DOI: https://doi.org/10.46811/apjnh/7.1.2

Clinical, Behavioral, and Social Determinants of Cardiometabolic Risk in Adults with Prediabetes: A Cross-Sectional Study from NHANES

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ABSTRACT
Prediabetes is often thought of as a middle ground between normal and diabetic blood glucose levels but prediabetes carries more than just a glycemic diagnosis. The purpose of this article is to define clinical, behavioral, and social factors of cardiometabolic risk that are relevant to adults with prediabetes, based on peer-reviewed evidence from the National Health and Nutrition Examination Survey (NHANES) through December 31, 2023. The manuscript is a secondary cross-sectional analysis based on survey weighted NHANES data and no new estimates of the NHANES respondents are generated. Adults with prediabetes were found to have significant comorbidities in NHANES 2011-2014 – dyslipidemia (51.2%), hypertension (36.6%), current smokers (24.3%), albuminuria (7.7%), and reduced estimated glomerular filtration rate (EGFR) (4.6%) (Ali et al., 2018). Cardiometabolic profiles (CMP) in pooled NHANES 1999-2018 that were associated with adverse health behaviors or older age with low physical activity were more likely to have prediabetes than a younger, socially disadvantaged reference profile. Prevalence of prediabetes was also higher among adults with less than high school education (49.3%) compared with college graduates (37.0%) (fully adjusted prevalence ratio 1.14 [95% CI 1.02, 1.26]) . All of these results suggest that there is a multi-dimensional risk environment of prediabetes in which dyslipidemia, hypertension, smoking, inactivity, adiposity, educational disadvantage, economic conditions and healthcare access are interwoven. The evidence from cross sectional NHANES data suggests that clinical assessment of risk for cardiometabolic diseases goes beyond glycemia to risk factors, health behaviors and social barriers to prevention.

Keywords: prediabetes, cardiometabolic risk, social determinants of health, physical activity, smoking, NHANES

Introduction
Prediabetes is a classification for blood glucose levels that are higher than normal, but not high enough to be diagnosed as diabetes.

Prediabetes, the leading worry of progression to type 2 diabetes, is not the only serious health issue associated with prediabetes. Predictive evidence suggests that prediabetes is linked to increased risks for cardiovascular disease, coronary heart disease, stroke and death. Prediabetes has been linked to an increased relative risk for composite cardiovascular disease (CVD) by 15%, coronary heart disease by 16% and stroke by 14% in general populations in an updated meta-analysis of over 10 million participants (Cai et al., 2020).

This excess risk is also biologically and epidemiologically plausible since dysglycemia is often accompanied by abnormalities anywhere along the cardiometabolic pathway, such as excess adiposity, elevated blood pressure, atherogenic lipid profiles, insulin resistance, renal dysfunction, and tobacco exposure. NHANES analyses also suggest that hypertension and dyslipidemia are prevalent among adults who already have laboratory criteria for prediabetes, suggesting that prediabetes is often more than just a laboratory value, and reflects a broader risk phenotype (Ali et al, 2018).

Behavioral determinants are also applicable. Physical activity, diet, sleep, smoking and alcohol are factors that can affect energy balance, insulin sensitivity, vascular function, body composition, and progression to diabetes. In a cross-sectional analysis of the National Health and Nutrition Examination Survey (NHANES) 2015–2016, adults who reported no recreational physical activity had higher odds of having prediabetes (OR = 1.26, 95% CI [1.08, 1.47]) as compared to adults who reported some physical activity (Pazmino et al., 2021). Randomized evidence also shows that lifestyle changes can impact the natural history of high-risk dysglycemia. The Diabetes Prevention Program (DPP) used lifestyle intervention, which lowered incident type 2 diabetes by 58% when compared to the placebo group (Knowler et al., 2002).

Social conditions do not exist on their own, but with health behaviors. Many factors related to education, income, work, food environments, neighborhood conditions, health care access, and social context may limit or facilitate health promoting behavior. The literature on the social determinants, however, warns against seeing individual behaviors as solely personal decisions. The availability of healthy foods, preventive health services, safe places for physical activity, medications, health information, and opportunities to maintain lifestyle change are among the environmental and structural factors that affect access to healthful food and nutrition (Hill-Briggs et al., 2021).

The value of NHANES for examining these intersections is that it collects interviews, physical exams, lab measures, dietary and behavioral data, and sociodemographic data in probability samples that represent the U.S. civilian, noninstitutionalized population. The NHANES research in recent years has progressed beyond the one-dimensional approach of analyzing a single risk factor to the multi-dimensional approach of modeling the metabolic measures together with behavioral and social factors. For instance, Ding et al. (2023) identified 16 social and behavioral and 13 metabolic risk factors to classify the adults (n=38,476) into different cardiometabolic profiles.

The intent of this article is to put together evidence from peer-reviewed NHANES that supports clinical, behavioral and social factors of cardiometabolic risk among adults with prediabetes. The three questions that drive the analysis are: What is the clinical cardiometabolic burden seen in adults with prediabetes concurrently? What is the relationship between prediabetes and behavioral profiles with metabolic risk? What do educational, economic, and racial/ethnic, health care access, and cumulative social-risk gradients explain about the observed cardiometabolic disparities?

Method

Study Design

This manuscript is a secondary analysis of published cross sectional NHANES results using a structured approach. It does not provide a new respondent-level analysis of NHANES public use files. This distinction will make it impossible to present prevalence estimates or regression coefficients from the survey without supporting data. Any numerical estimate provided in the Results section can be linked to a peer-reviewed source published no later than on December 31, 2023.

Data Source and Population Framework

The incorporated studies analyzed adult participants from NHANES survey cycles ranging from 1988-1994 through March 2020. NHANES uses a complex multistage probability sampling design and combines standardized interviews with physical examinations and laboratory assessment. Individual studies applied survey weights and design variables appropriate to their selected cycles and analytic subsamples. Ding et al. (2023), for example, analyzed pooled 1999-2018 data from 38,476 U.S. adults without previously diagnosed diabetes and incorporated measured hemoglobin A1c (HbA1c), fasting glucose, anthropometric measures, blood pressure, lipids, and other metabolic indicators together with social and behavioral variables.

Prediabetes Definition

The NHANES analyses most directly relevant to this synthesis defined prediabetes among adults without diagnosed diabetes as fasting plasma glucose of 100-125 mg/dL and/or HbA1c of 5.7%-6.4%. Ali et al. (2018) applied this definition in serial NHANES surveys and conducted sensitivity analyses using alternative glucose and HbA1c thresholds; the overall patterns of cardiovascular and renal burden were similar across definitions. Ding et al. (2023) likewise classified adults without known diabetes as having prediabetes when HbA1c was 5.7%-6.4% or fasting glucose was 100-125 mg/dL.

Domains of Cardiometabolic Risk

Clinical determinants included hypertension, dyslipidemia, adiposity-related measures, albuminuria, reduced estimated glomerular filtration rate (eGFR), lipid levels, blood pressure, and calculated cardiovascular risk. Behavioral determinants included cigarette smoking, physical activity, dietary quality, alcohol consumption, and sleep duration. Social determinants included educational attainment, family income or poverty-income ratio, health insurance, healthcare access, marital status, and cumulative measures of social disadvantage. Race and ethnicity were interpreted as socially patterned variables rather than innate biological causes because observed differences may reflect unequal exposure to economic conditions, discrimination, neighborhood environments, healthcare access, and other structural factors (Formagini et al., 2023; Hill-Briggs et al., 2021).

Evidence Selection and Interpretation

Only peer-reviewed journal literature published through December 31, 2023 was used. Preference was given to NHANES analyses directly addressing prediabetes, cardiometabolic risk, social determinants, cardiovascular health, or lifestyle behavior. Prospective studies and randomized trials were used only to contextualize the clinical implications of cross-sectional NHANES findings. Because exposures and outcomes in NHANES cross-sectional analyses are measured within the same survey period, associations were not interpreted as causal effects. Odds ratios, prevalence ratios, prevalence estimates, and confidence intervals are reported using the terminology and values of the original studies.

Results

Clinical Cardiometabolic Burden

The strongest direct evidence of concurrent clinical burden among U.S. adults with

prediabetes comes from Ali et al. (2018), who analyzed serial NHANES surveys from 1988 through 2014. In the 2011-2014 period, 36.6% (95% CI [32.8, 40.5]) of adults with prediabetes had hypertension and 51.2% (95% CI [47.0, 55.3]) had dyslipidemia. Current smoking remained prevalent at 24.3% (95% CI [21.7, 27.3]). Renal manifestations were also present: 7.7% (95% CI [6.8, 8.8]) had albuminuria and 4.6% (95% CI [3.7, 5.9]) had reduced eGFR. Depending on the cardiovascular-risk equation used, estimated 10-year cardiovascular event risk was approximately 5%-7%.

Table 1: Selected NHANES Indicators of Cardiometabolic Burden Among Adults With Prediabetes, 2011-2014

Indicator	Weighted estimate	95% CI
Dyslipidemia	51.2%	47.0%-55.3%
Hypertension	36.6%	32.8%-40.5%
Current smoking	24.3%	21.7%-27.3%
Albuminuria	7.7%	6.8%-8.8%
Reduced eGFR	4.6%	3.7%-5.9%

Note. Values are survey-weighted estimates reported by Ali et al. (2018). Reduced eGFR was defined in the source analysis as eGFR < 60 mL/min/1.73 m².

The temporal findings are also clinically relevant. From 1988-1994 to 2011-2014, hypertension prevalence among adults with prediabetes increased by 9.7 percentage points, while smoking decreased by 6.4 percentage points. Treatment among participants with identified hypertension and dyslipidemia improved substantially over time. Blood-pressure treatment increased from 54.2% to 81.4%, while lipid-lowering treatment increased from 6.6% to 40.2%. Achievement of treatment goals also improved, although substantial residual cardiometabolic burden remained (Ali et al., 2018).

These data indicate that prediabetes should not be interpreted as a low-risk condition solely because diagnostic diabetes thresholds have not yet been reached. More than one half of adults with prediabetes in the 2011-2014 NHANES analysis had dyslipidemia, more than one third had hypertension, and approximately one quarter continued to smoke. Cardiovascular risk modification can therefore be clinically relevant at the prediabetes stage rather than only after diabetes develops.

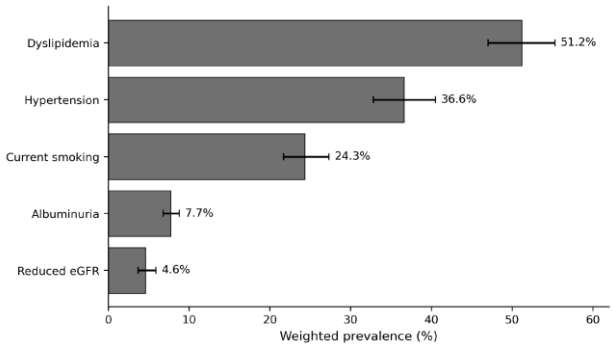

Figure 1: Cardiometabolic Burden Among U.S. Adults With Prediabetes, NHANES 2011-2014

**Note. Weighted prevalence estimates and 95% confidence intervals are from Ali et al. (2018). Error bars represent reported 95% confidence intervals.*

Behavioral Determinants

Physical activity was always identified as an important correlate of behavior. Pazmino et al. (2021) found that the prevalence of prediabetes was higher in inactive adults compared to physically active adults at work and during leisure time in NHANES 2015-2016. The multivariate model showed that a relationship existed between lack of recreation exercise and increased risk for prediabetes (OR = 1.26, 95% CI [1.08, 1.47]).

Ding et al. (2023) have shown that behaviors should not be considered as single exposures but as multiple clusters. In their analysis of pooled NHANES 1999-2018, they found there to be three cardiometabolic profiles. The middle-aged adults

in cluster 1 tended to be smoking and drinking a lot of alcohol, sleeping less and eating worse. Cluster 2 was younger, and included a higher proportion of non-White, low-income, and under-insured individuals, and those with less access to health care. The Cluster 3 group was mostly made up of older men who had the lowest physical activity levels, and the highest insurance coverage and access to healthcare in comparison with the other clusters.

Relative to cluster 2, the adjusted odds of prediabetes were 1.8 (95% CI [1.6, 1.9]) in cluster 1 and 2.1 (95% CI [1.8, 2.4]) in cluster 3 (Ding et al., 2023). The higher odds in both groups is informative as it was a combination of exposures. While there were great differences in social characteristics, both the behaviorally adverse middle-aged profile and the older, physically inactive profile were linked to increased odds for prediabetes.

Smoking is another clinically relevant determinant as it has a direct and increased association with vascular events and is associated with dysglycemia. Ali et al., (2018) observed that 24.3% of the people who had prediabetes were smokers in 2011-2014. Thus, smoking cessation in older adults who have prediabetes is not only a diabetes prevention intervention but a component of complete cardiovascular risk management.

There is experimental evidence supporting lifestyle intervention outside NHANES. The Diabetes Prevention Program (DPP) has enrolled adults at high risk for type 2 diabetes into one of three groups: intensive lifestyle intervention, metformin, or a placebo. The lifestyle intervention, which targeted weight reduction and increased physical activity, reduced diabetes incidence by 58% compared with placebo (Knowler et al., 2002). Although the trial does not establish that every behavioral association observed in NHANES is causal, it demonstrates that modification of related lifestyle exposures can substantially alter progression to diabetes.

Educational and Socioeconomic Gradients

Educational attainment showed a clear gradient in the 2011-March 2020 NHANES fasting sample analyzed by Formagini et al. (2023). Unadjusted prediabetes prevalence was 49.3% (95% CI [46.1, 52.5]) among adults with less than a high school education, 46.7% (95% CI [43.9, 49.6]) among high school graduates, 38.3% (95% CI [35.3, 41.4]) among adults with some college education, and 37.0% (95% CI [34.2, 39.8]) among college graduates.

Adjustment attenuated but did not eliminate the association. After adjustment for age, sex, income, race and ethnicity, physical activity, smoking, alcohol use, energy intake, health insurance, usual source of care, weight status, and waist circumference, adults with less than a high school education had a prevalence ratio of 1.14 (95% CI [1.02, 1.26]) relative to college graduates. High school graduates had a prevalence ratio of 1.12 (95% CI [1.02, 1.23]). Adults with some college education did not differ significantly from college graduates after full adjustment (Formagini et al., 2023).

Educational attainment was intertwined with other determinants. In the same analysis, adults with less education were more likely to have household incomes at or below the federal poverty level, whereas higher educational attainment was associated with greater participation in physical activity and lower smoking prevalence. Physical activity was reported by 68.6% of adults with less than a high school education and 83.3% of college graduates; smoking prevalence was 33.7% and 9.9%, respectively (Formagini et al., 2023). These cross-sectional patterns support a framework in which educational and economic conditions can influence behavioral and clinical risk simultaneously rather than operating as isolated background characteristics.

Prediabetes awareness also differed by education. Overall awareness among individuals meeting laboratory criteria for prediabetes was approximately 15%. After full covariate

adjustment, adults with less than a high school education had lower awareness than college graduates (PR = 0.66, 95% CI [0.47, 0.92]) (Formagini et al., 2023). This is clinically consequential because unrecognized prediabetes reduces opportunities for early counseling, cardiovascular-risk assessment, and referral to structured prevention programs.

Cumulative Social Risk

Evidence from broader NHANES populations suggests that social determinants have cumulative rather than merely independent associations with cardiovascular health. Caleyachetty et al. (2015) created a cumulative social-risk index incorporating low income, low educational attainment, non-White race and ethnicity, and living alone. Compared with adults with no measured social risks, the odds of having five to seven ideal cardiovascular-health metrics were progressively lower with increasing cumulative risk: OR = 0.58 for one risk, 0.27 for two risks, and 0.19 for three or four risks.

Similarly, Echouffo-Tcheugui et al. (2016) analyzed NHANES 1999-2006 and found a graded association between cumulative social disadvantage and diabetes. Adults with three or more social-risk factors had 2.72 times the odds of diabetes relative to those with no social risk after additional adjustment for family history, body mass index, smoking, dietary intake, and leisure-time physical activity. The persistence of the association after adjustment for behavioral factors suggested that adiposity and health behaviors explained only part of the social gradient.

These studies were not restricted to adults with prediabetes and therefore should not be interpreted as effect estimates within the prediabetes subgroup. Their relevance lies in demonstrating that cardiometabolic health in U.S. adults is systematically patterned by accumulated social disadvantage. That pattern is consistent with the educational gradients documented directly in prediabetes by Formagini et al. (2023).

Race and Ethnicity in Social Context

Formagini et al. (2023) reported unadjusted prediabetes prevalence of 39.4% among Asian adults, 40.8% among White adults, 41.6% among Hispanic adults, and 45.7% among Black adults. After full adjustment, the prevalence ratios relative to White adults were 1.26 (95% CI [1.18, 1.35]) for Asian adults, 1.17 (95% CI [1.08, 1.25]) for Black adults, and 1.10 (95% CI [1.02, 1.19]) for Hispanic adults.

These differences should not be interpreted as evidence of inherent racial biology. Race and ethnicity function in U.S. epidemiology as markers of complex social exposures, including differences in economic opportunity, discrimination, residential environments, healthcare experiences, food and physical-activity environments, and other structural conditions. Hill-Briggs et al. (2021) identified socioeconomic status, neighborhood and physical environment, food environment, healthcare, and social context as major domains through which social conditions influence diabetes risk and outcomes.

Discussion

Principal Findings

The central finding of this analysis is that cardiometabolic risk among adults with prediabetes is multidimensional. Dysglycemia exists alongside substantial clinical burden, including hypertension, dyslipidemia, smoking exposure, and early renal abnormalities. Simultaneously, physical inactivity, adverse diet-related patterns, inadequate sleep, and smoking are embedded within socioeconomic and healthcare environments that may increase or constrain opportunities for risk reduction.

The magnitude of concurrent clinical burden is particularly important. Dyslipidemia prevalence exceeding 50% and hypertension prevalence exceeding one third among adults with prediabetes indicate that glucose-focused

management alone would leave major cardiovascular risk factors insufficiently addressed. Ali et al. (2018) also showed that cardiovascular risk management improved over time, including substantial increases in antihypertensive and lipid-lowering treatment, yet a high residual prevalence of risk factors remained.

These findings are consistent with prospective evidence establishing prediabetes as a marker of elevated cardiovascular risk. Cai et al. (2020) found increased risks of cardiovascular disease, coronary heart disease, stroke, and mortality among individuals with prediabetes across a large body of prospective evidence. Identifying prediabetes should therefore prompt assessment of the broader cardiometabolic phenotype rather than a narrow recommendation to recheck glucose at a later date.

Interaction of Clinical and Behavioral Risk

The clustering analysis by Ding et al. (2023) challenges single-variable risk models. A middle-aged profile characterized by smoking, alcohol exposure, short sleep, and lower diet quality had elevated prediabetes odds, but so did an older profile distinguished particularly by physical inactivity. This heterogeneity suggests that two adults with the same HbA1c may have substantially different modifiable risks, barriers, and intervention priorities.

Behavioral assessment should consequently be individualized. For one person, smoking cessation may provide the greatest near-term cardiovascular benefit. For another, increasing physical activity and reducing excess adiposity may be more important. Others may require dietary support, sleep assessment, blood-pressure management, or lipid treatment. The Diabetes Prevention Program demonstrates that intensive lifestyle modification can substantially reduce diabetes progression, but translating such interventions into routine practice requires recognizing the environments in which behavioral change must occur (Knowler et al., 2002).

Social Determinants as Upstream Risk Conditions

The educational gradient reported by Formagini et al. (2023) is unlikely to represent education acting through a single biological mechanism. Educational attainment correlates with employment opportunities, income, health literacy, residential context, access to healthcare, food security, and the ability to allocate time and financial resources to preventive health. Attenuation of the education-prediabetes association after adjustment for behavioral, healthcare, and obesity-related variables suggests that some of these factors may lie on or confound the observed pathway. Persistence of a statistically significant gradient after adjustment also indicates that measured covariates do not fully account for the relationship.

This interpretation is aligned with the broader diabetes literature. Hill-Briggs et al. (2021) concluded that socioeconomic conditions, food environments, neighborhood and physical environments, healthcare access and quality, and social context are central determinants of diabetes disparities. Likewise, NHANES studies of cumulative social risk demonstrate progressively poorer cardiovascular health as social disadvantage accumulates (Caleyachetty et al., 2015).

Clinical approaches that identify physical inactivity without assessing whether a patient has safe places to exercise, or recommend dietary change without evaluating affordability and food access, may misclassify structural barriers as individual nonadherence. A social-determinants framework does not remove individual agency; rather, it improves specification of the conditions under which behavior occurs.

Implications for Screening and Clinical Practice

The evidence supports a broader assessment when prediabetes is identified. In addition to confirming glycemic status, clinicians should evaluate blood pressure, lipid status, body mass

index and central adiposity, smoking, physical activity, and relevant renal indicators when clinically appropriate. Cardiovascular-risk estimation may be useful in age-appropriate patients because prediabetes frequently coexists with other risk components.

Behavioral assessment should extend beyond a generic recommendation to exercise and lose weight. Tobacco exposure, recreational and occupational activity, dietary constraints, and sleep patterns should be considered. Referral to evidence-based lifestyle programs is appropriate when available, especially given randomized evidence supporting diabetes prevention through intensive lifestyle modification (Knowler et al., 2002).

Social screening can identify barriers to implementation. Educational limitations, financial strain, inadequate insurance, lack of a usual source of care, transportation problems, and limited access to healthy food or safe physical-activity environments may influence whether recommended interventions are feasible. Low overall awareness of prediabetes, particularly among adults with lower educational attainment, also indicates a need for communication strategies that are accessible and actionable across levels of health literacy (Formagini et al., 2023).

Public Health Implications

At the population level, the findings argue against prevention strategies based exclusively on identifying elevated glucose. Prediabetes prevention intersects with cardiovascular prevention, smoking control, obesity prevention, food policy, physical-activity environments, preventive healthcare access, and socioeconomic inequality.

Cumulative-risk findings are especially important for program design. A person exposed simultaneously to low income, limited education, poor healthcare access, and an adverse neighborhood environment may face qualitatively different barriers from someone with a single risk factor. Caleyachetty et al. (2015) found a steep graded decline in ideal cardiovascular health as the number of adverse social factors increased. This pattern supports integrated interventions that combine medical risk management with social-resource linkage rather than addressing one determinant at a time.

Strengths and Limitations

One of the best assets of the evidence is the standardized examinations and laboratory measurements NHANES uses in nationally representative samples of the United States. The studies explored glycemia and cardiometabolic factors, which are objectively measured, instead of just self-reported disease status. Some analyses employed complex survey weights, and some multivariable modeling, while the evidence ranges across clinical, behavioral, and socioeconomic domains. Another advantage of the present synthesis is the fact that there was no unreported prevalence value, odds ratio, prevalence ratio, or confidence interval that was built for this manuscript. Estimates directly reported from peer-reviewed NHANES are used in the table and figure.

Finally, the main drawback is a cross-sectional design. It is not always possible to determine the temporal order between social conditions, behavioral exposures, cardiometabolic abnormalities and prediabetes. The association between physical inactivity and prediabetes could be due to a physical inactive lifestyle impacting metabolic risk, a health limitation that is impacting activity levels, common causes or a combination of these.

Second, the studies included are of varying NHANES cycles. Direct comparisons may be restricted across periods due to secular changes in obesity, smoking, clinical treatment, access to health care and the population's composition. Thirdly, there was variation in definitions for the analyses. Prediabetes can be defined as fasting glucose, HbA1c and/or OGTT. The cardiovascular and renal patterns were similar regardless of the definition of prediabetes, though

there were still classification differences (Ali et al., 2018).

Fourth, a few behavioral and social measures were self-reported, which can be subject to recall and social-desirability bias. Structural racism, longitudinal economic instability, neighborhood change, discrimination, wealth, and cumulative disadvantage in life are not fully measured by social determinants in NHANES. Fifth, this is a structured secondary synthesis rather than a de-novo re-analysis of respondent level data. It cannot thus provide a single newly estimated multivariable model that quantifies all clinical, behavioral, and social determinants, across one uniformly defined prediabetes sample. Such an analysis would require direct harmonization of NHANES microdata, fasting-subsample weights where applicable, masked variance strata and primary sampling units, prespecified missing-data procedures, and survey-weighted regression models.

Conclusion

Prediabetes is part of a large cardiometabolic and social-risk landscape among U.S. adults. NHANES data demonstrate high rates of dyslipidaemia and hypertension, and significant smoking exposure and renal abnormalities in adults with prediabetes, based on peer-reviewed data. Inactive, smoking, poor diet, short sleep, or a combination of these behavioral factors are linked to differential prediabetes risk. Gradients in education and in socioeconomic status are present even after controlling for several demographic, behavioural, medical and adiposity-related factors.

These results help shift the paradigm from prediabetes management towards comprehensive cardiometabolic prevention. Dysglycemia is detected by HbA1c and fasting glucose but they do not define the overall risk. Blood pressure, lipids, adiposity, smoking, exercise and appropriate social barriers should be included in the assessment process. Diabetes prevention interventions need to take into account the upstream economic and social context that influences the ability of the population to sustain behavior changes.

The relationships observed in this study should not be viewed as causal due to the cross-sectional nature of the evidence. However, results from nationally representative NHANES analyses, the prospective cardiovascular evidence and randomized evidence of lifestyle interventions suggest that prediabetes is an opportune time for earlier and more integrated cardiovascular, metabolic, behavioral, and social risk reduction.

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