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ORIGINAL RESEARCH

Addition of Social Determinants of Health to Coronary Heart Disease Risk Prediction: The Multi-Ethnic Study of Atherosclerosis

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BACKGROUND: Social determinants of health (SDoH) are associated with cardiovascular risk factors and outcomes; however, they are absent from risk prediction models. We aimed to assess if the addition of SDoH improves the predictive ability of the MESA (Multi-Ethnic Study of Atherosclerosis) Risk Score.

METHODS AND RESULTS: This was a community-based prospective population cohort study that enrolled 6286 men and women, ages 45–84 years, who were free of clinical coronary heart disease (CHD) at baseline. Data from 10-year follow-up were examined for CHD events, defined as myocardial infarction, fatal CHD, resuscitated cardiac arrest, and revascularization in cases of anginal symptoms. Participants included 53% women with average age of 62 years. When adjusting for traditional cardiovascular risk factors, SDoH, and coronary artery calcium, economic strain, specifically low family income, was associated with a greater risk of CHD events (hazard ratio [HR], 1.42 [95% CI, 1.17–1.71], *P* value<0.001). Area under the curve of risk prediction with SDoH was 0.822, compared with 0.816 without SDoH. The calibration slope was 0.860 with SDoH and 0.878 in the original model.

CONCLUSIONS: Significant associations were found between economic/financial SDoH and CHD risk factors and outcomes. Incorporation of SDoH into the MESA Risk Score did not improve predictive ability of the model. Our findings do not support the incorporation of SDoH into current risk prediction algorithms.

Key Words: coronary disease ■ risk ■ social determinants

Over 20 million Americans are estimated to have coronary heart disease (CHD) and it remains a leading cause of death worldwide.[1] Fortunately, there has been a significant decline in mortality in recent decades due to early identification and improved therapies[2]; however, these outcomes have been unequally distributed between different racial groups, whereby some groups have not experienced the same magnitude of improvement as others.[3,4] For instance, non-Hispanic Black adults have a 2-fold higher risk of cardiovascular death compared with non-Hispanic White adults.[5,6] These observed differences in cardiovascular health and outcomes can be explained, in part, by social determinants of health (SDoH).[7,8]

SDoH include "conditions in the places where people live, learn, work, and play that affect a wide range of health and quality-of-life risks and outcomes."[9] Unfavorable SDoH, such as unemployment and lower educational attainment, are associated with greater prevalence of cardiovascular risk factors and incident disease.[10] Despite well-established evidence demonstrating the relationship between SDoH and

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CLINICAL PERSPECTIVE

What Is New?

- Significant associations were found between economic and financial social determinants of health and coronary heart disease risk factors and outcomes.
- Incorporation of social determinants of health into the coronary heart disease risk prediction did not improve the model's predictive ability, possibly secondary to social determinants of health risk being captured in risk scores via changes in coronary heart disease risk factors.

What Are the Clinical Implications?

- Our findings do not support the incorporation of social determinants of health into current risk prediction algorithms.

Nonstandard Abbreviations and Acronyms

MESA	Multi-Ethnic Study of Atherosclerosis
PCE	pooled cohort equation

cardiovascular outcomes, there is no integration of this information within current clinical algorithms for cardiovascular risk prediction.

Multiple clinical tools exist to estimate cardiovascular disease risk such as the pooled cohort equation from the American Heart Association and American College of Cardiology, the Framingham Risk Model, and the MESA (Multi-Ethnic Study of Atherosclerosis) Risk Score.[11] The MESA Risk Score was a novel risk calculator created to estimate 10-year CHD events and was found to be noninferior, and in some cases superior, to the pooled cohort equation in predicting cardiovascular events.[12–14] These risk tools, like many others, lack important SDoH known to influence cardiovascular outcomes. When socioeconomic factors were incorporated into other clinical algorithms such as the Framingham risk model, calibration improved with a reduction in bias.[15] We aimed to evaluate if incorporating SDoH into the MESA Risk Score for CHD risk prediction would produce similar improvements in model calibration and discrimination.

METHODS

Anonymized data and materials are publicly available after reasonable request on BioLINCC and can be requested at https://biolincc.nhlbi.nih.gov/studies/mesa/.

Study Population

MESA is a multiethnic, community-based prospective cohort study designed to understand the progression of subclinical cardiovascular disease, as previously described.[16] Briefly, MESA enrolled 6814 men and women, ages 45–84 years, who were free of clinical CHD at baseline across 6 US communities. Informed consent was obtained and institutional review board approval was completed at each of the 6 field centers. Individuals self-identified as White, Hispanic, Chinese, or Black, which are the prespecified racial and ethnic groups used in our analysis. We excluded participants with missing MESA risk scores due to absence of data, zero follow-up time, or missing SDoH variables (Figure 1).

Social Determinants of Health

The SDoH collected within MESA include employment, family income, house tenure, financial strain, education, marital status, social support, chronic stress, everyday discrimination compositive score, neighborhood cohesion composite score, neighborhood problems, neighborhood safety, usual source of health care, and health insurance. These 14 variables were organized into 5 composite SDoH domains based on the domains identified by the US Department of Health and Human Services' Healthy People 2030: economic stability, education, community and social context, neighborhood and physical environment, and health care.[10] Table S1 depicts the definitions and scoring system used for the SDoH variables and domains. Some variables were scored as binary variables and others on a discrete scale.

MESA Risk Score

The derivation of the MESA Risk Score has been previously described.[13] Traditional risk factors included in the model include diabetes, current smoking, family history of heart attack, total cholesterol, high-density lipoprotein cholesterol, systolic blood pressure, use of lipid lowering medication, and use of hypertension medication. Additionally, age, sex, race, ethnicity and computed tomography coronary artery calcium (CAC) are included in the score. The risk score's novelty lies in its ability to provide a risk estimate in the absence and presence of coronary artery calcium. It provides a 10-year risk estimate for CHD events, defined as myocardial infarction, fatal CHD, resuscitated cardiac arrest, and revascularization in cases of anginal symptoms.

Statistical Analysis

All statistical analyses were performed in R v4.3.1. We first analyzed the relationship between MESA CHD risk factors and SDoH measures by calculating Pearson's

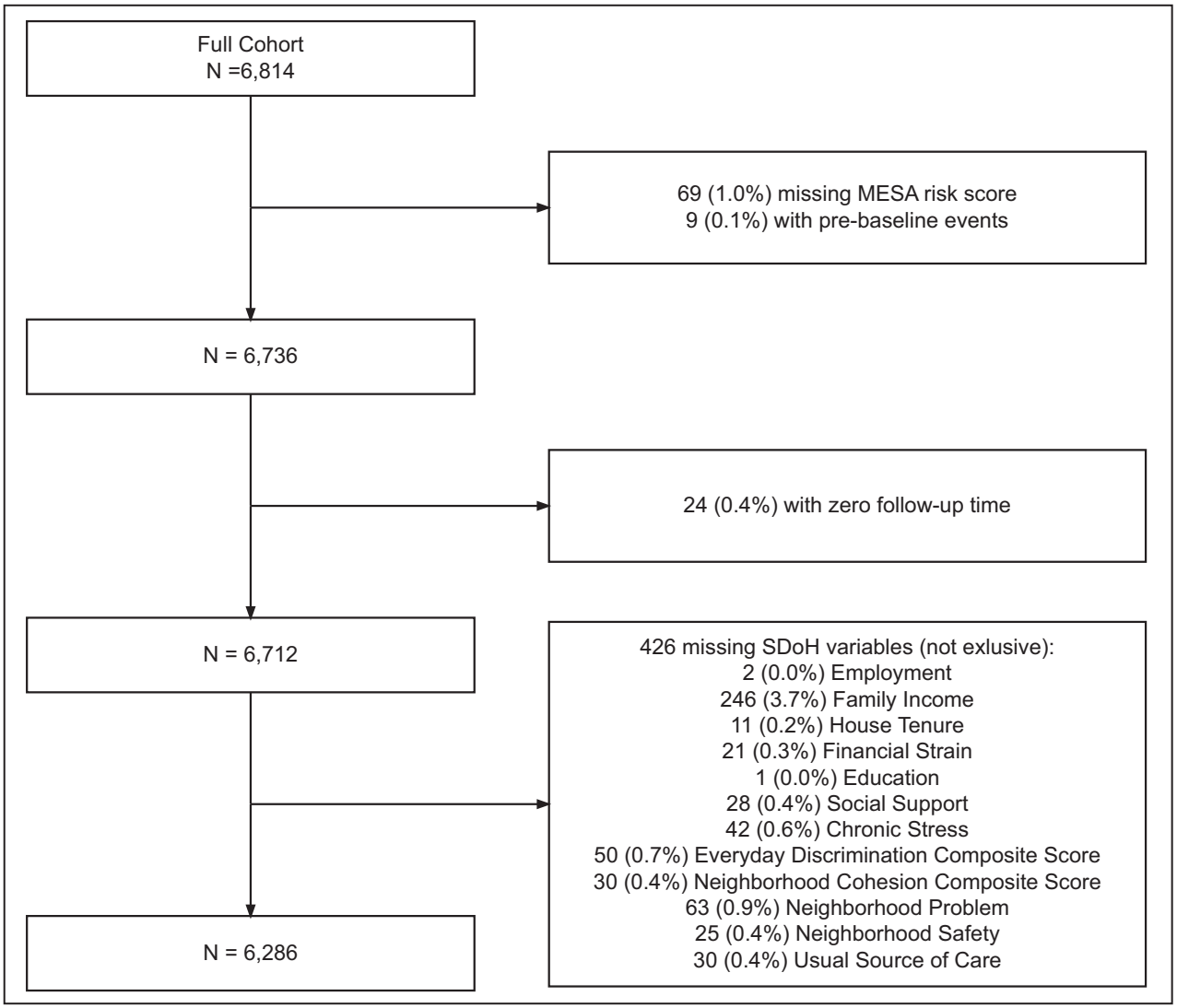

Figure 1. Flow chart of study inclusion and exclusion criteria. Sample size in the analysis is n=6286.
MESA indicates multi-ethnic study of atherosclerosis; and SDoH, social determinants of health.

correlation coefficients (Figure 2). Race was excluded from the correlation heatmap but used to stratify the descriptive statistics for SDoH measures (Table 1). To compare SDoH measures among 4 racial and ethnic groups, we performed chi-square tests for binary SDoH variables and ANOVA tests for semicontinuous SDoH scores.

We defined 5 SDoH "domains" for investigation, where domain refers to a set of related variables as described previously. We then used a Cox proportional hazards model with robust SE estimates to examine the association between SDoH domains and the risk of CHD events. In Model 1, we analyzed how each domain individually relates to the risk of CHD events. For each SDoH domain, we adjusted for traditional CHD risk factors including age, sex, race, ethnicity, diabetes, family history of heart attack, lipid-lowering medication, hypertension medication, current smoking, systolic blood pressure, total cholesterol, and high-density lipoprotein cholesterol. Model 2 added of all SDoH variables to Model 1. Model 3 included the addition of CAC to Model 2. For each model, we assessed hazard ratios (HRs) by comparing unfavorable SDoH status to favorable status for binary SDoH factors and by comparing the impact of a 1-unit change in the SDoH score. We evaluated the statistical strength of evidence individually as well as in composite.

To assess improvement of the MESA prediction algorithm for CHD by incorporating SDoH factors, we used a penalized Cox regression model with Lasso penalty. A 10-fold cross-validation was performed to select the optimal tuning parameter that minimizes the cross-validated log-likelihood. This approach ensured the inclusion of traditional variables already included

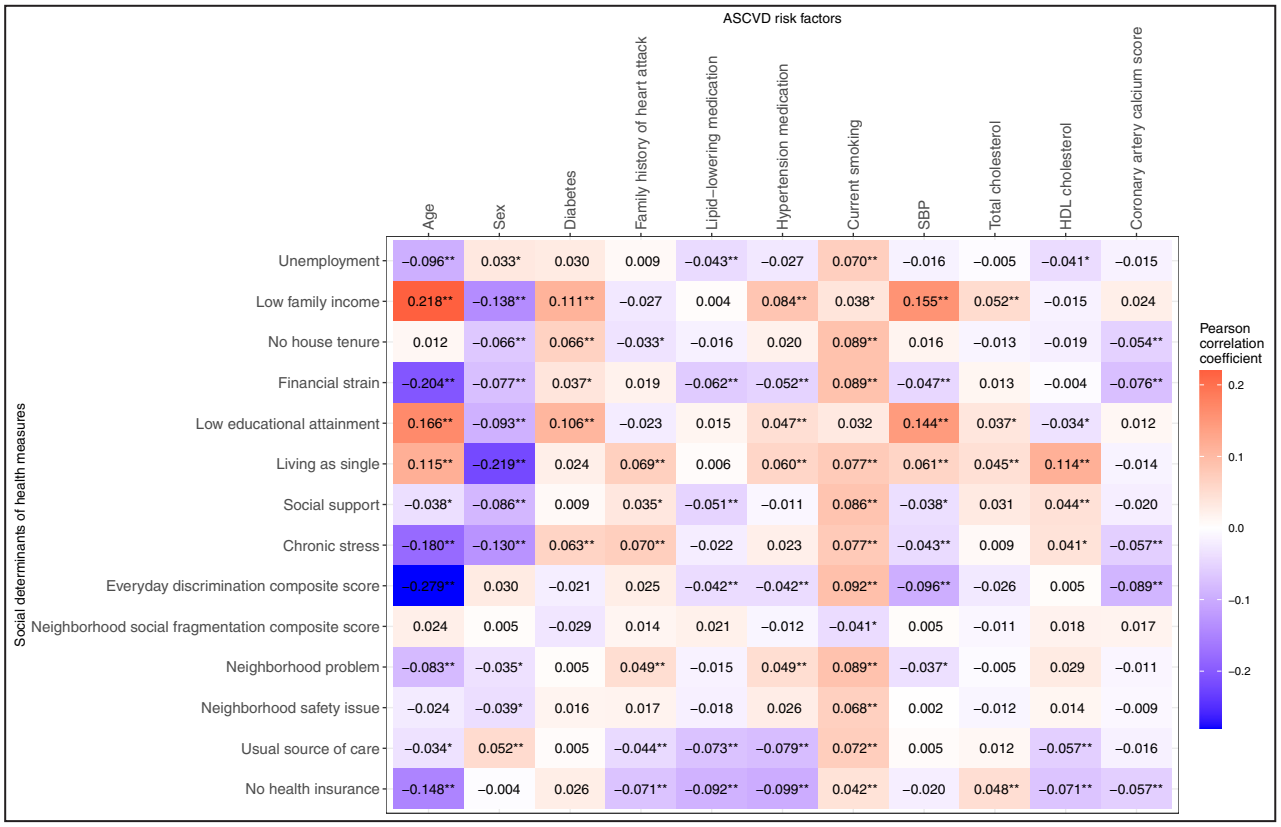

Figure 2. Relationship between social determinants of health and traditional atherosclerotic cardiovascular disease risk factors.
Pearson correlation coefficient is shown between social determinants of health measures (*y* axis) and each of the ASCVD risk factors (*x* axis). *Denotes *P* value less than 0.01. **Denotes *P*-value less than 0.001. ASCVD indicates atherosclerotic cardiovascular disease; HDL, high-density lipoprotein; and SBP, systolic blood pressure.

in the MESA Risk Score while removing less influential variables whose coefficients were reduced to zero by the lasso penalty among the 14 defined SDoH factors. This lasso regularization helped mitigate the risk of overfitting, while retaining the most important variables. We compared this model with the existing MESA Risk Score using discrimination (area under the curve and Akaike information criterion) and calibration (calibration slope and intercept).

RESULTS

Study Population

The full MESA cohort consists of 6814 participants. A total of 528 people were excluded from our analysis for the following reasons: missing MESA risk score (N=69), prebaseline cardiovascular events (N=9), lack of follow-up (N=24), and missing SDoH variables (N=426) (Figure 1). A total of 6286 participants remained in the final analysis. The racial and ethnic distribution of participants included in the analysis was 2457 White (39%), 789 Chinese (13%), 1627 Black (26%), and 1413 Hispanic individuals (22%). Approximately half (53%) of the study population were women. The average age at the study baseline was 62 years (Table 2).

Social Determinants of Health by Race and Ethnicity

The definition and scoring classification for each variable is found in Table S1. Table 1 displays the distribution of SDoH variables across the racial and ethnic groups. For binary variables, the table depicts the distribution of participants in each racial and ethnic group that meet the specified criteria. For continuous variables, the results are summarized as means, with higher number indicating less favorable SDoH.

Among all groups, the majority of individuals were currently employed, retired, or homemakers (97–99%). A larger percentage of White individuals had family incomes >$50 000 (58%) versus Hispanic/Latino participants, of whom only 18% had families earning that amount or higher. A total of 85% of White participants were paying toward or owned a home versus 43% of Hispanic/Latino participants. Financial strain was

Table 1. Summary of Social Determinants of Health (SDoH) Measures: Overall and by Race and Ethnic Group

	Total (N=6286)	White (N=2457)	Chinese (N=789)	Black (N=1627)	Hispanic/ Latino (N=1413)	*P* value
Unemployment						<0.01
1: Never or previously employed	141 (2%)	35 (1%)	18 (2%)	43 (3%)	45 (3%)	
0: Employed, retired or homemaker	6145 (98%)	2422 (99%)	771 (98%)	1584 (97%)	1368 (97%)	
Low family income						<0.001
1: <$50000	3772 (60%)	1036 (42%)	564 (71%)	1010 (62%)	1162 (82%)	
0: >=$50000	2514 (40%)	1421 (58%)	225 (29%)	617 (38%)	251 (18%)	
No house tenure						<0.001
1: Rent/other	2088 (33%)	378 (15%)	313 (40%)	593 (36%)	804 (57%)	
0: Pay a mortgage/own free and clear	4198 (67%)	2079 (85%)	476 (60%)	1034 (64%)	609 (43%)	
Financial strain						<0.001
1: Yes	1586 (25%)	538 (22%)	127 (16%)	505 (31%)	416 (29%)	
0: No	4700 (75%)	1919 (78%)	662 (84%)	1122 (69%)	997 (71%)	
Low educational attainment						<0.001
1: ≤High school	2231 (35%)	518 (21%)	321 (41%)	477 (29%)	915 (65%)	
0: ≥Some college	4055 (65%)	1939 (79%)	468 (59%)	1150 (71%)	498 (35%)	
Living as single						<0.001
1: Never married/widowed/divorced/separated/ prefer not to answer	2435 (39%)	825 (34%)	145 (18%)	901 (55%)	564 (40%)	
0: Living as married	3851 (61%)	1632 (66%)	644 (82%)	726 (45%)	849 (60%)	
Social isolation	11.8 (5.25)	11.9 (5.22)	12.1 (4.94)	11.8 (5.15)	11.6 (5.55)	0.24
Chronic stress	1.2 (1.21)	1.2 (1.19)	0.8 (1.07)	1.4 (1.26)	1.3 (1.21)	<0.001
Everyday discrimination composite score	14.5 (6.01)	14.3 (5.03)	12.5 (4.77)	16.8 (7.09)	13.3 (6.01)	<0.001
Neighborhood social fragmentation composite score	17.5 (2.89)	18.0 (2.79)	17.0 (2.38)	17.6 (3.06)	16.9 (2.99)	<0.001
Neighborhood problem	10.4 (3.38)	10.5 (2.99)	8.8 (2.87)	11.0 (3.69)	10.6 (3.59)	<0.001
Neighborhood safety issue						<0.001
1: Somewhat unsafe/not at all safe	998 (16%)	315 (13%)	35 (4%)	321 (20%)	327 (23%)	
0: Very/somewhat safe/safe	5288 (84%)	2142 (87%)	754 (96%)	1306 (80%)	1086 (77%)	
Usual source of care						<0.001
1: Hospital/emergency department, other	448 (7%)	68 (3%)	52 (7%)	116 (7%)	212 (15%)	
0: Doctor's office/clinic	5838 (93%)	2389 (97%)	737 (93%)	1511 (93%)	1201 (85%)	
No health insurance						<0.001
1: Yes	563 (9%)	62 (3%)	153 (19%)	100 (6%)	248 (18%)	
0: No	5723 (91%)	2395 (97%)	636 (81%)	1527 (94%)	1165 (82%)	

expressed by 31% of Black individuals versus only 16% of Chinese individuals. A total of 79% of White individuals in the cohort had some college education, whereas only 35% of Hispanic/Latino individuals had received some college education. The percentage of married individuals varied greatly from 45% in Black participants to 82% among Chinese participants. Neighborhood safety was expressed by 96% of Chinese participants compared with 77% of Hispanic/Latino participants. Most individuals received their health care at a doctor's office/clinic (≥85), and most were insured (≥82). (Table 1).

There were highest levels of chronic stress, discrimination, and neighborhood problem in Black individuals, whereas White individuals had the greatest amount of neighborhood fragmentation. The prevalence of social isolation was similar among the groups. (Table 1).

Association Between Social Determinants of Health and Atherosclerotic Cardiovascular Disease Risk Factors

Significant associations were most notably observed between family income and age (Pearson correlation coefficient 0.218), family income and systolic blood pressure (0.155), educational attainment and age (0.166), financial strain and age (–0.204), discrimination score and age (–0.279), and living as a single individual and sex (–0.219). Additional weaker associations were observed between multiple variables as depicted on Figure 2.

Table 2. Baseline Characteristics for Multi-Ethnic Study of Atherosclerosis Participants Included in Analysis: Overall and By Race and Ethnic Group

	Total (N=6286)	White (N=2457)	Chinese (N=789)	Black (N=1627)	Hispanic/Latino (N=1413)
Age, y	61.9 (10.21)	62.2 (10.19)	62.4 (10.32)	61.6 (9.98)	61.2 (10.43)
Female sex	3324 (53%)	1279 (52%)	406 (51%)	913 (56%)	726 (51%)
Diabetes	760 (12%)	140 (6%)	102 (13%)	274 (17%)	244 (17%)
Family history of heart attack	2497 (40%)	1184 (48%)	144 (18%)	642 (39%)	527 (37%)
Lipid-lowering medications	1014 (16%)	453 (18%)	113 (14%)	263 (16%)	185 (13%)
Hypertension medications	2283 (36%)	811 (33%)	224 (28%)	792 (49%)	456 (32%)
Current smoking	814 (13%)	291 (12%)	45 (6%)	288 (18%)	190 (13%)
Systolic blood pressure (mm Hg)	126.2 (21.36)	123.2 (20.35)	124.5 (21.57)	131.0 (21.29)	126.8 (22.03)
Total cholesterol (mg/dL)	194.3 (35.80)	195.6 (35.17)	192.6 (31.65)	189.8 (36.72)	198.2 (37.41)
High-density lipoprotein cholesterol (mg/dL)	51.0 (14.78)	52.3 (15.71)	49.6 (12.70)	52.5 (15.13)	47.7 (13.11)
Coronary artery calcium score (AU)					
0	3176 (51%)	1069 (44%)	394 (50%)	935 (57%)	778 (55%)
1–99	1665 (26%)	669 (27%)	232 (29%)	397 (24%)	367 (26%)
100–399	842 (13%)	405 (16%)	113 (14%)	168 (10%)	156 (11%)
400+	603 (10%)	314 (13%)	50 (6%)	127 (8%)	112 (8%)

Association Between SDoH and CHD Outcomes

Table 3 depicts the association between SDoH variables and cardiovascular events. Model 1 assessed this association while adjusting for traditional risk factors where associations are reported by individual SDoH variables and composite groups. Model 2 incorporated all SDoH variables while adjusting for

Table 3. Association Between Social Determinants of Health, Individually and in Composite, and Cardiovascular Events

Domain	Individual	Model 1*				Model 2†				Model 3‡			
		HR	95% CI	*P* value		HR	95% CI	*P* value		HR	95% CI	*P* value	
Economic strain	Unemployment	1.54	(0.96–2.45)	0.07	<0.001	1.49	(0.92–2.39)	0.10	0.01	1.42	(0.89–2.25)	0.14	0.01
	Low family income	1.42	(1.17–1.71)	<0.001		1.36	(1.11–1.67)	<0.01		1.35	(1.10–1.65)	<0.01	
	No house tenure	1.03	(0.86–1.23)	0.79		1.01	(0.83–1.22)	0.94		1.06	(0.88–1.29)	0.52	
	Financial strain	1.10	(0.91–1.34)	0.32		0.98	(0.76–1.26)	0.87		0.99	(0.76–1.29)	0.93	
Education	Low educational attainment	1.10	(0.93–1.30)	0.28	0.28	1.03	(0.86–1.23)	0.75	0.75	1.02	(0.86–1.22)	0.82	0.82
Community and social context	Living as single	1.24	(1.04–1.48)	0.02	<0.01	1.15	(0.95–1.38)	0.14	0.08	1.14	(0.94–1.37)	0.19	0.07
	Social isolation	1.01	(1.00–1.03)	0.08		1.01	(1.00–1.03)	0.15		1.01	(0.99–1.03)	0.18	
	Chronic stress	1.05	(0.98–1.12)	0.20		1.04	(0.95–1.13)	0.39		1.04	(0.95–1.13)	0.40	
	Discrimination	1.01	(0.99–1.02)	0.42		1.01	(0.99–1.02)	0.25		1.01	(1.00–1.03)	0.11	
	Neighborhood social fragmentation	1.01	(0.98–1.04)	0.44		1.01	(0.98–1.04)	0.44		1.01	(0.98–1.04)	0.67	
Neighborhood and physical environment	Neighborhood problem	1.02	(1.00–1.05)	0.08	0.12	1.01	(0.98–1.04)	0.47	0.26	1.00	(0.97–1.03)	0.93	0.27
	Neighborhood safety issue	0.82	(0.65–1.05)	0.11		0.82	(0.65–1.04)	0.11		0.83	(0.65–1.05)	0.13	
Health care	Usual source of care	1.15	(0.82–1.61)	0.41	0.39	1.07	(0.76–1.49)	0.71	0.85	1.11	(0.80–1.53)	0.53	0.63
	No health insurance	1.14	(0.81–1.62)	0.44		1.05	(0.74–1.50)	0.77		1.10	(0.77–1.56)	0.61	

Traditional risk factors include age, sex, race, ethnicity, diabetes, family history of heart attack, lipid-lowering medication, hypertension medication, current smoking, systolic blood pressure, total cholesterol, high-density lipoprotein cholesterol, and CAC.

*Five composite blocks were defined, and for each composite, individual variables in a given composite-level block were included together in a model. Each model was fitted with adjustment for traditional risk factors except for CAC.

†A model was fitted to incorporate all SDoH variables, adjusting for traditional risk factors except for CAC. The *P* value, which compared models with and without SDoH variables while maintaining the same adjustment variables, was found to be statistically significant at <0.01.

‡A model was fitted to incorporate all SDoH variables, adjusting for traditional risk factors including log-transformed CAC. The *P* value, which compared models with and without SDoH variables while maintaining the same adjustment variables, was found to be statistically significant at <0.001.

CAC indicates coronary artery calcium; HR, hazard ratio; and SDoH, social determinants of health.

Table 4. Ten-Year Coronary Heart Disease Risks Prediction Models With and Without Social Determinants of Health Variables

	Model with SDoH*			Model without SDoH		
	HR	95% CI	*P* value	HR	95% CI	*P* value
Age	1.02	(1.01–1.03)	<0.001	1.02	(1.01–1.03)	<0.001
Male sex	1.53	(1.27–1.84)	<0.001	1.37	(1.15–1.64)	<0.001
Race or ethnicity						
White	ref	–	–	ref	–	–
Chinese	0.95	(0.72–1.25)	0.71	1.00	(0.77–1.30)	1.00
Black	0.96	(0.77–1.20)	0.71	1.08	(0.88–1.33)	0.45
Hispanic/Latino	1.05	(0.84–1.30)	0.68	1.15	(0.94–1.41)	0.18
Diabetes	1.49	(1.21–1.83)	<0.001	1.52	(1.24–1.86)	<0.001
Family history of heart attack	1.39	(1.19–1.63)	<0.001	1.41	(1.21–1.65)	<0.001
Lipid-lowering medications	1.16	(0.96–1.41)	0.13	1.14	(0.95–1.39)	0.17
Antihypertensive medications	1.11	(0.93–1.32)	0.25	1.10	(0.93–1.31)	0.27
Current smoker	1.42	(1.13–1.78)	<0.01	1.49	(1.18–1.87)	<0.001
Systolic blood pressure (mm Hg)	1.01	(1.00–1.01)	<0.001	1.01	(1.00–1.01)	<0.001
Total cholesterol (mg/dL)	1.00	(1.00–1.00)	0.03	1.00	(1.00–1.01)	0.01
High-density lipoprotein cholesterol (mg/dL)	0.99	(0.98–1.00)	<0.001	0.99	(0.98–0.99)	<0.001
ln(coronary artery calcium+1)	1.31	(1.26–1.37)	<0.001	1.31	(1.26–1.36)	<0.001
Low family income	1.39	(1.15–1.69)	<0.001			
Living as single	1.16	(0.96–1.39)	0.12			
Social isolation	1.01	(1.00–1.03)	0.17			
Chronic stress	1.04	(0.97–1.12)	0.23			
Discrimination	1.01	(1.00–1.03)	0.15			
Neighborhood social fragmentation	1.00	(0.98–1.04)	0.75			
Neighborhood problem	1.00	(0.97–1.03)	0.94			
Neighborhood safety issue	0.83	(0.65–1.06)	0.14			

*Eight SDoH variables were selected among 14 variables by fitting a penalized Cox regression with lasso penalty. Unpenalized Cox regression was fitted with risk factors plus selected 8 SDoH variables.

HR indicates hazard ratio; and SDoH, social determinants of health.

traditional risk factors. This model, when assessed with and without SDoH variables, was found to be statistically significant at <0.01. Model 3 incorporated all SDoH variables, while adjusting for traditional risk factors and CAC. Comparing this model with and without SDoH was found to be statistically significant at <0.001.

In the first Cox model, which adjusted for traditional risk factors, economic strain and community and social context domains were associated with greater risk of CHD events (*P*<0.001 and<0.01, respectively). Economic strain continued to be significant in models 2 and 3, which incorporated all SDoH variables, with and without CAC (*P*=0.01).

In all 3 Cox models, economic strain was associated with increased risk for cardiovascular events, mainly driven by low family income (HR, 1.42 [95% CI, 1.17–1.71], *P*<0.001 in model 1, HR, 1.36 [95% CI, 1.11–1.67], *P*<0.01 in model 2, and HR, 1.35 [95% CI, 1.10–1.65], *P*<0.01 in model 3). Among the variables represented in community and social context, living as a single individual was the only significant variable in model 1 (HR, 1.24 [95% CI, 1.04–1.48], *P* 0.02), where disadvantage in this domain was associated with higher cardiovascular risk. Once other SDoH variables were added, this association lost statistical significance. The remaining 3 domains and their respective variables were not statistically significant in any of the models.

The 10-Year CHD Risk Prediction Model With and Without SDoH

Table 4 depicts the 10-year CHD risk prediction model with and without chosen SDoH. Eight of the 14 SDoH variables were selected for the updated model, which included low family income, living as a single, social isolation, chronic stress, discrimination, neighborhood social fragmentation, neighborhood problem, and neighborhood safety issue; however, low family income was the only variable with a significant contribution to the model and was associated with increased risk of CHD events (HR, 1.39 [95% CI, 1.15–1.69], *P*<0.001).

In the SDoH model, the traditional risk factors with statistically significant hazard contribution were age (HR, 1.02 [95% CI, 1.01–1.03], *P*<0.001), male sex (HR, 1.53 [95% CI, 1.27–1.84], *P*<0.001), diabetes (HR, 1.49 [95% CI, 1.21–1.83], *P*<0.001), family history of heart attack (HR, 1.39 [95% CI, 1.19–1.63], *P*<0.001), current smoking (HR, 1.42 [95% CI, 1.13–1.78], *P*<0.01), systolic blood pressure (HR, 1.01 [95% CI, 1.00–1.01], *P*<0.001), high-density lipoprotein cholesterol (HR, 0.99 [95% CI, 0.98–1.00], *P*<0.001), and CAC (HR, 1.31 [95% CI, 1.26–1.37], *P*<0.001). These variables were similarly significant in the model without SDoH, with small differences in HR (Table 4). Race or ethnicity was not a significant contributor to risk in either model. Of the 8 chosen SDoH variables, low family income was the only significant contributor to increased risk of CHD events (HR, 1.39 [95% CI, 1.15–1.69], *P*<0.001). All other chosen variables made nonsignificant contributions to the risk prediction model.

The discrimination of the CHD risk prediction model with the addition of SDoH (area under the curve 0.822) compared with the model without SDoH (area under the curve 0.816) is depicted in Figure 3. The calibration slope of the model with SDoH addition was 0.860, compared with the original model with a slope of 0.878 (Figure 4).

Because CAC can be considered a CHD outcome as opposed to a risk factor, we performed a sensitivity analysis in which we assessed the impact of adding SDoH to the MESA Risk Score without CAC. We found similar results concerning the impact of SDoH on prediction when CAC was excluded from the model (Table S2 and Figures S1, S2).

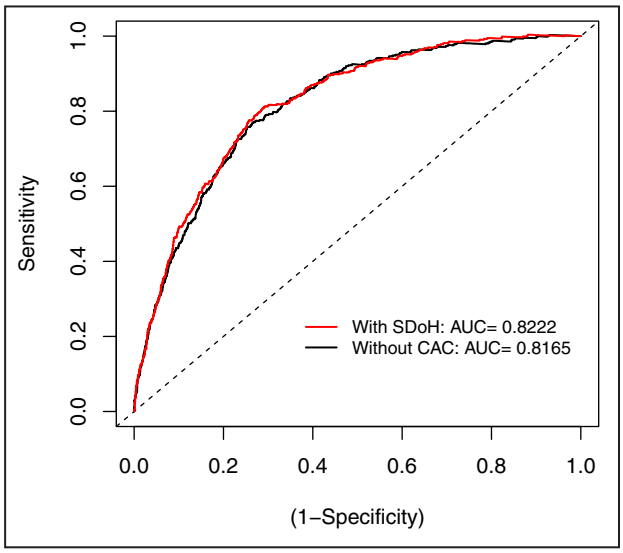

Figure 3. Discrimination comparison of the 10 Year coronary heart disease risk prediction models with and without social determinants of health variables.
Receiver-operator characteristic curves for the risk scores with and without SDoH variables are presented. AUC indicates area under the curve; and SDoH, social determinants of health.

DISCUSSION

Cardiovascular disease risk prediction algorithms are used daily in clinical practice to assist with recommendations for patients' therapeutic choices; however, there is room for improvement in refining these tools, especially in racially diverse populations. Common CVD risk prediction tools have been shown to overestimate risk by up to 60–90% when replicated in diverse racial and ethnic populations.[17–19]

Within the MESA study population, racial and ethnic disparities have been observed in all-cause and cardiovascular mortality. In addition, SDoH varied across racial and ethnic groups and were found to be independently associated with mortality, before adjustment for traditional cardiovascular risk factors.[20] Although there are observed differences in the prevalence of CHD risk factors and outcomes between different racial and ethnic groups, there is a paucity of evidence to show that equivalent levels of traditional risk factors of atherosclerotic cardiovascular disease (ie, hypertension, diabetes, tobacco use) differentially affect this risk in Black versus White individuals.[17] Such evidence supports the hypothesis that differences in CHD event rates by race and ethnicity is secondary to differences in prevalence of known CHD risk factors as opposed to differential impact of these risk factors on CHD events by race. As such, SDoH may, at least in part, account for observed differences in CHD by race or ethnicity secondary to the differences in SDoH by race or ethnicity and the impact that SDoH have on the prevalence of known CHD risk factors.[21]

At an individual variable level, we found a clustering of the strong associations between financial variables (including low family income and financial strain) and traditional risk factors including age, sex, and systolic blood pressure. It has been previously shown that individuals faced with poverty had higher levels of A1C, cigarette use, and atherosclerotic disease,[22] which may in part explain why we found that economic instability was associated with increased CHD risk and clinical outcomes. Variables included in the composite group of community and social context had a significant association with cardiovascular events when analyzed in isolation, in agreement with previous studies.[7,23] The effect of community and social context was no longer significant when all SDoH domains were included together, with and without CAC, which may be explained by the incorporation of financial factors that outweigh the contribution of community and social SDoH variables. The other SDoH domains including education, neighborhood and physical environment,

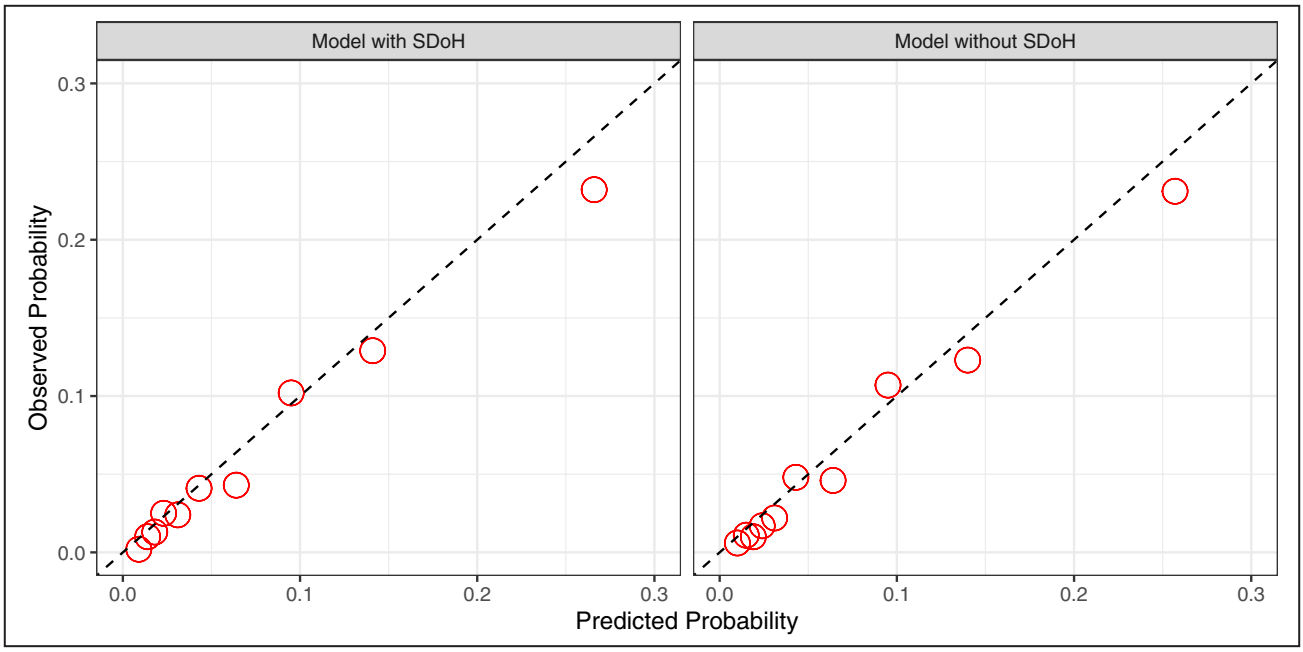

Figure 4. Calibration comparison of the Multi-Ethnic Study of Atherosclerosis Risk Score with and without social determinants of health variables.
Predicted probability was divided into 10 equal-sized bins. Observed probability was calculated as the average of the event indicators. Predicted probability was calculated as the mean of predicted risks in the bin. SDoH indicates social determinants of health.

and health care had overall weaker correlations with traditional risk factors, which may explain why they did not provide significant contributions to our CHD outcomes model.

Although the addition of SDoH improved risk prediction in a prior analysis,[15] we did not see a significant difference in calibration or discrimination within the MESA Risk score. This is in agreement with newer data that have demonstrated that although SDoH are associated with mortality, addition of these factors does not improve risk prediction.[24] We hypothesize this was in part due to SDoH's relationship and representation in variables that are already included in the score. In an analysis using our same 5 domains and 14 SDoH variables, increasing levels of social disadvantage was associated with higher levels of cardiovascular risk factors and inflammation.[10] Further, SDoH can explain differences in mortality among various racial and ethnic groups; however, these analyses assess for SDoH impact before the incorporation of traditional cardiovascular risk factors.[20] When SDoH are added to risk prediction after the inclusion of tradition risk factors, they do not offer additional predictive benefit. This can be explained by viewing SDoH's impact on cardiovascular health via an upstream pathway to cardiovascular risk factors and events.[21] SDoH such as economic instability and neighborhood factors affect access to care, healthy diet, and education, which in turn affect individual behaviors. Similarly, poor SDoH are associated with higher risk behaviors that portend increased risk for cardiovascular diseases.[25] When we measure the outcomes of these behaviors, we are accounting for the SDoH that contribute to and mediate the observed outcomes. Thus, social disadvantage, although not currently directly incorporated to risk prediction, may be represented through its impact on traditional cardiovascular risk factors. Given the upstream relationship to traditional risk factors included in the existing risk prediction algorithm, adding a social disadvantage component does not contribute additional risk than what is already represented in these components.

Our study has several limitations. First, we were limited to analyzing the 14 SDoH items collected from MESA participants. There is a possibility that other SDoH variables may be associated with CHD events; however, these data were not collected as part of the initial survey and thus are not included in our analyses. Additionally, SDoH variables were self-reported and therefore subject to desirability bias. SDoH can also vary over time, and depending on the overall direction of change, may bias our estimates toward or away from the null. This was not captured in our study.

CONCLUSIONS

In summary, we observed significant associations between important SDoH and CHD risk factors and

outcomes, particularly economic SDoH; however, incorporating SDoH variables into CHD risk prediction was not associated with observed improvements in calibration or discrimination of the MESA risk score. SDoH are likely acting upstream of CHD risk factors and captured in current risk models through this relationship. Our findings do not support the addition of these variables into current risk-prediction models.

ARTICLE INFORMATION

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Supplemental Material

Data S1

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