rather, they are applicable to all conditions and populations of health inequity. Table 3 displays recommendations from the WHO Commission on Social Determinants of Health (27), the National Academies of Sciences, Engineering, and Medicine (NASEM) (formerly, Institute of Medicine) Committee on the Recommended Social and Behavioral Domains and Measures for Electronic Health Records (80), the NASEM Committee on Educating Health Professionals to Address the Social Determinants of Health (301), and the NASEM Committee on Integrating Social Needs Care into the Delivery of Health Care to Improve the Nation's Health (5).

The WHO recommendations are unique in their emphasis on root-cause, multi-sector interventions designed to remove the SDOH as a barrier to health equity. The NASEM recommendations are based in the health care sector and, collectively, focus on integration of SDOH into the health care mission, operations, and financial model. Accountable care organizations, value-based purchasing, and shared savings programs could be intentionally designed to support and incentivize health care systems to address patients' health-related social needs as a strategy to improve health outcomes (5). The Accountable Health Communities is one current CMS demonstration project examining impact on health care costs of three models for health care response to SDOH through linkages with community services: awareness (screening for social needs within the health care setting and patient referral to services using an inventory of available local community services), assistance (screening, referral, plus navigation to enable access to and use of community services), and alignment (screening, referral, community service navigation, plus partner alignment using a "backbone" organization for capacity building, data sharing among community and health care partners, and scaling of services) (302). Many health care systems are utilizing electronic medical records and health information exchanges to capture SDOH data and commercially available SDOH algorithms to identify patients at social risk and trigger service referrals (303). NASEM provided assessment questions to capture SDOH domains and frequencies for assessment (304) with

evidence of feasibility (305). In addition, Table 4 displays publicly available resources and tools to aid providers in addressing individual patients' social needs.

DISCUSSION

There is SDOH evidence supporting associations of SES, neighborhood and physical environment, food environment, health care, and social context with diabetes-related outcomes. Inequities in living and working conditions and the environments in which people reside have a direct impact on biological and behavioral outcomes associated with diabetes prevention and control (12,48). Life-course exposure based on the length of time one spends living in resource-deprived environments—defined by poverty, lack of quality education, or lack of health care—significantly impacts disparities in diabetes risk, diagnosis, and outcomes (12,48,306). Although the review reports SDOH intervention studies for aspects of housing, built and food environment, and health care, there appears to be relatively limited U.S.-based research examining impact on diabetes of interventions designed to target education, income, occupation, toxic environmental exposures, social cohesion, and social capital.

In the U.S., integrating social context into health care delivery has become a priority strategy (5–8). A clinical context alone, however, is too narrow to accommodate systemic SDOH influences. Structural and legal interventions are needed to address root causes driving SDOH (27,307). Similarly, additional emphasis is needed on a next generation of research that prioritizes interventions impacting the root causes of diabetes inequities, rather than compensatory interventions assisting the individual to adapt to inequities (18,308). For example, in the U.S., proficient literacy and resulting health literacy are disproportionately low in marginalized populations and communities (42), with historical sociopolitical root causes. U.S. antiliteracy laws for Blacks, which prohibited Blacks from being taught to read or write, persisted until the 1930s in some states (309,310), and laws prohibiting African Americans from attending public and private schools Whites attended continued until 1954 and 1976, respectively (311). Although adapting health materials for low-literacy suitability is an

effective intervention to compensate for centuries of legal racial discrimination in educational access and quality, a next-generation intervention might target the education sector and implement delivery of high-quality early education to all within both the public and private school systems and with equitable educational funding for sociodemographic populations. Similarly, while partnerships to bring bags of healthy groceries to low-income families living in food deserts are important to compensate for food deserts, a next-generation approach might target historical redlining and zoning policies that are the root cause of absence of supermarkets and fresh food markets in minority and lower-income neighborhoods (312–314).

The review has limitations. First, the undertaking was designed to summarize literature on the range of SDOH identified as having impact on diabetes outcomes. As such, this article describes findings from systematic reviews and meta-analyses as well as more recent published studies on the named SDOH; it was not designed as a primary systematic review of all published research on the topic. Second are limitations of the research itself, including wide variability in measures and definitions used in studies within an SDOH area, making it more difficult to describe outcomes for an SDOH area in a consistent or uniform manner or to report quantitative outcomes derived from meta-analyses. Third, this review was U.S.-focused; conclusions from SDOH research in other countries, which in some instances may utilize more standardly defined SDOH variables (e.g., occupation) are not part of this initial review. Finally, the many complexities of SDOH and their potentially different pathways and impacts on populations are beyond the scope of this initial review and require attention to specificity in designs of future SDOH research in diabetes.

Recommendations for SDOH research in diabetes resulting from this SDOH review are described in Table 5 and include establishing consensus SDOH definitions and metrics, designing studies to examine specificities based on populations, prioritizing next-generation interventions, embedding SDOH context within dissemination and implementation science in diabetes, and training researchers in methodological techniques for

future SDOH intervention studies. By addressing these critical elements, there is potential for progress to be realized in achieving greater health equity in diabetes and across health outcomes that are socially determined.

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