Original Research

Development and validation of a polysocial risk score for atherosclerotic cardiovascular disease

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ARTICLE INFO

ABSTRACT

Objective: To date, the extent to which social determinants of health (SDOH) may help identify individuals with atherosclerotic cardiovascular disease (ASCVD) – beyond traditional risk factors – has not been quantified using a cumulative social disadvantage approach. The objective of this study was to develop, and validate, a polysocial risk score (PsRS) for prevalent ASCVD in a nationally representative sample of adults in the United States (US).
Methods: We used data from the 2013–2017 National Health Interview Survey. A total of 38 SDOH were identified from the database. Stepwise and criterion-based selection approaches were applied to derive PsRS, after adjusting for traditional risk factors. Logistic regression models were fitted to assign risk scores to individual SDOH, based on relative effect size magnitudes. PsRS was calculated by summing risk scores for individual SDOH, for each participant; and validated using a separate validation cohort.
Results: Final sample comprised 164,696 adults. PsRS included 7 SDOH: unemployment, inability to pay medical bills, low income, psychological distress, delayed care due to lack of transport, food insecurity, and less than high school education. PsRS ranged from 0–20 and exhibited excellent calibration and discrimination. Individuals with the highest PsRS (5th quintile) had nearly 4-fold higher ASCVD prevalence, relative to those with the lowest risk scores (1st quintile). Area under receiver operating curve (AU-ROC) for PsRS with SDOH alone was 0.836. Addition of SDOH to the model with only demographic and clinical risk factors (AU-ROC=0.852) improved overall discriminatory power, with AU-ROC for final PsRS (demographics + clinical + SDOH) = 0.862.
Conclusions: Cumulatively, SDOH may help identify individuals with ASCVD, beyond traditional cardiovascular risk factors. In this study, we provide a unique validated PsRS for ASCVD in a national sample of US adults. Future study should target development of similar scores in diverse populations, and incorporate longitudinal study designs.

1. Introduction

Social determinants of health (SDOH), such as educational attainment, economic stability, neighborhood and physical environment, community and social context, food insecurity, and healthcare, are key upstream determinants of population cardiovascular health.[1–3] A compelling body of science has demonstrated that individuals and communities experiencing unfavorable SDOH such as low income, low

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education, or poor access to healthcare have a higher risk of atherosclerotic cardiovascular disease (ASCVD) incidence and mortality.[4–7]

With heightened emphasis on patient-centered care and prevention in recent years in the US, extensive information on SDOH is increasingly being collected via survey databases, administrative claims data, disease registries, and electronic medical record (EMR) systems; thus providing unprecedented opportunities to identify socially disadvantaged individuals at increased risk of ASCVD, and inform current prevention and management guidelines.[8–10] It is unclear, however, to what extent SDOH – cumulatively – may help identify individuals with ASCVD, independent of traditional clinical and demographic risk factors.[11] Further, robust methodological approaches to create a polysocial risk score (PsRS) for ASCVD have not been tested previously.

Existing population-based cardiovascular risk estimation tools such as QRISK3 utilize zip code level sociodemographic measures, which may be imperfect proxies for individual-level SDOH.[12,13] To the best of our knowledge, a multidimensional risk score for ASCVD, based on an exhaustive framework that incorporates individual-level SDOH measures, is currently lacking. The aim of this study was to develop and validate a PsRS for prevalent ASCVD in a nationally representative sample of US adults.

2. Methods

2.1. Data source

We used data from the National Health Interview Survey (NHIS), a database compiled by the National Center for Health Statistics (NCHS) / Centers for Disease Control and Prevention (CDC). The NHIS is constructed from annual, cross-sectional national surveys which incorporate complex, multi-stage sampling to provide estimates on the noninstitutionalized US population.[14] The NHIS questionnaire is divided into four core components: Household Composition, Family Core, Sample Child Core and Sample Adult Core.[15] The Household Composition file collects basic demographic information about all persons in a household; the Family Core file collects information on additional sociodemographic characteristics, indicators of health status, activity limitations, injuries, health insurance coverage, access to healthcare, and utilization of health services, additionally surveying individual families should more than one live in a specific household. Both the Household and Family components acquire information at the household and family level, respectively. From each family, one adult and one child are randomly surveyed for additional information, including (but not limited to): work characteristics, medical conditions, health status and activity limitations, health behaviors, and healthcare access and utilization.

The present study used data from the Sample Adult, Family, and Household Composition files. All NHIS data presented in this study are based on participant self-report. NHIS data are publicly available and de-identified, hence, this study was exempt from the purview of Houston Methodist's Institutional Review Board.[16]

2.2. Research design and study population

This was a cross-sectional study of NIHS data for years 2013 to 2017. We included all participants 18 years of age and older, with complete information during the study period. Total study population included 164,696 adults ≥18 years of age. For validation purposes, we split the study population 50/50 into two cohorts, i.e. derivation (n = 82,471 [50.07%] and validation (n = 82,225 [49.93%]), using a random number generation function in Stata.

2.3. Variables

SDOH: Based on the published literature,[1–4,17–18] we identified a total of 38 SDOH from 6 distinct domains: 1) economic stability, 2)

neighborhood and physical environment 3) community and social context, 4) food insecurity 5) education, and 6) healthcare system (Table 1). [19] The individual questions used to record information on each SDOH in the original survey, and the operational definitions used in this study to classify each SDOH as "favorable" or "unfavorable" are listed in Supplementary Table S1.

ASCVD: Prevalent ASCVD was defined as history of coronary artery disease (CAD) or stroke. Specifically, individuals were categorized as having ASCVD if they reported having CAD ("yes" to any of the following 3 questions: "have you ever been told by a doctor or other health professional that you had … coronary heart disease?", "… angina, also called angina pectoris?", "… a heart attack [also called myocardial infarction]?"), and/or stroke ("… a stroke"). Information on past revascularization procedures was not available in the database and therefore, not used in the current ASCVD definition. ASCVD was analyzed as a binary (yes/no) variable.

Covariates: Age (continuous), sex (male/female), race/ethnicity (non-Hispanic White (NHW), non-Hispanic Black (NHB), non-Hispanic Asian (NHA), Hispanic) and clinical cardiovascular risk factors (diabetes, hypertension, hyperlipidemia and smoking status) were included as covariates in the base model for score derivation (see 'Statistical Analyses'). Each covariate was analyzed as a binary (yes/no) variable.

2.4. Statistical analyses

2.4.1. Exploratory analysis

We identified 38 SDOH from the database, and assigned each a value of '1' if unfavorable (e.g., uninsured), and '0' if favorable (e.g., insured). We calculated aggregate SDOH burden in the population by summing the 38 individual SDOH, with a resulting range of 0–35. Distribution of the aggregate burden was examined in the total population, and compared in individuals with and without ASCVD (Fig. 1).

2.4.2. PsRS derivation

In the derivation cohort, we used two statistical approaches to identify relevant SDOH and develop a parsimonious model, which was subsequently used to derive the PsRS. We tested the association between individual SDOH and ASCVD, and identified the most parsimonious, best fitting model using stepwise and criterion-based selection methods.

A) Stepwise selection: We performed forward stepwise regression using the 38 SDOH, with each SDOH as an independent variable and ASCVD as the dependent variable. Base model was adjusted for sociodemographic (age, sex, race/ethnicity), and clinical (hypertension, diabetes, high cholesterol and smoking) risk factors. We used a cut-off of $p \leq 0.05$ for variable inclusion, and $p \geq 0.1$ for variable exclusion.

B) Criterion-based selection: Second, we fitted separate logistic regression models for the SDOH-ASCVD association, successively adding SDOH to the base model. In an iterative process, we used $\alpha = 0.05$ cut-off for variable inclusion into the base model. At each stage of model building, we compared the following measures of model performance: area under the curve (AUC) and Akaike's information criterion (AIC), to inform final model selection.

Results from both approaches were compared. Overall model fit, clinical relevance of candidate variables, and model parsimony were considered for final variable selection. This process was repeated multiple times to identify the most parsimonious, best fitting model, as has been reported in prior studies.[20]

Using the set of variables in the final (parsimonious) model, we developed the PsRS based on relative effect size magnitudes for individual SDOH. To assign risk scores to individual SDOH, we generated ß coefficients for each SDOH, and divided the coefficient for each by the smallest ß coefficient in the model, rounding off the resulting number (i.e. risk score) to the nearest integer. We estimated cumulative risk score for
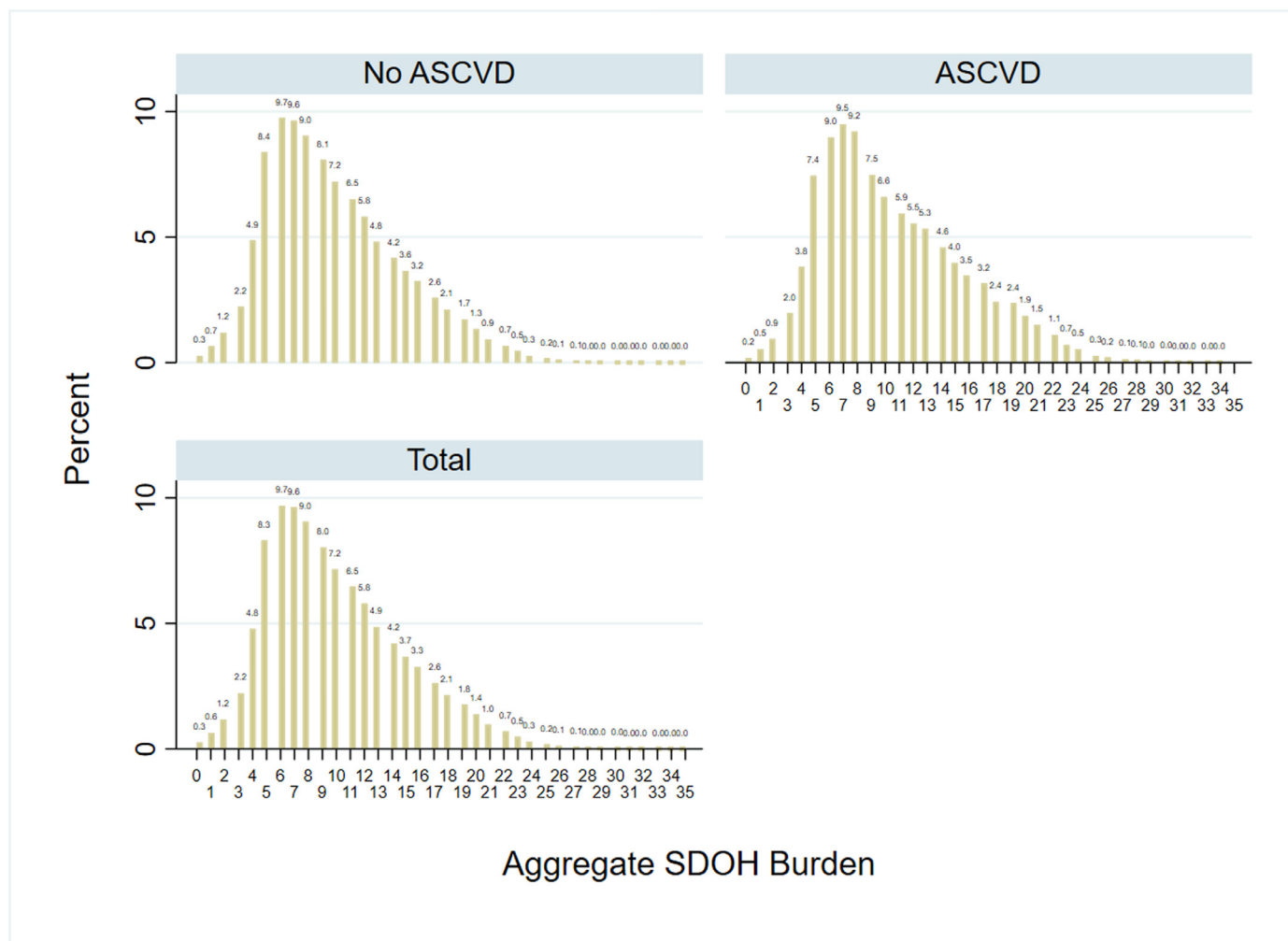
Fig. 1. Distribution of Aggregate SDOH Burden, Overall and by ASCVD Status.
Abbreviations: SDOH, social determinants of health; ASCVD, atherosclerotic cardiovascular disease.

each participant in the study population, based on their unique sociode-mographic background (i.e. presence/absence of SDOH), and examined the distribution of PsRS – overall, and by ASCVD and race/ethnicity status. We reported the distribution of ASCVD prevalence with increasing PsRS in the study population – overall and by ASCVD status. In additional analyses, we examined uni- and multivariate association between PsRS and ASCVD, by quintiles of the former.

2.4.3. PsRS validation

To allow for cross-validation, we examined both calibration and discrimination of the risk score in the validation cohort. Model *calibration* was assessed by assigning a risk score (i.e. PsRS value) to each participant – based on their overall social risk – and calculating ASCVD prevalence across risk score quintiles; the resulting distribution was compared between the validation and derivation cohorts. Model calibration was further assessed using a calibration (observed vs expected) plot for the final risk score in the validation cohort. Model *discrimination* was assessed by creating finer cut-points of the risk score, and plotting ASCVD prevalence by PsRS percentiles. We further evaluated discrimination using c-statistic and area under receiver operating curves (AU-ROC) for the base and final models. In additional analyses, overall model fit (*discrimination + calibration*) was assessed using Brier statistic.

In order to assess variation in model performance and overall predictive accuracy resulting from different model building approaches, we compared the initial (38 SDOH), base (sociodemographic + CVD risk factors), and final (based on model selection criteria discussed previously) models, and reported comparative statistics using ROC analysis. In additional analyses, we reported the AU-ROC for PsRS with SDOH alone (without clinical risk factors, i.e. sociodemographic factors + SDOH only). Further, we compared model performance for different racial/ethnic groups.

All analyses were performed using Stata 16 (College Station, TX) and took into account NHIS' complex survey design.

3. Results

3.1. Demographic characteristics

Final analytic sample comprised 164,696 adults ≥18 years of age, representing 242.3 million annualized US adults. Table 1 highlights the demographic, clinical and SDOH characteristics of the study population. Overall, 15,758 adults had a diagnosis of ASCVD, representing 19.6 million annualized US adults (8.1% of total population). Participants with ASCVD were older and more likely to be males and NHW (mean age: 65.3; males: 56.4%; NHW: 74.6%), compared to participants without ASCVD (mean age: 45.5; males: 47.5%; NHW: 65.5%).

Overall, the prevalence of 29 out of 38 unfavorable SDOH was found to be higher among individuals with a history of ASCVD than those without ASCVD. (Table 1). As shown in Fig. 1, we found higher burden of unfavorable SDOH in individuals with ASCVD, relative to

Table 1

General Demographic and SDOH Characteristics Among Adults With and Without ASCVD, from the National Health Interview Survey, 2013–17.

	No ASCVD	ASCVD	p value
Sample (N)	148,938	15,758	
Weighted sample, (weighted %)	222,633,078 (91.9)	19,643,514 (8.1)	
Demographic characteristics			
Age, mean (SD)	45.5 (17.3)	65.3 (15.5)	<0.001
Age Category, n (weighted %)			<0.001
18-44	67,223 (49.9)	1,066 (8.5)	
45-64	50,323 (34.2)	5,094 (35.8)	
65 & Above	31,392 (16.0)	9,598 (55.7)	
Sex, n (weighted %)			<0.001
Male	65,778 (47.5)	8,218 (56.4)	
Female	83,160 (52.5)	7,540 (43.6)	
Race/Ethnicity, n (weighted %)			<0.001
Non-Hispanic White	95,835 (65.5)	11,317 (74.6)	
Non-Hispanic Black	19,352 (12.2)	2,248 (12.2)	
Non-Hispanic Asian	8,754 (6.1)	445 (3.0)	
Hispanic	23,115 (16.2)	1,522 (10.1)	
Hypertension, n (weighted %)	44,741 (27.0)	11,684 (72.8)	<0.001
Diabetes, n (weighted %)	12,669 (7.7)	4,722 (30.8)	<0.001
High cholesterol, n (weighted %)	36,955 (23.4)	9,876 (63.5)	<0.001
Current smoker, n (weighted %)	24,493 (15.6)	2,934 (18.5)	<0.001
SDOH CHARACTERISTICS			
ECONOMIC STABILITY			
Never or Previously Employed, n (weighted %)	31,408 (21.8)	4,725 (29.9)	<0.001
No Sick Leave at current/most recent job, n (weighted %)	62,212 (44.5)	6,701 (45.6)	0.05
Low family income, n (weighted %)	48,876 (30.5)	6,841 (40.9)	<0.001
Difficulty Paying Medical Bills, n (weighted %)	26,196 (20.5)	2,767 (21.7)	0.01
Unable to Pay Medical Bills, n (weighted %)	10,697 (9.3)	1,839 (14.7)	<0.001
Moderately to very worried about …			
… Money for retirement, n (weighted %)	66,258 (46.0)	6,383 (44.1)	<0.001
… Medical costs of illness/accident, n (weighted %)	62,162 (43.2)	5,923 (40.8)	<0.001
… Maintaining std of living, n (weighted %)	55,475 (38.5)	5,913 (40.6)	<0.001
… Medical costs of normal healthcare, n (weighted %)	42,273 (29.5)	4,502 (31.3)	<0.001
… Paying monthly bills, n (weighted %)	42,053 (28.8)	4,907 (32.7)	<0.001
… Paying rent/mortgage/housing costs, n (weighted %)	33,673 (23.0)	3,706 (24.9)	<0.001
Cost-related medication non-adherence, n (weighted %)	9,671 (6.0)	1,774 (11.4)	<0.001
Foregone/Delayed Care due to Cost, n (weighted %)	17,146 (10.0)	2,089 (12.3)	<0.001
NEIGHBOURHOOD, PHYSICAL ENVIRONMENT AND SOCIAL COHESION			
House Tenure (rent/other arrangement), n (weighted %)	59,520 (35.1)	5,533 (29.3)	<0.001
Somewhat/Definitely Disagree …			
… People in neighborhood help each other, n (weighted %)	25,459 (17.6)	2,863 (18.5)	0.04
… There are people I can count on in neighborhood, n (weighted %)	25,986 (18.0)	2,646 (17.3)	0.09
… People in neighborhood can be trusted, n (weighted %)	24,712 (16.7)	2,660 (17.2)	0.24
… This is a close-knit neighborhood, n (weighted %)	50,995 (35.7)	5,292 (36.1)	0.47
COMMUNITY AND SOCIAL CONTEXT			
Psychological Distress (Kessler K6 Scale), n (weighted %)	4,872 (3.1)	1,239 (7.8)	<0.001
FOOD INSECURITY, n (weighted %)	15,206 (9.3)	2,605 (14.9)	<0.001
EDUCATION			
Education: ≤ High School, n (weighted %)	55,641 (36.9)	8,165 (50.3)	<0.001
Poor English Language proficiency, n (weighted %)	7,459 (5.6)	797 (6.2)	0.05
In the past 12 months, did you …			
… Looked up health info on Internet ("No"), n (weighted %)	75,108 (49.0)	10,593 (65.1)	<0.001
… Filled a prescription on Internet ("No"), n (weighted %)	135,136 (91.5)	14,267 (90.6)	0.005
… Scheduled medical appointment on Internet ("No"), n (weighted %)	133,487 (89.7)	14,687 (93.7)	<0.001
… Communicated with health care provider by email ("No"), n (weighted %)	132,035 (89.0)	14,354 (91.4)	<0.001
… Used chat groups to learn about health topics ("No"), n (weighted %)	141,706 (96.3)	15,106 (97.0)	0.002
HEALTHCARE SYSTEM			
Uninsured, n (weighted %)	18,464 (12.5)	765 (5.5)	<0.001
No Usual Source of Care, n (weighted %)	21,246 (14.5)	670 (4.9)	<0.001
In the past 12 months, did you encounter any of the following?			
… Trouble finding a doctor/provider, past 12m, n (weighted %)	4,330 (2.8)	595 (3.8)	<0.001
… MD's office did not accept you as new patient, past 12m, n (weighted %)	3,661 (2.4)	501 (3.2)	<0.001
… MD's office did not accept your insurance, past 12m, n (weighted %)	4,676 (3.2)	640 (4.3)	<0.001
… Delayed Medical Care: Couldn't get through on phone, n (weighted %)	3,453 (2.3)	599 (3.7)	<0.001
… Delayed Medical Care: Couldn't get appt soon enough, n (weighted %)	8,612 (5.7)	1,283 (8.2)	<0.001
… Delayed Medical Care: Wait too long at MD's office, n (weighted %)	5,773 (3.8)	999 (6.6)	<0.001
… Delayed Medical Care: Not open when you could go, n (weighted %)	4,018 (2.6)	530 (3.3)	<0.001
… Delayed Medical Care: No transportation, n (weighted %)	2,863 (1.6)	811 (4.4)	<0.001
Quality of Care (Satisfaction), n (weighted %)			<0.001
Somewhat/Very Satisfied	121,239 (83.4)	13,965 (90.4)	
Somewhat/Very Dissatisfied or No healthcare in past year	24,187 (16.6)	1,427 (9.6)	

Abbreviations: SDOH; social determinants of health; SD, standard deviation; MD, medical doctor

Table 2
PsRS Derivation.

SDOH	Parsimonious Model		Risk Score
	Adjusted ß* (95% CI)	Adjusted OR* (95% CI)	
Economic Stability			
Unemployed	0.64 (0.52, 0.76)	1.90 (1.69, 2.13)	5
Unable to Pay Medical Bills	0.52 (0.36, 0.68)	1.68 (1.44, 1.97)	4
Low Income	0.17 (0.08, 0.27)	1.19 (1.08, 1.31)	1
Community and Social Context			
Psychological Distress	0.46 (0.25, 0.68)	1.59 (1.29, 1.97)	4
Healthcare			
Delayed Care: Did Not Have Transport	0.33 (0.10, 0.57)	1.39 (1.10, 1.76)	3
Food Insecurity	0.30 (0.14, 0.46)	1.35 (1.15, 1.58)	2
Education			
Less than HS	0.13 (0.04, 0.22)	1.14 (1.04, 1.24)	1
PsRS (Total): 20			

Abbreviations: PsRS, polysocial risk score; SDOH, social determinants of health; OR, odds ratio.

*Adjusted for age, sex, race/ethnicity, diabetes, hypertension, hyperlipidemia, smoking status.

those without. Participants with ASCVD had higher burden for all measures of economic stability, including employment, family income, difficulty/inability to pay medical bills and cost-related medication non-adherence, reported greater psychological distress and food insecurity, and had lower educational attainment and health literacy. Further, those with ASCVD were more likely to experience delayed care and trouble finding a doctor. Conversely, a greater proportion of participants with ASCVD reported being insured, having a usual source of care and overall satisfaction with quality of care, relative to their counterparts.

3.2. Variable selection

Stepwise and criterion-based variable selection processes yielded similar results overall, with slight differences in the final model. From the final list of SDOH generated by stepwise selection, we excluded the following, based on statistical significance of the association with AS-CVD, incremental value toward overall model fit, and clinical relevance toward ASCVD: doctor's office not accepting new patients, health information technology, not having a usual source of care and ability to pay rent.

Final (parsimonious) model included the following variables – selected by both stepwise and criterion-based approaches – classified into respective domains: *economic stability*: inability to pay medical bills, unemployment (i.e. never or previously employed), and low income; *community and social context*: psychological distress; *food insecurity; healthcare*: delayed medical care due to lack of transport and *education*: less than high school.

3.3. PsRS

Results from multivariable regression are presented in Table 2. After adjusting for demographics (age, sex, race/ethnicity) and traditional (clinical) risk factors, unemployment was the strongest determinant of ASCVD (OR = 1.90; 95% CI = 1.69, 2.13), followed by inability to pay medical bills (OR = 1.68; 95% CI = 1.44, 1.97) and psychological distress (OR = 1.59; 95% CI = 1.29, 1.97). Similarly, delayed medical care due to lack of transport, food insecurity, low income and less than high school education were associated with 1.35, 1.35, 1.19 and 1.14 fold increased odds of ASCVD, respectively (Table 2).

PsRS for individual SDOH are presented in Table 2. Each SDOH was assigned risk scores as follows: unemployment: 5; inability to pay medical bills: 4; psychological distress: 4; delayed medical care due to lack of transport: 3; food insecurity: 2; and low income and less than HS education: 1 point each. Final PsRS ranged from 0-20, with a mean score of 3.75 (SD 4.8) among those with ASCVD, and 2.45 (3.4) among those without.

Table 3
Association between PsRS and ASCVD, by Quintiles of PsRS.

	Unadjusted	Adjusted£
	OR (95% CI)	OR (95% CI)
PsRS-Qx		
Quintile 1	Reference	Reference
Quintile 2	1.43 (1.28, 1.59)	1.21 (1.07, 1.37)
Quintile 3	2.03 (1.77, 2.33)	1.67 (1.43, 1.94)
Quintile 4	1.40 (1.24, 1.57)	2.25 (1.96, 2.57)
Quintile 5	2.54 (2.30, 2.81)	3.81 (3.34, 4.34)

Abbreviations: PsRS, polysocial risk score; SDOH, social determinants of health; OR, odds ratio.

£ Adjusted for age, sex, race/ethnicity, diabetes, hypertension, hyperlipidemia, smoking status

Distribution of PsRS in the study population overall, and by AS-CVD status is presented in Figure S1 (Supplement). Overall, risk scores were higher in participants with ASCVD than those without (Figure S1). Examination by race/ethnicity revealed that overall, risk scores were higher in non-Hispanic Blacks and Hispanics, relative to non-Hispanic Whites (Supplement: Figure S2).

3.4. Validation

Final model exhibited excellent calibration. ASCVD prevalence was nearly identical between derivation and validation cohorts. In both cohorts, prevalence of ASCVD ranged from nearly 4% in the first quintile of PsRS to 15% in the 5th quintile (Fig. 2). Findings from calibration plot are shown in Figure S3 (Supplement). As shown, final model exhibited excellent calibration, with E:0 ratio close to unity, i.e. 1.007.

Final model showed excellent discrimination. In the validation cohort, we found a graded increase in ASCVD prevalence across increasing percentiles of PsRS. ASCVD prevalence increased by nearly 4-fold – from 5% to 20% – between the 10th and 100th percentile, respectively (Central Illustration). Similar results were seen in fully adjusted models, suggesting nearly 4-fold increased odds of ASCVD for PsRS-Q5 vs Q1 (Table 3). Final model showed good discrimination based on ROC, with AU-ROC = 0.862 (95% CI 0.85, 0.86) (Central Illustration). We examined Brier statistic for overall model performance, allowing for simultaneous assessment of model discrimination and calibration; and documented good performance overall, with Brier score = 0.067; z-statistic = 1.567; $p = 0.059$.

In additional analyses, we examined ASCVD distribution and model performance by race/ethnicity and found consistent results overall, with similar distribution across PsRS-Qx, and excellent discrimination across racial/ethnic groups (Supplement: Figure S4; S5).
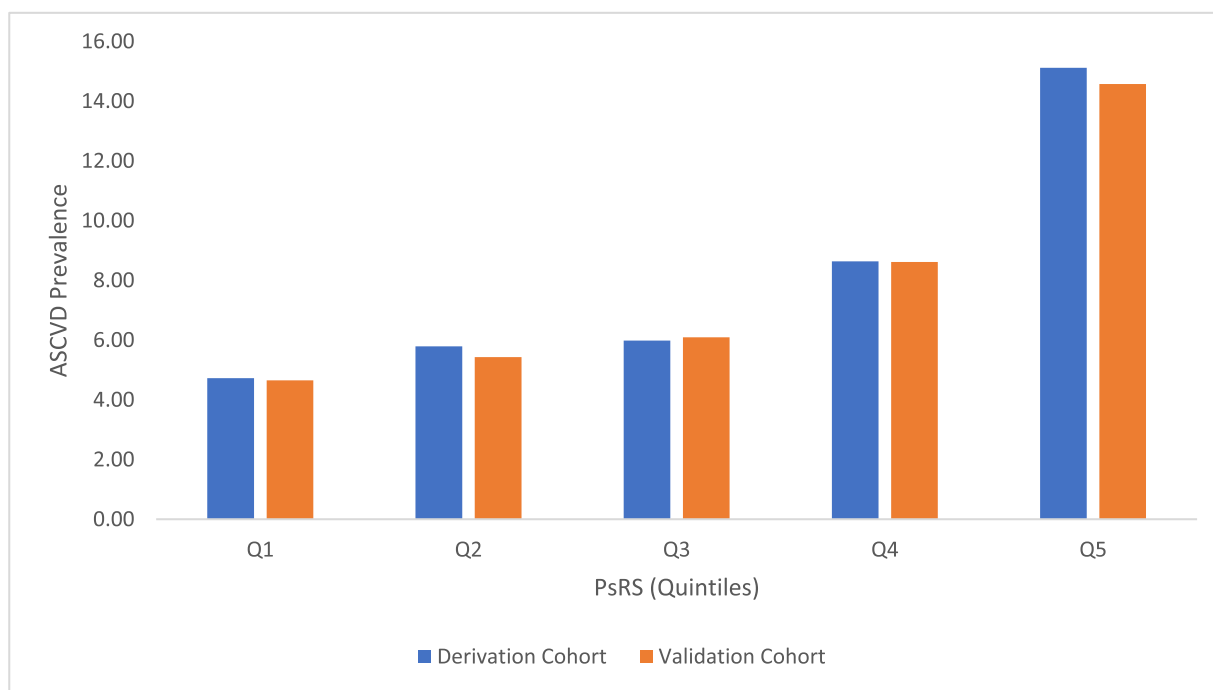
Fig. 2. Prevalence of ASCVD by PsRS Quintiles
Abbreviations: PsRS, polysocial risk score; ASCVD, atherosclerotic cardiovascular disease

3.5. Model comparison

We compared model performance for the base (age, sex, race/ethnicity, clinical risk factors) and final (parsimonious: base + 7 SDOH) models, and found higher AU-ROC for the latter (0.862), compared to the former (0.852). The improvement in AU-ROC between base (age, sex, race/ethnicity and traditional clinical risk factors) and final (parsimonious: base + 7 SDOH) models was statistically significant ($\chi 2 = 529.98$; $p < 0.01$). In addition, we compared the parsimonious model with the initial 38-SDOH model, and found nearly identical AUROC for the two (Central Illustration); which underlines the unique statistical and clinical value of SDOH included in the PsRS as independent risk factors for ASCVD, and shows that nearly the same predictive power can be achieved with as few as 7 SDOH, relative to the initial 38 SDOH model. In addition, we found that the model with the final 7 SDOH alone (without clinical risk factors) demonstrated strong discrimination, with AU-ROC = 0.836 (Supplement: Figure S6), which further highlights the relevance and unique value of SDOH toward improved ASCVD prediction.

4. Discussion

In this population-based study, we developed a novel tool – PsRS – to quantify cumulative SDOH risk for ASCVD. We applied a variety of statistical methods to operationalize an exhaustive SDOH framework, and generated a unique polysocial risk score. We used multiple methodological tools to demonstrate the validity of the score – including assessment of discrimination and calibration. We found that the addition of SDOH to traditional risk factors improves overall accuracy of the model, and discriminatory power to detect ASCVD. Our findings show that, beyond demographic and traditional clinical risk factors, SDOH may independently help identify individuals with existing ASCVD, or those with high ASCVD risk. To the best of our knowledge, this is the first large-scale study to develop, and validate, PsRS for ASCVD in a nationally representative sample of US adults.

While each SDOH has been separately examined as a risk factor for cardiovascular disease (CVD),[21,22] this is the first population-based study to develop a multidimensional risk score for ASCVD in the adult US population, comprising SDOH from 5 distinct domains. In a recent study, Hamad et al analyzed the association between low socioeconomic status (SES) and premature coronary heart disease (CHD) in middle aged and older adults, and found that individuals in the low SES group (<150% of federal poverty level or education < high school) had nearly twice the rate of early MI and CHD deaths, compared to those in the high SES group.[23] However, the authors did not include any other SDOH in the model. In contrast, we presented fully adjusted, multivariable regression estimates for each SDOH, accounting for a variety of factors that may impact CVD risk, such as demographics and traditional clinical risk factors.

Consistent with our findings, recent evidence points to an increased risk of CVD associated with food insecurity, and healthcare access barriers. Kelman and colleagues [24] reported increased risk of coronary artery calcification (CAC) with exposure to unhealthy food environment (e.g. convenience stores). Similarly, Parekh and colleagues recently studied the impact of 4 SDOH domains on CVD, using data for over 50,000 participants in the Behavior Risk Factor Surveillance System (BRFSS); and reported that food insecurity and healthcare access hardship were both associated with 1.5 times increased odds of CVD. [22] The authors also adjusted for various demographic factors and traditional CVD risk factors; however, the study was based on only 7 SDOH. In our study, we examined 38 SDOH to create the final PsRS. Ours is the first national study to create a robust risk score, based on SDOH from 6 major domains.

In supplementary analyses, we reported that PsRS with the 7 SDOH alone predicted ASCVD with nearly comparable predictive accuracy to the model inclusive of traditional cardiovascular risk factors, such as diabetes, hypertension, hypercholesterolemia, etc. While the AU-ROC for the SDOH-only model is expectedly lower compared to model including established clinical cardiovascular risk factors, our results demonstrate the unique, and often unrecognized potential of SDOH to improve clinical risk prediction, with significant implications for CVD detection and early intervention.

In the context of a renewed interest in disease prevention and patient-centered care, the idea of a PsRS to address SDOH has garnered

Central Illustration 1. Improving ASCVD Prediction Using A Unique Polysocial Risk Score (PsRS)
Abbreviations: OR=Odds Ratio; PsRS, Polysocial Risk Score; SDOH, Social Determinants of Health; ASCVD, Atherosclerotic Cardiovascular Disease
Top left: Association between individual SDOH and ASCVD; top right: distribution of PsRS, by SDOH domains; bottom left: Receiver Operating Curves (ROC), showing improved model discrimination with SDOH; bottom right: ASCVD distribution by percentiles of PsRS
Base Model = age + sex + race + cardiovascular risk factors; Final Model = Base Model + 7 SDOH, obtained using various model selection approaches for PsRS derivation (see Methods: PsRS Derivation); All (38 SDOH) Model: Base Model + Initial Set of 38 SDOH (see Methods: Exploratory Analysis).

considerable attention in recent years.[11] For example, the Protocol for Responding to and Assessing Patients' Assets, Risks, and Experiences (PRAPARE) is a unique tool that affords providers the ability to tailor care, based on the patients' SDOH profile.[18] However, such efforts are limited, and similar tools must be developed and tested in diverse sociodemographic settings. In the REGARDS study, Safford and colleagues [25] examined the risk of coronary heart disease (CHD) associated with number of SDOH; however the authors did not create a risk score, as was done in our study. Further, only 9 SDOH were included in the analytic model. In contrast, we examined 38 SDOH in this study to develop a comprehensive polysocial risk score. Future efforts should aim for development of similar risk scores in large prospective cohorts.

In a relatively small-scale, clinic-based, retrospective cohort study of middle aged and older adults published recently, Palacio and colleagues tested the association between a social risk score, and modifiable risk factors for CVD.[26] The study reported that SDOH score was associated with nearly all modifiable CVD risk factors, and that increasing (i.e., worsening) SDOH score was linked to increased risk of not achieving established standards of CVD risk factor control. While these findings are useful from a prevention standpoint, the study had several notable limitations, including lack of a comprehensive SDOH framework, poor gen-

eralizability to the general US adult population, and focus on CVD risk factors vs disease outcomes. Further, no study to date has validated such a score in a representative sample of the US population. Our study contributes significantly to existing literature by presenting the first piece of evidence of a validated PsRS for ASCVD in a representative sample of US adults.

While the link between SDOH and CVD is well established, biological and psychosocial pathways linking individual and cumulative SDOH to CVD outcomes are less well established, and merit further study.[21] Cumulative social disadvantage is linked to allostatic load, increased stress hormone reactivity, and resulting inflammation, may increase the risk of CVD directly or indirectly.[27–31] In addition, depression, anxiety and other psychological states have been associated with both social disadvantage, and poor CVD outcomes.[32–34] However, much evidence of the SDOH-mental health link is based on SES as a risk factor for poor mental health;[35,36] Little is known about the impact of other SDOH on psychological wellbeing in the context of CVD, and should be explored in future work.

In general, current evidence on the SDOH-ACVD link is predominantly cross-sectional in nature, or based on small population subsets, with limited generalizability to the entire population. Data from

prospective studies is essential to understanding the longitudinal effects of SDOH on CVD, including possible life-course impacts beginning in childhood. [37,38] Particular attention should be paid to the relative effects of SDOH on cardiovascular wellbeing of racial/ethnic minority populations, which are often exposed to distinct sociodemographic disadvantage and stressors such as racism and discrimination, with potential long-term health consequences. While we found similar patterns of ASCVD burden and overall model performance for different racial/ethnic groups, future studies should further investigate possible racial/ethnic variation in incident ASCVD.

4.1. Strengths and limitations

Our study has several notable strengths, including development and validation of the first SDOH-based PsRS for prevalent ASCVD; large sample size; robust methodological approaches; and a nationally representative study population. In addition, NHIS is a unique, rich source of SDOH, and an excellent resource for assessing cross-sectional association between both traditional/clinical and non-traditional (e.g. SDOH) risk factors, and major disease outcomes such as ASCVD. Our findings are generalizable to the general adult US population, with important implications for addressing SDOH, and improving CVD care and patient outcomes.

A major strength of our study is the methodological approach, which includes application of various statistical techniques to derive the PsRS, as well as external validation using separate derivation and validation cohorts. This study provides a robust, validated PsRS, which may be applied to diverse clinical settings in order to enhance existing clinical algorithms for identifying individuals with ASCVD, or those with a high risk.

Our study has a few limitations. First, information contained in NHIS is based on self-report, hence it is prone to misreporting/under-reporting and recall bias. Second, NHIS is cross-sectional by design, which precludes assessment of causality. While the possibility of reverse causation cannot be ruled out, existing evidence predominantly supports the role of SDOH as risk factors – or *predictors* – of ASCVD, [25,39] i.e. the posited direction of association is from SDOH *to* CVD, and not otherwise. ASCVD may increase exposure to certain unfavorable SDOH including financial hardship from medical care and/or lost productivity; [40] however, it is unlikely that a diagnosis of ASCVD independently *predicts* other SDOH included in the 39-variable framework, such as lower educational attainment, delayed care due to transportation barriers, downward social mobility, or lack of health insurance. Nevertheless, future work should further explore the plausibility and methodological implications of reverse causation in the SDOH-CVD context. Third, ours is not a traditional prediction model with incident clinical outcome (s); future studies should develop similar scores for ASCVD, and other cardiovascular outcomes using longitudinal follow up.

4.2. Conclusions

This study provides a novel, integrative PsRS for ASCVD in a population-based sample of US adults, using comprehensive SDOH data. We provide a robust methodological framework to capture polysocial risk for ASCVD, beyond traditional CVD risk factors; which offers unique opportunities to highlight, and address, disparities in cardiovascular care and outcomes. Our results may inform targeted ASCVD screening modalities for improved ASCVD diagnosis, and advance tailored management interventions for individuals and communities experiencing varying levels of social disadvantage. In particular, such risk estimation tools should be developed and validated in diverse populations, and carefully integrated with existing CVD care delivery paradigms for maximal societal benefit. Such approaches are critical toward quantifying SDOH risk in vulnerable populations, and narrowing disparities in CVD care and outcomes on a population level.

These findings may inform additional approaches for polysocial risk score development and validation in the future. In particular, our results serve as a blueprint, and steppingstone for future SDOH-based risk score development for CVD, including possible replication of the methodology presented herein using longitudinal study designs for incident outcomes.

Polysocial scores such as the PsRS provide important opportunities to capture the broad spectrum of an individual's SDOH risk, such as via 'SDOH screening' for high-risk populations. Our findings offer unique insights into the added value of SDOH as robust determinants of ASCVD, and their potential role in informing current and future approaches for tailored cardiovascular care, based on patients' unique SDOH burden.

Statement of authorship

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Declaration of Competing Interest

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ajpc.2021.100251.

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