ORIGINAL RESEARCH

Ideal Cardiovascular Health Predicts Functional Status Independently of Vascular Events: The Northern Manhattan Study

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***Background*—**We hypothesized that the American Heart Association's metric of ideal cardiovascular health (CVH) predicts improved long-term functional status after adjusting for incident stroke and myocardial infarction.

***Methods and Results*—**In the prospective, multiethnic Northern Manhattan Study, stroke-free individuals in northern Manhattan aged ≥40 years had annual assessments of the primary outcome of functional status with the Barthel index (BI), for a median of 13 years. Ideal CVH was calculated as a composite of 7 measures, each scored on a scale of 0 to 2. Primary predictors were (1) number of ideal CVH metrics, and (2) total score of all CVH metrics. Of 3219 participants, mean age was 69 years (SD 10), 63% were female, 21% were white, 25% were non-Hispanic black, and 54% were Hispanic. Twenty percent had 0 to 1 ideal CVH metrics, 32% had 2, 30% had 3, 14% had 4, and 4% had 5 to 7. Both number of ideal CVH categories and higher CVH metric scores were associated with higher mean BI scores at 5 and 10 years. 0047 Gradients persisted when results were adjusted for incident stroke and myocardial infarction, when mobility and nonmobility domains of the BI were analyzed separately, and when BI was analyzed dichotomously. At 10 years, in a fully adjusted model, differences in mean BI score were lower for poor versus ideal physical activity (3.48 points, $P<0.0001$) and fasting glucose (4.58 points, $P<0.0001$).

***Conclusions*—**Ideal CVH predicts functional status, even after accounting for incident vascular events. Vascular functional impairment is an important outcome that can be reduced by optimizing vascular health. **(*J Am Heart Assoc*. 2015;4:e001322 doi: 10.1161/JAHA.114.001322)**

Key Words: cerebrovascular disorders • epidemiology • stroke

Ideal cardiovascular health (CVH) was proposed by the American Heart Association/American Stroke Association in 2010 to identify factors that, considered together, represent a healthy profile associated with longevity without cardiovascular disease.[1] Ideal CVH has 7 components: 4 favorable behaviors (nonsmoking, ideal body mass index, physical activity at goal, and dietary patterns that promote cardiovascular health) and 3 favorable factors (ideal levels of total cholesterol, blood pressure, and fasting glucose [FG]). In prior studies, ideal CVH has been associated with reduced vascular and nonvascular mortality[2] and nonfatal vascular events,[3,4] as well as subclinical disease markers such as arterial stiffness,[5] carotid intima media thickness,[6] retinal microvascular changes,[7] coronary artery calcification,[8] and intracranial stenosis.[9] Ideal CVH has also been associated with reduced incidence of depression[10] and cancer,[11] reflecting its potential use to monitor and predict improved health in noncardiovascular diseases that may share common causes with vascular disease.

However, no prior study has examined associations between ideal CVH and disability, which is tightly linked to vascular risk factors and events such as stroke and myocardial infarction (MI). Clinically evident stroke is the leading cause of disability,[12] but subclinical infarcts have also been associated with disability and may be as much as 5 times more prevalent as clinically evident strokes.[13] Furthermore, white matter disease appears to be caused by vascular risk factors and is associated with functional decline, cognitive impairment, and reduced quality of life.[13] Disability is a patient-centered outcome that may more comprehensively reflect population health than measures of events such as mortality, stroke, or MI.[14]

In a prior analysis in the stroke-free cohort of the Northern Manhattan Study,[15] there was a mean annual decline of 1.02 points in the Barthel index (BI), and predictors of decline in BI

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Table 1. Variable Definitions for the 7 Cardiovascular Health Indicators

Cardiovascular Health Indicator	Poor	Intermediate	Ideal
Smoking	Current	Quit ≤1 year	Never or quit >1 year
Body mass index	≥30 kg/m^2	25 to <30 kg/m^2	<25 kg/m^2
Physical activity	No moderate or vigorous activity	1 to 149 min/wk moderate intensity, 1 to 74 min/wk vigorous intensity, or equivalent combination	≥150 min/wk moderate intensity, ≥75 min/wk vigorous intensity, or equivalent combination
Diet*	0 to 1 healthy components	2 to 3 healthy components	4 to 5 healthy components
Total cholesterol	≥240 mg/dL	Treated to <200 or 200 to 239 mg/dL	Untreated and <200 mg/dL
Blood pressure	≥140/90 mm Hg	Treated to <120/<80 mm Hg or 120 to 139/80 to 89 mm Hg	Untreated and <120/<80 mm Hg
Fasting plasma glucose	≥126 mg/dL	Treated to <100 or 100 to 125 mg/dL	Untreated and <100 mg/dL

*Based on 5 health dietary metrics: (1) ≥4.5 cups of fruits and vegetables/d, (2) >2 3.5-oz servings of fish/wk, (3) >3 1-oz-equivalent servings of fiber-rich whole grains/d, (4) <1500 mg sodium/d, and (5) ≤450 kcal sugar-sweetened beverages/wk).

included age, female sex, diabetes, depression, and cholesterol level. In the present study, we modeled the effect of ideal CVH on disability in the Northern Manhattan Study. Although effects of single risk factors on disability have been previously examined, the aggregation of these in the construct of ideal CVH has not yet been studied. This analysis would provide essential population-based data that is aligned with national goals for health promotion. We hypothesized that progressively improved CVH, measured by the American Heart Association/American Stroke Association's ideal CVH metric, is associated with improved long-term functional status, even when adjusting for the effect of incident stroke and MI.

Methods

The Northern Manhattan Study, a prospective cohort study of 3298 subjects in a community-based sample of a racially and

Table 2. BI Score and Sample Characteristics at Baseline

Characteristics	N (%)	BI Score Mean±SD	Age-Adjusted Mean Difference (SE)	*P* Value
All	3219 (100)	97.1±8.1	—	—
Age at baseline (mean±SD: 69±10), y				
<70	1686 (52)	98.5±5.1	Reference	
≥70	1533 (48)	95.6±10.2	−2.93 (0.28)	<0.0001
Sex				
Female	2027 (63)	96.4±9.1	Reference	
Male	1192 (37)	98.4±5.8	1.50 (0.29)	<0.0001
Ethnicity				
Non-Hispanic white	690 (21)	97.1±8.8	Reference	
Non-Hispanic black	803 (25)	96.7±8.4	−0.85 (0.41)	0.04
Hispanic	1726 (54)	97.4±7.6	−1.29 (0.37)	0.0004
High school education or higher				
No	1763 (55)	96.7±8.8	Reference	
Yes	1456 (45)	97.7±7.0	1.15 (0.28)	<0.0001
Medicaid or uninsured				
No	1783 (56)	98.0±6.3	Reference	
Yes	1436 (44)	96.1±9.8	−2.71 (0.28)	<0.0001

Continued

Table 2. Continued

Characteristics	N (%)	BI Score Mean±SD	Age-Adjusted Mean Difference (SE)	*P* Value
Marital status				
Other	2200 (68)	96.6±9.0	Reference	
Married	1018 (32)	98.3±5.5	0.99 (0.30)	0.001
Number of friends				
<3	481 (15)	94.8±12.6	Reference	
3+	2737 (85)	97.6±6.9	2.37 (0.39)	<0.0001
Moderate alcohol use				
No	2160 (67)	96.5±9.1	Reference	
Yes	1059 (33)	98.5±5.0	1.49 (0.29)	<0.0001
Depression				
No	2890 (90)	97.6±7.1	Reference	
Yes	329 (10)	93.4±13.5	−4.35 (0.45)	<0.0001
History of coronary artery disease				
No	2530 (79)	97.5±7.7	Reference	
Yes	689 (21)	95.7±9.2	−1.16 (0.34)	0.0006
History of peripheral vascular disease				
No	2711 (84)	97.5±7.6	Reference	
Yes	508 (16)	95.0±9.8	−2.55 (0.37)	<0.0001
No. of ideal CVH metrics				
0 to 1	633 (20)	96.5±8.9	Reference	
2	1037 (32)	97.0±8.2	0.61 (0.39)	0.12
3	960 (30)	97.1±8.5	0.92 (0.40)	0.02
4	447 (14)	98.3±6.1	2.26 (0.48)	<0.0001
5 to 7	142 (4)	98.1±5.1	1.56 (0.72)	0.03
Score of CVH metrics				
0 to 5	718 (22)	96.1±9.4	Reference	
6	528 (16)	96.8±8.3	0.91 (0.45)	0.04
7	623 (19)	96.8±9.2	0.90 (0.43)	0.03
8	550 (17)	97.5±7.3	1.64 (0.44)	0.0002
9 to 13	800 (25)	98.2±5.7	2.56 (0.40)	<0.0001

BI indicates Barthel index; CVH, cardiovascular health.

ethnically diverse population, was approved by the institutional review boards of Columbia University and the University of Miami, and all participants provided informed consent.

Cohort Selection

Subjects were recruited between 1993 and 2001[16,17] and were enrolled if they were ≥40 years of age, lived in northern Manhattan for ≥3 months in a household with a telephone, and were stroke-free. Subjects were contacted by random digit dialing of published and unpublished telephone numbers. The telephone response rate was 91%, 87% of eligible subjects indicated willingness to participate, and enrollment response rate was 75%. Seventy-nine subjects who were not classified as Hispanic, white, or black were excluded from the present analysis, for a final cohort of 3219 participants.

Baseline Assessment

Baseline examination included comprehensive medical history, physical examination, medical record review, and fasting blood samples. Standardized questions were adapted from

Table 3. CVH Status and BI Score at Follow-Up

	Year 5 of Follow-Up				Year 10 of Follow-Up			
	Model 1		Model 2		Model 1		Model 2	
CVH Metrics	Estimate* (SE)	*P* Value	Estimate* (SE)	*P* Value	Estimate* (SE)	*P* Value	Estimate* (SE)	*P* Value
BI score, total								
No. of ideal CVH metrics								
0 to 1 vs 2	−1.26 (0.57)	0.027	−0.89 (0.56)	0.108	−2.26 (0.59)	0.0001	−1.56 (0.58)	0.007
0 to 1 vs 3	−1.60 (0.58)	0.006	−0.91 (0.57)	0.108	−2.46 (0.60)	<0.0001	−1.28 (0.59)	0.030
0 to 1 vs 4	−2.24 (0.71)	0.002	−1.34 (0.69)	0.054	−2.78 (0.73)	0.0002	−1.28 (0.72)	0.074
0 to 1 vs 5 to 7	−2.26 (1.06)	0.033	−1.24 (1.03)	0.231	−4.21 (1.08)	0.0001	−2.32 (1.05)	0.028
Score of CVH metrics								
0 to 5 vs 6	−1.10 (0.65)	0.090	−0.65 (0.63)	0.299	−1.13 (0.67)	0.092	−0.45 (0.65)	0.493
0 to 5 vs 7	−1.38 (0.62)	0.027	−0.77 (0.61)	0.205	−1.98 (0.64)	0.002	−0.97 (0.63)	0.123
0 to 5 vs 8	−2.26 (0.64)	0.0005	−1.39 (0.63)	0.027	−3.18 (0.67)	<0.0001	−1.66 (0.65)	0.011
0 to 5 vs 9 to 13	−2.86 (0.60)	<0.0001	−1.80 (0.58)	0.002	−3.46 (0.62)	<0.0001	−1.71 (0.60)	0.005
BI score, mobility domain								
No. of ideal CVH metrics								
0 to 1 vs 2	−0.58 (0.25)	0.023	−0.43 (0.25)	0.086	−1.11 (0.26)	<0.0001	−0.82 (0.26)	0.001
0 to 1 vs 3	−0.80 (0.26)	0.002	−0.52 (0.25)	0.040	−1.31 (0.27)	<0.0001	−0.83 (0.26)	0.002
0 to 1 vs 4	−1.27 (0.32)	<0.0001	−0.89 (0.31)	0.004	−1.62 (0.33)	<0.0001	−1.00 (0.32)	0.002
0 to 1 vs 5 to 7	−1.03 (0.47)	0.028	−0.61 (0.46)	0.183	−2.06 (0.48)	<0.0001	−1.28 (0.47)	0.007
Score of CVH metrics								
0 to 5 vs 6	−0.40 (0.29)	0.165	−0.22 (0.28)	0.440	−0.49 (0.30)	0.104	−0.20 (0.29)	0.486
0 to 5 vs 7	−0.64 (0.28)	0.020	−0.39 (0.27)	0.147	−0.84 (0.29)	0.003	−0.42 (0.28)	0.130
0 to 5 vs 8	−1.19 (0.29)	<0.0001	−0.83 (0.28)	0.003	−1.60 (0.30)	<0.0001	−0.97 (0.29)	0.0008
0 to 5 vs 9 to 13	−1.44 (0.27)	<0.0001	−1.00 (0.26)	0.0001	−1.80 (0.28)	<0.0001	−1.08 (0.27)	<0.0001
BI score, nonmobility domain								
No. of ideal CVH metrics								
0 to 1 vs 2	−0.68 (0.34)	0.044	−0.46 (0.33)	0.159	−1.14 (0.35)	0.001	−0.73 (0.34)	0.034
0 to 1 vs 3	−0.79 (0.34)	0.023	−0.39 (0.34)	0.249	−1.13 (0.36)	0.002	−0.45 (0.35)	0.202
0 to 1 vs 4	−0.97 (0.42)	0.021	−0.44 (0.41)	0.281	−1.15 (0.44)	0.008	−0.28 (0.43)	0.511
0 to 1 vs 5 to 7	−1.21 (0.62)	0.053	−0.61 (0.61)	0.315	−2.12 (0.64)	0.001	−1.02 (0.63)	0.104
Score of CVH metrics								
0 to 5 vs 6	−0.69 (0.38)	0.072	−0.43 (0.37)	0.251	−0.63 (0.40)	0.113	−0.23 (0.39)	0.549
0 to 5 vs 7	−0.73 (0.37)	0.047	−0.37 (0.36)	0.297	−1.13 (0.38)	0.003	−0.54 (0.37)	0.148
0 to 5 vs 8	−1.06 (0.38)	0.005	−0.55 (0.37)	0.138	−1.56 (0.40)	<0.0001	−0.68 (0.39)	0.081
0 to 5 vs 9 to 13	−1.41 (0.35)	<0.0001	−0.79 (0.35)	0.022	−1.64 (0.37)	<0.0001	−0.62 (0.36)	0.084

Model 1: adjusted for age, sex, race-ethnicity, education, health insurance, marital status, number of friends, moderate alcohol drinking, depression, history of coronary artery disease, and history of peripheral vascular disease. Model 2: model 1 additionally adjusted for incident stroke and myocardial infarction at follow-up. BI indicates Barthel index; CVH, cardiovascular health.

*Mean difference.

the Centers for Disease Control and Prevention Behavioral Risk Factor Surveillance System. Race-ethnicity was self-identified and modeled after the U.S. Census. Smoking was based on self-reported age of starting and quitting smoking. Education was dichotomized at high school education. Marital status was classified as married versus other. Insurance status was characterized as Medicare/private insurance versus Medicaid/no insurance.[18] Diet was assessed through

a structured in-person interview using questions adapted from the National Cancer Institute food frequency questionnaire.[19] Alcohol use was defined as low/no (<1 drink/month), moderate (1 drink/month to 2 drinks/day), and heavy (>2 drinks/day). Blood pressure, height, weight, and FG were measured with standard methods as described previously.[20,21] Fasting total cholesterol was measured with a Hitachi 705 automated spectrophotometer (Boehringer Mannheim, Mannheim, Germany). Leisure-time physical activity was measured with a questionnaire based on the National Health Interview Survey.[22] The Hamilton Depression Rating Scale measured symptoms of depression; a score of ≥8 signified depression.

Classification of CVH

Following American Heart Association/American Stroke Association definitions,[1] 7 CVH factors were classified into ideal, intermediate, or poor categories as previously described[3] and as outlined in Table 1. CVH was analyzed according to 2 definitions. For "number of ideal CVH metrics," we classified participants into 5 groups, defined by number of ideal CVH metrics present at baseline (0 to 1, 2, 3, 4, and 5 to 7). We collapsed 0 with 1 and 5 with 6 and 7 ideal metrics because of relatively few subjects who had 0 (2.3% of total cohort) or 6 (0.5% of total cohort; none had 7). For "score of CVH metrics," 0 was assigned for a category of "poor," 1 was assigned for "intermediate," and 2 for "ideal." The score was calculated by summing values for each of the 7 CVH metrics (possible range 0 to 14).[3]

Prospective Follow-Up

Subjects were followed annually by telephone, with average annual contact rate of 99%. The telephone interview assessed change in vital status, neurological symptoms and events, hospitalizations, and functional status via the BI. The BI[23,24] measures 10 core activities of daily living and the scale ranges from 0 to 100 in 5-point increments; 100 indicates normal. The BI has several strengths: it has been extensively used in geriatric populations,[25,26] stroke observational studies, and clinical trials as a disability measure.[27] Previous research has examined the psychometric properties of the scale and has demonstrated the reliability of telephone BI assessments.[28] A limitation of the BI is the ceiling effect due to its lack of sensitivity to small deficits in functioning.[29] However, it is a robust and well-accepted measurement of disability.[30]

Positive screens for potential neurological or cardiac events were followed by in-person confirmation. Nearly 70% of vascular events lead to hospitalizations at Columbia University Medical Center. We prospectively screened all admissions and discharges. Hospital records were reviewed to classify all outcomes as previously reported.[16] Stroke included ischemic stroke, intracerebral hemorrhage, and subarachnoid hemorrhage, but not transient ischemic attack or venous sinus thrombosis. A consensus of stroke neurologists assessed stroke subtype using modified Stroke Data Bank criteria and all available information, as previously described.[31] MI was defined by criteria adapted from the Cardiac Arrhythmia Suppression trial[32] and the Lipid Research Clinics Coronary Primary Prevention trial[33] as previously described,[34] and cardiologists adjudicated all MI cases independently.

Statistical Analysis

Mean BI score was calculated for categories of demographic variables, risk factors, number of ideal CVH metrics, and score of ideal CVH metrics. Age-adjusted mean differences were estimated using linear regression.

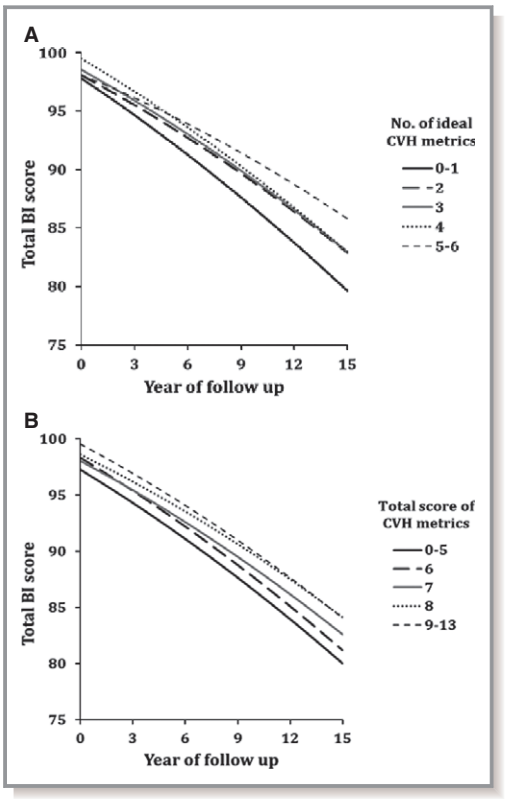

Figure 1. Adjusted mean Barthel index (BI) scores over time by the number of ideal cardiovascular health (CVH) metrics (A) or by total score of CVH metrics (B). Mean BI scores were adjusted for age, sex, race-ethnicity, education, health insurance, marital status, number of friends, moderate alcohol drinking, depression, history of coronary artery disease, and history of peripheral vascular disease.

For the association of CVH metrics with functional change, the BI was primarily analyzed as a continuous variable. Linear mixed models were used to assess associations of predictor variables with repeated BI measures over time. All available BI measurements were used, and missing values were not imputed. We reported difference in mean BI score based on 2 categories of CVH: (1) number of ideal CVH metrics (reference 0 to 1) and (2) score of CVH metrics (reference 0 to 5). We selected covariates for adjustment that are known confounders of the relationship between vascular risk factors and disability from previous studies in this cohort.[15,18] Model 1 adjusted for age, sex, race-ethnicity, education, health insurance, marital status, number of friends, moderate alcohol drinking, depression, history of MI, coronary artery disease, and peripheral vascular disease, and Model 2 additionally adjusted for incident stroke and MI occurring during follow-up. The differences in mean BI score at 5 and 10 years of follow-up were presented separately.

Although the BI measures a single disability construct, it consists of mobility and nonmobility domains, and we examined whether CVH predictor profiles differed for mobility (transfers, mobility, and stair use) and nonmobility (feeding, bathing, grooming, dressing, bowels, bladder, and toilet use) domains.[15] We also tested for interactions among time, CVH scores, and race-ethnicity, as well as interactions among time, CVH scores, and sex.

In secondary analysis, we modeled time to a dichotomous definition of disability (incident BI score of <95 among those with baseline BI ≥95. We selected this cutoff based upon prior research in our cohort.[18,35] For each participant, time at risk for disability was computed from date of enrollment to occurrence of incident disability, or the most recent follow-up date, whichever came first. Cox proportional hazards models were used to estimate the cumulative hazard function, hazard ratio, and 95% CIs after adjusting for the same covariates in Model 1, and additionally with time censored at incident stroke and MI in Model 2. We calculated hazard ratio and 95% CI for each category of number of ideal CVH metrics and score of CVH metrics, as well as a *P*-value to test significance of the trend across categories. All models met the proportional hazards assumption.

In supplementary analyses, we calculated mean BI and age-adjusted mean difference in BI among categories (poor, intermediate, and ideal) of the 7 CVH metrics. Using Models 1 and 2, we also calculated the difference in mean BI for each category, and calculated hazard ratio for dichotomous definitions of the BI, as above.

Regression analyses were also performed to show the combined effects of the numbers of 4 ideal CVH behaviors (smoking, body mass index, physical activity, and diet) and 3 ideal CVH factors (blood pressure, total cholesterol, and FG) on mean BI score (using mixed-effects models) and disability

Table 4. CVH Status at Baseline and Disability at Follow-Up

	BI Score <95 at Follow-Up			
	Model 1		Model 2	
CVH Metrics	HR (95% CI)	*P* Value	HR (95% CI)	*P* Value
No. of ideal CVH metrics				
0 to 1	Reference		Reference	
2	0.83 (0.72 to 0.94)	0.005	0.86 (0.75 to 0.99)	0.047
3	0.77 (0.67 to 0.89)	0.0002	0.82 (0.71 to 0.95)	0.010
4	0.67 (0.57 to 0.80)	<0.0001	0.69 (0.58 to 0.83)	<0.0001
5 to 7	0.55 (0.42 to 0.73)	<0.0001	0.59 (0.44 to 0.80)	0.0005
Trend		<0.0001		<0.0001
Score of CVH metrics				
0 to 5	Reference		Reference	
6	0.96 (0.82 to 1.12)	0.578	1.01 (0.86 to 1.19)	0.871
7	0.79 (0.68 to 0.92)	0.002	0.83 (0.71 to 0.97)	0.022
8	0.71 (0.61 to 0.83)	<0.0001	0.72 (0.63 to 0.88)	0.0006
9 to 13	0.65 (0.57 to 0.76)	<0.0001	0.69 (0.59 to 0.81)	<0.0001
Trend		<0.0001		<0.0001

Model 1: adjusted for age, sex, race-ethnicity, education, health insurance, marital status, number of friends, moderate alcohol drinking, depression, history of coronary artery disease, and history of peripheral vascular disease. Model 2: model 1 but censored at incident stroke and myocardial infarction at follow-up. BI indicates Barthel index; CVH, cardiovascular health; HR, hazard ratio.

(using a Poisson model). All data analyses were performed with SAS version 9.2 (SAS Institute Inc, Cary, NC).

Results

Among 3219 participants, median follow-up was 13 years (interquartile range, 7 to 15 years); there were a total of 37 081 BI assessments (median 13 per participant, interquartile range, 7 to 15). Mean baseline BI score was 97.1. There were significant age-adjusted mean differences in BI scores between categories of baseline variables including sex, race-ethnicity, education, and other risk factors. There was a gradient of progressively higher mean BI scores with higher numbers of ideal CVH and higher scores of CVH metrics (Table 2).

Table 3 and Figure 1 show adjusted relationships between number of ideal CVH metrics, scores of CVH metrics, and follow-up BI scores. There was a gradient of progressively higher total BI scores with progressively higher numbers of ideal CVH metrics, in both Model 1 and Model 2, and the magnitude of difference was higher with 10 years of follow-up compared to 5 years. For example, in Model 1, adjusted mean BI score at 5 years was 2.26 points higher among individuals with 5 to 7 ideal CVH metrics compared to those with 0 to 1. This difference was 4.21 points at 10 years. There was a similar gradient when the score of CVH metrics was examined; in Model 1, mean BI score at 10 years for a score of 9 to 13 was 3.46 points higher compared to a score of 0 to 5. The gradients persisted when the mobility and nonmobility domains of the BI were analyzed separately.

These gradients also persisted after adjusting for incident stroke and MI as a time-varying covariate, although the absolute mean differences were reduced. The effect of incident stroke or MI occurring during follow-up was to reduce mean BI score by 17.0 points (95% CI −17.7 to −16.3, $P<0.0001$), for both definitions of CVH. As a comparison, in Model 2, the effect of age on total BI score was −0.55 points per year (95% CI −0.60 to −0.51, $P<0.0001$) for number of ideal CVH metrics and −0.60 points per year (95% CI −0.65 to −0.56, $P<0.0001$) for score of CVH metrics.

Table 4 and Figure 2 show associations between CVH metrics and the BI dichotomized at a score of 95. Even with a dichotomous BI definition, a gradient remained; increasing numbers of ideal CVH metrics, and higher scores of CVH metrics, were associated with reduced incidence of disability.

Table 5 shows mean BI scores by categories of the 7 CVH metrics. There were significant mean differences among categories of body mass index (1.62 points higher score for ideal versus poor body mass index), physical activity (2.80 points higher score for ideal versus poor activity), FG (1.01 points higher score for ideal versus poor glucose), and total cholesterol (0.81 points lower score for ideal versus poor cholesterol). Table 6 shows adjusted mean BI scores by categories of the 7 CVH metrics, at 5 and 10 years. At 10 years, in a fully adjusted model, there were significant and large differences in mean BI score for poor versus ideal physical activity (3.37 points lower, $P<0.0001$) and FG (4.57 points lower, $P<0.0001$). Figure 3 demonstrates a gradient in incidence rates of disability stratified by number of ideal health factors and behaviors. There were significant interactions among CVH scores, time, and race-ethnicity (all interaction P-values <0.0015). Overall, there were significant, increasing magnitudes of effect with higher numbers of ideal CVH and higher scores of CVH metrics among non-Hispanic whites, Hispanics, and women, but less definite gradients among non-Hispanic blacks and men (Table 7).

Discussion

In this large, urban, multiethnic population-based cohort study with long-term follow-up, we found a gradient of improved function with increasing numbers of ideal CVH metrics and higher CVH metric scores. This gradient was seen in fully

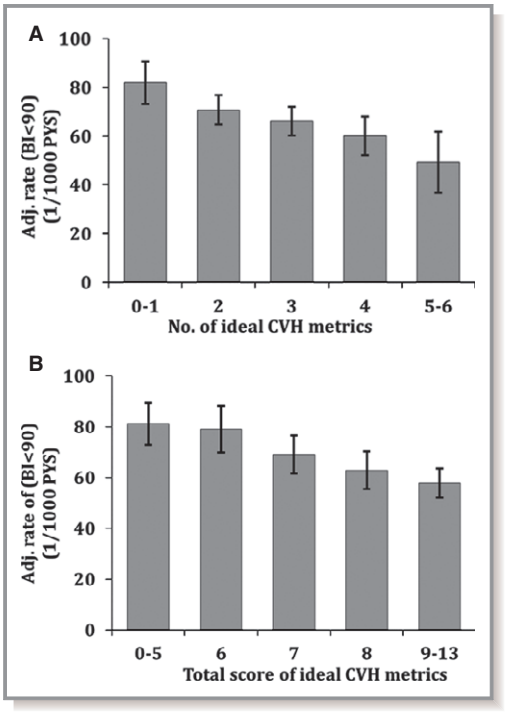

Figure 2. Adjusted incidence rates of BI<95 by the number of ideal health metrics (A) and by total score of CVH metrics for BI<95 (B). Incidence rates were adjusted for age, sex, race-ethnicity, education, health insurance, marital status, number of friends, moderate alcohol drinking, depression, history of coronary artery disease, and history of peripheral vascular disease. BI indicates Barthel index; CVH, cardiovascular health; PYS, person years. Errors bars are significant at $P < 0.05$.

Table 5. BI Score by CVH Metrics at Baseline

Characteristics	N (%)	BI Score Mean±SD	Age-Adjusted Mean Difference (SE)	*P* Value
Smoking				
Poor	556 (17)	98.3±4.8	Reference	
Intermediate	67 (2)	97.7±7.5	−0.51 (1.01)	0.61
Ideal	2587 (81)	96.9±8.6	−0.58 (0.37)	0.11
Body mass index				
Poor	882 (28)	96.6±8.5	Reference	
Intermediate	1346 (42)	97.6±7.4	1.48 (0.33)	<0.0001
Ideal	974 (30)	97.2±8.1	1.62 (0.36)	<0.0001
Physical activity				
Poor	1358 (42)	95.7±10.5	Reference	
Intermediate	794 (25)	97.7±6.2	2.03 (0.34)	<0.0001
Ideal	1067 (33)	98.5±4.8	2.80 (0.32)	<0.0001
Diet				
Poor	2151 (75)	97.3±7.7	Reference	
Intermediate	718 (25)	97.2±7.6	0.07 (0.32)	0.82
Ideal	11 (0)	97.3±5.2	0.12 (2.24)	0.96
Blood pressure				
Poor	1211 (38)	97.0±7.9	Reference	
Intermediate	1804 (56)	97.2±8.2	−0.07 (0.29)	0.82
Ideal	189 (6)	97.3±7.9	−0.48 (0.61)	0.43
Fasting glucose				
Poor	505 (16)	96.6±8.2	Reference	
Intermediate	653 (21)	97.0±8.6	0.64 (0.44)	0.15
Ideal	1912 (62)	97.6±7.3	1.01 (0.37)	0.007
Total cholesterol				
Poor	525 (17)	97.9±6.7	Reference	
Intermediate	1289 (42)	97.3±7.1	−0.50 (0.38)	0.19
Ideal	1284 (41)	97.2±8.1	−0.81 (0.38)	0.03

BI indicates Barthel index; CVH, cardiovascular health.

adjusted models and was sustained even after adjusting for stroke and MI occurring during follow-up, although the absolute values of the differences were reduced. This suggests that even when accounting for the predominant vascular events that cause reduced function, CVH predicts long-term disability. CVH was associated with both mobility and nonmobility BI domains, suggesting an effect not only on gross motor function but also fine motor and cognitive function. In a fully adjusted model, the mean BI score at 10 years of follow-up was 4.21 points higher among individuals with 5 to 7 ideal CVH metrics compared to those with 0 to 1. This mean difference is approximately equivalent to 1 level of function on the BI; for example, a shift from needing help with stairs to being independent, or from being dependent in bathing to being independent. Put another way, this magnitude of difference is approximately equivalent to the effect on function of being 7 years younger. When stroke and MI were adjusted for, the magnitude of difference was reduced but still significant at 2.32 points. For an individual, this represents about half of 1 level of function on the BI, or the equivalent of being 3 to 4 years younger. Such a magnitude, although potentially small for an individual, would translate to a large effect on disability in the entire population. Even with a dichotomous definition of the BI,[18] there remained a gradient such that increasing numbers of ideal CVH metrics, and higher scores of CVH metrics, were

Table 6. CVH Metrics and Total BI Score at Follow-Up

CVH Metrics	Year 5 of Follow-Up		Year 10 of Follow-Up	
	Estimate* (SE)	*P* Value	Estimate* (SE)	*P* Value
Smoking				
Poor vs intermediate	−0.32 (1.46)	0.827	−0.42 (1.52)	0.784
Poor vs ideal	−0.64 (0.54)	0.242	1.27 (0.56)	0.025
Body mass index				
Poor vs intermediate	−1.32 (0.49)	0.007	−1.60 (0.50)	0.002
Poor vs ideal	−1.28 (0.54)	0.018	−0.72 (0.56)	0.197
Physical activity				
Poor vs intermediate	−1.30 (0.50)	0.010	−0.97 (0.52)	0.064
Poor vs ideal	−2.91 (0.47)	<0.0001	−3.37 (0.49)	<0.0001
Diet				
Poor vs intermediate	−0.50 (0.46)	0.280	0.90 (0.48)	0.060
Poor vs ideal	−2.77 (3.20)	0.386	−2.03 (3.33)	0.542
Blood pressure				
Poor vs intermediate	−0.15 (0.42)	0.714	−1.11 (0.44)	0.011
Poor vs ideal	1.44 (0.90)	0.108	−0.72 (0.92)	0.436
Fasting glucose				
Poor vs intermediate	−1.75 (0.67)	0.009	−3.61 (0.70)	<0.0001
Poor vs ideal	−2.35 (0.57)	<0.0001	−4.57 (0.59)	<0.0001
Total cholesterol				
Poor vs intermediate	0.02 (0.57)	0.973	−0.61 (0.59)	0.297
Poor vs ideal	1.27 (0.59)	0.030	0.31 (0.60)	0.612

BI indicates Barthel index; CVH, cardiovascular health.
*Mean difference was adjusted for age, sex, race-ethnicity, education, health insurance, marital status, number of friends, moderate alcohol drinking, depression, history of coronary artery disease, and history of peripheral vascular disease.

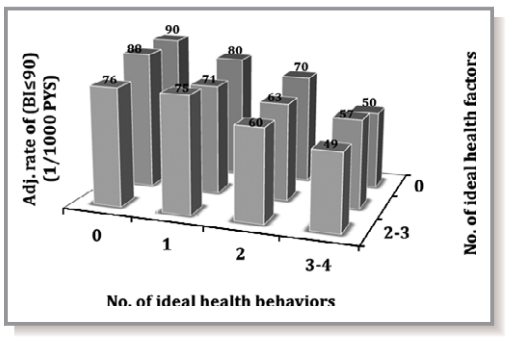

Figure 3. Adjusted incidence rates of Barthel index (BI)<95 by the numbers of ideal health behaviors (smoking, obesity, physical activity, and diet) and health factors (blood pressure, cholesterol, and glucose). Incidence rates were adjusted for age, sex, race-ethnicity, education, health insurance, marital status, number of friends, moderate alcohol drinking, depression, history of coronary artery disease, and history of peripheral vascular disease.

associated with improved functional status. Specifically, those with 5 to 7 ideal CVH metrics were approximately twice as likely to be independent over time as those with 0 to 1 metrics.

The strong gradient of function and predictive ability of the ideal CVH metric suggest that vascular functional impairment may be a useful construct. Analogous to the concept of vascular cognitive impairment, vascular functional impairment posits that vascular risk factors, which are encapsulated in the ideal CVH metric, lead to cerebrovascular disease, both clinical and subclinical. The effects of clinical cerebrovascular disease on disability have been well studied. Subclinical effects of vascular risk factors include subclinical infarcts,[13,36] subclinical cardiac disease, white matter disease,[37–40] and vascular dysfunction,[41] which may cause cognitive impairment, gait disorders, parkinsonism, and incontinence, and which have other direct effects on function. These effects may become apparent even before clinical events are appreciated and hence would be independent of vascular events such as

Table 7. CVH Status and Total BI Score at Follow-Up by Race-Ethnicity and Sex

	NH-White		NH-Black		Hispanic		Men		Women	
CVH Metrics	Estimate* (SE)	*P* Value	Estimate* (SE)	*P* Value	Estimate* (SE)	*P* Value	Estimate* (SE)	*P* Value	Estimate* (SE)	*P* Value
Year 5 of follow-up										
No. of ideal CVH metrics										
0 to 1 vs 2	−2.09 (1.43)	0.145	−0.72 (1.29)	0.573	−1.22 (0.70)	0.083	−1.01 (0.81)	0.216	−1.54 (0.76)	0.043
0 to 1 vs 3	−4.90 (1.39)	0.0004	−1.74 (1.31)	0.185	−0.16 (0.73)	0.832	−1.18 (0.82)	0.148	−1.95 (0.79)	0.013
0 to 1 vs 4	−3.76 (1.50)	0.012	0.13 (1.59)	0.937	−2.67 (0.97)	0.006	−1.20 (0.93)	0.198	−2.68 (1.00)	0.008
0 to 1 vs 5 to 7	−4.71 (1.96)	0.016	−0.73 (2.38)	0.759	−1.42 (1.53)	0.355	−1.67 (1.25)	0.182	−2.91 (1.65)	0.078
Score of CVH metrics										
0 to 5 vs 6	−0.41 (1.65)	0.805	−0.47 (1.48)	0.751	−1.50 (0.79)	0.058	−2.23 (0.95)	0.019	−0.79 (0.85)	0.355
0 to 5 vs 7	−3.56 (1.54)	0.021	−1.72 (1.40)	0.219	−0.58 (0.77)	0.455	−1.75 (0.86)	0.042	−1.72 (0.84)	0.042
0 to 5 vs 8	−4.23 (1.55)	0.006	−0.85 (1.46)	0.563	−2.24 (0.81)	0.006	−3.17 (0.88)	0.0003	−2.13 (0.88)	0.016
0 to 5 vs 9 to 13	−4.76 (1.35)	0.0004	−1.53 (1.32)	0.246	−2.56 (0.79)	0.001	−2.83 (0.81)	0.0005	−3.03 (0.82)	0.0002
Year 10 of follow-up										
No. of ideal CVH metrics										
0 to 1 vs 2	−5.10 (1.51)	0.0007	−1.68 (1.36)	0.218	−1.73 (0.72)	0.017	−2.03 (0.86)	0.018	−2.48 (0.79)	0.002
0 to 1 vs 3	−7.03 (1.46)	<0.0001	−1.10 (1.38)	0.427	−1.34 (0.76)	0.075	−2.61 (0.86)	0.002	−2.26 (0.81)	0.006
0 to 1 vs 4	−3.78 (1.58)	0.017	−1.40 (1.68)	0.403	−3.56 (0.98)	0.0003	−0.91 (0.98)	0.351	−3.21 (1.03)	0.002
0 to 1 vs 5 to 7	−7.05 (2.03)	0.0005	−3.01 (2.43)	0.215	−3.76 (1.57)	0.016	−3.01 (1.29)	0.020	−4.14 (1.68)	0.014
Score of CVH metrics										
0 to 5 vs 6	−1.69 (1.75)	0.334	0.42 (1.57)	0.790	−1.51 (0.81)	0.064	−3.80 (1.01)	0.0002	−0.21 (0.88)	0.807
0 to 5 vs 7	−4.49 (1.63)	0.006	−1.29 (1.48)	0.383	−1.51 (0.79)	0.058	−3.50 (0.91)	0.0001	−1.30 (0.87)	0.136
0 to 5 vs 8	−4.48 (1.64)	0.006	−0.22 (1.53)	0.886	−3.98 (0.83)	<0.0001	−5.07 (0.93)	<0.0001	−2.24 (0.91)	0.014
0 to 5 vs 9 to 13	−5.10 (1.43)	0.0003	−1.48 (1.38)	0.285	−3.84 (0.81)	<0.0001	−3.41 (0.86)	<0.0001	−3.18 (0.85)	0.0002

BI indicates Barthel index; CVH, cardiovascular health; NH, non-Hispanic.

*Mean difference, adjusted for age, education, health insurance, marital status, number of friends, moderate alcohol drinking, depression, history of coronary artery disease, history of peripheral vascular disease, and sex and race-ethnicity if applicable.

clinical stroke and MI. Also, the pathways causing vascular functional impairment would likely be independent of arthritis and pain, 2 major causes of disability that were not systematically measured in this study. However, future research would clarify the relationships between vascular risk factors and these nonvascular causes of disability.

Although the original definition of ideal CVH[1] was the simultaneous presence of all 7 ideal CVH metrics, this rarely occurs;[2,8,42] in the Northern Manhattan Study, no subject had all 7 ideal metrics and only 0.5% of the cohort had 6. Hence, ideal CVH may be considered an ideal that is currently rarely attained, although the hope is that it becomes more prevalent over time. Hence, to operationalize the construct of ideal CVH and analyze its predictive utility, we used 2 definitions. The first was a sum score of the number of ideal CVH metrics for each individual, which has been used in previous research in this cohort and others.[3,11] The second definition was a sum score of an individual's scores on each CVH metric, with 0 assigned to the poor category, 1 to intermediate, and 2 to ideal.[3] With both of these definitions, we found a gradient in functional outcomes such that higher scores on each metric were associated with improved functional ability. This suggests that the recognition not only of ideal CVH status but also poor and intermediate status is informative for functional

ability as well as vascular events, as seen in previous research.[3]

In secondary analyses, we found significant differences in function among categories of each CVH metric. Specifically, the mean BI score for poor physical activity was 3.37 points lower compared to ideal physical activity, and the mean BI score was 4.57 points higher with ideal FG levels compared to poor. These findings confirm and extend prior research in this cohort, which found a strong effect of diabetes on physical function, even when censoring vascular events such as stroke and MI.[15] Also, increased physical activity has been shown to promote functional status.[43] We also found significant race-ethnic and sex-related differences in associations between ideal CVH metrics and disability, with a clearer significant gradient seen among non-Hispanic whites, Hispanics, and women, but not among non-Hispanic blacks and men. It is possible that vascular disease, as represented by the ideal CVH metrics, is a predominant cause of disability among non-Hispanic whites, Hispanics, and women, while other nonvascular causes of decreased function play a larger role among non-Hispanic blacks and men.

Strengths of this study include large sample size, long-term follow-up, minimal loss to follow-up, annual functional status assessments with a validated activities of daily living measure, and representation of an urban, multiethnic underlying population. Limitations include lack of information about conditions such as arthritis and pain that have an impact on functional status. Also, CVH measures were assessed at study entry, and we do not have data in the entire cohort on status of CVH metrics during follow-up. However, the purpose of this study was to determine the predictive ability of the ideal CVH construct to assess long-term disability, and for this baseline measurements of CVH status are most relevant.

In conclusion, we found a gradient of improved functional status with improved CVH, as measured by the American Heart Association/American Stroke Association's 7 ideal CVH metrics. The fact that this gradient was maintained even after accounting for incident stroke and MI suggests that vascular functional impairment may cause a significant proportion of disability in a population, independent of clinical events. Vascular functional impairment is a patient-centered outcome whose impact may be reduced by optimizing cardiovascular health. Further study will refine this concept, and future interventions to improve ideal CVH would likely have an impact not only on vascular events but also disability.

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Disclosures

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