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ORIGINAL RESEARCH

Impaired Balance Predicts Cardiovascular Disease in 70-Year-Old Individuals—An Observational Study From the Healthy Aging Initiative

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BACKGROUND: Limited research has explored balance problems as a prospective risk factor for cardiovascular disease (CVD). This study aimed to characterize the association between balance measures and the risk of incident CVD in a population of 70-year-olds.

METHODS AND RESULTS: From 2012 to 2022 a cohort of 4927 older individuals who were CVD free underwent balance assessments using a balance board. Measurements included lateral and anterior–posterior sway, along with a safety limit of stability in a subcohort (N=2782). Time to first hospitalization for CVD, encompassing stroke, myocardial infarction, or angina pectoris was the primary outcome. Multivariable regression models assessed associations between balance parameters and CVD risk. Over a mean follow-up of 4.9 years, 320 individuals were hospitalized for CVD. In a balance test with eyes open, increased lateral sway at baseline was associated with a higher risk of CVD (hazard ratio [HR], 1.014 [95% CI, 1.004–1.025], *P*=0.005, per mm increased sway), after adjustment for traditional risk factors for CVD. Similarly, individuals with CVD during follow-up exhibited higher lateral sway with eyes closed at baseline (HR, 1.015 [95% CI, 1.005–1.025], *P*=0.002, per mm increased sway), after multivariable adjustment. The 4 strongest independent predictors of CVD included lateral sway and were associated with a population attributable fraction of 61% (95% CI, 54–68).

CONCLUSIONS: In community-dwelling 70-year-olds, impaired lateral balance was an independent predictor of later CVD, after adjustment for traditional risk factors. This may suggest that position balance could be used as an early risk marker for underlying atherosclerotic disease.

Key Words: balance ■ cardiovascular disease ■ risk factor

Ischemic heart disease and stroke, ranked as the leading causes of global mortality, were responsible for about 27% of all worldwide deaths in 2015.[1] Beyond its immediate health impact, cardiovascular disease (CVD) inflicts a substantial and lasting toll on individuals in the process of recovery. The challenges extend beyond the physical realm to include significant mental and social obstacles, culminating in a protracted decline in health-related quality of life.[2] Hence, the identification of modifiable risk factors and early predictors of CVD assumes a paramount role in both clinical practice and the realm of public health.

Recent investigations suggest a potential connection between balance and cardiovascular function. Balance pertains to the capacity for maintaining an upright postural control, achieved by ensuring that the center of pressure remains within the confines of a supportive base.[3] Balance, a multifaceted physiological process, integrates sensory cues from proprioceptors,

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CLINICAL PERSPECTIVE

What Is New?

- In the present study, increased lateral sway was a risk factor for future myocardial infarctions and stroke.
- The associations were independent of traditional risk factors for cardiovascular disease.

What Are the Clinical Implications?

- In clinical practice, reduced balance could be an early risk marker for cardiovascular disease.

Nonstandard Abbreviations and Acronyms

HAI	Healthy Ageing Initiative
PAF	population-attributable fraction

vision, and the vestibular system, regulated by the central nervous system.[4–6]

Other studies underscore the intricate interplay between balance function and cardiovascular health.[7–10] Notably, individuals carrying elevated risk factors for CVD, including hypertension and diabetes, often present with discernible deficits in balance.[11,12] Furthermore, vascular risk factors and subclinical CVD have been correlated with observable alterations in balance, particularly evident in assessments of postural sway.[13,14] Yet, it is not known whether impaired balance predicts the later risk of stroke or ischemic heart disease in older people.

Therefore, this study aims to investigate whether poor balance, assessed as increased postural sway, increases the risk of later stroke and ischemic heart disease in community-dwelling older individuals who were free from CVD at baseline.

METHODS

Study Design and Setting

The individuals considered for inclusion in the present study included all women and men who participated in a health investigation called the HAI (Healthy Ageing Initiative).[15] Initiated in May 2012, the HAI operates as a primary prevention study situated in Umeå, a municipality in northern Sweden with a population of about 132000 inhabitants. All assessments in this project were performed at a single clinic in Umeå by 4 research nurses, with 2 chief physicians as backup (A.N. and P.N.). We used the Strengthening the Reporting of Observational Studies in Epidemiology cohort checklist when writing our report. The data of the present study are not publicly available due to Swedish regulations.

Participant Recruitment

The primary recruitment criteria for HAI were residency in Umeå municipality and an exact age of 70 years. There were no specific exclusion criteria. Participants were identified using public population registers, and as of the last assessment, the HAI has seen participation from 54% of the 70-year-olds in Umeå municipality. Potential participants, pinpointed via population registers, were first provided with written information about the HAI. Following this initial contact, they were contacted remotely over the telephone for further engagement. Those expressing interest were then scheduled for an in-person visit to the clinic, during which they provided written consent and subsequently began the testing phase.

For the present study all individuals who participated in the HAI from 2012 until 2022 were considered for inclusion (N=6649). After exclusion of individuals who lacked balance assessments or had been hospitalized for a myocardial infarction, stroke, or angina pectoris at baseline, 4927 individuals remained for the present study (Figure 1).

Balance Assessment

Balance was evaluated using a Wii balance board device, specifically identified as the Nintendo RVL-WBC-01, which operates at a 100 Hz sampling rate as previously described in the HAI cohort.[16] This device connected to a standard computer through a Bluetooth interface, employing the Wiimote Management Library v1.7.00 developed by Brian Peek. The assessment software was developed in Microsoft C#. Additionally,

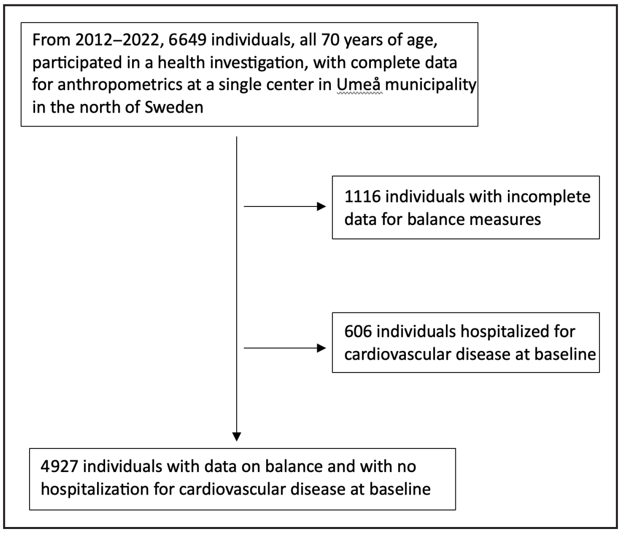

Figure 1. Descriptive characteristics of the cohort.

the device's power source transitioned from a battery to a USB connection.

Participants underwent two 60-second assessments in a controlled environment, with 1 trial group having their eyes open and the other with eyes closed. The tests of balance with eyes closed were performed to challenge the individuals, because vision contributes to balance. They were guided to stand upright, remain relaxed, and refrain from any significant head or arm movements. The Wii balance board device recorded the overall center of pressure sway length, capturing the combined postural sway in both anteroposterior and mediolateral directions in millimeters. In addition, the safety limit of stability was documented. This metric quantifies in millimeters the total sway relative to the individual's maximum limits across various directions before balance is lost.

Covariates

Anthropometric measurements, including weight and height, were captured using standardized equipment. Body mass index was estimated. Blood pressure (mm Hg) was measured in supine position after at least 5 minutes rest using an automatic standardized device. Data on diagnoses were gathered from the Swedish NPR (National Patient Register), overseen by the National Board of Health and Welfare. This register employs the *International Classification of Diseases* (*ICD*) codes for diagnostic classification. Past assessments have confirmed the reliability of the NPR's diagnostic entries, with its accuracy estimated to be in general between 65% and 100%, 95% and above for ischemic heart disease and 68.5% and 99% in 2 studies evaluating stroke.[17] Additionally, data on prescription medications were obtained from the Prescribed Drug Register, which has cataloged all medication transactions in Sweden since July 2005. Further details, such as mortality statistics during the observation period, were extracted from the Cause of Death Register, also managed by the National Board of Health and Welfare. To determine the highest educational qualifications of participants, the study combined cohort information with data from the Statistics Sweden repository.

Outcome

The primary outcome was being hospitalized for myocardial infarction, stroke, or angina pectoris during follow-up.

Ethics and Approval

The research adheres to the guidelines set forth by the World Medical Association's Declaration of Helsinki and has received ethical approval from the local ethics committee and later the Swedish ethics review authority (Number 07-031 with extensions). All participants gave their written consent to participate.

Statistical Analysis

Descriptive data were presented as means±SD if not otherwise described. Differences between 2 subgroups were investigated using a *t* test for independent samples for continuous variables and a chi-square test for categorical variables. Associations between various balance parameters and the later risk of CVD were determined using Cox regression models. The first model was unadjusted. The second model was adjusted for variables that were significantly different at baseline between those who were later hospitalized for CVD and the rest of the cohort, according to Table 1, with the exception of body mass index, because weight and height were included in the model. The proportional hazard assumption was evaluated by using Schoenfeld's residuals. A product interaction term was computed between lateral sway and the variables that were significantly different between those who suffered a stroke during follow-up and the rest of the cohort (Table 1). This product interaction term was added to the Cox regression together with the other covariates in the fully adjusted model. To evaluate whether lateral sway was associated with an increased risk of CVD in a dose-dependent manner, quartiles of lateral sway, tested with eyes closed, was added to the Cox regression in the fully adjusted model. The population-attributable fraction (PAF), attributed to the independent effects of sex, lateral sway, medication for hypertension, and anticoagulants, was estimated using the *punafcc* command based on the baseline hazards estimated in a Cox regression model. The PAF is a measure used to estimate the proportion of disease cases in a population that can be attributed to a specific exposure or exposures. In other words, it quantifies the proportion of disease burden in a population that could theoretically be prevented if the exposure to the risk factors was eliminated. The SPSS software (version 28) and Stata software (version 16.1) were used to fit the statistical models and graphically illustrate the results. A 2-sided *P* value of <0.05 or 95% CIs not including 1 were set as statistically significant.

RESULTS

Baseline Characteristics

The cohort studied consisted of 4927 unique individuals with a mean age of 70.4±0.2 years at baseline, and with no previous hospitalization for myocardial infarction, stroke, or angina pectoris (Table 1). Those with subsequent CVD (N=320) were slightly older, predominantly men, with higher weight, height, and body mass index, lower education, and more frequent use

Table 1. Descriptive Characteristics of the Cohort

	Total cohort	CVD during follow-up		
	(N=4927)	Yes (n=320)	No (n=4607)	*P* value
Age, y±SD	70.4±0.2	70.4±0.1	70.4±0.2	<0.001
Sex, male, N (%)	2231 (45.3%)	206 (64.4%)	2025 (44.0%)	<0.001
Weight, kg±SD	77.1±14.6	79.7±14.4	76.9±14.6	0.001
Height, cm±SD	170±9.2	171±9	169±9	0.04
Body mass index, m/kg^2±SD	26.8±4.6	27.4±5.6	26.7±4.5	0.01
Education, N (%)				<0.001
<9y elementary school	335 (6.8%)	43 (13.4%)	292 (6.3%)	
≥9y elementary school	296 (6.0%)	11 (3.4%)	285 (6.2%)	
2y secondary high school	1386 (28.1%)	92 (28.7%)	1294 (28.1%)	
>2y secondary high school	535 (10.9%)	37 (11.6%)	498 (10.8%)	
Education after secondary high school	2371 (48.1%)	136 (42.5%)	2235 (48.5%)	
Current smoker, N (%)	242 (4.9%)	20 (6.3%)	222 (4.8%)	0.25
Diagnoses at baseline, N (%)				
Diabetes or antidiabetic drugs	412 (8.4%)	34 (10.6%)	378 (8.2%)	0.13
Fracture	829 (16.8%)	44 (13.8%)	785 (17.0%)	0.13
Depression or antidepressants	870 (17.7%)	45 (14.1%)	825 (17.9%)	0.08
Medications, N (%)				
Antihypertensives	2893 (58.7%)	226 (70.6%)	2667 (57.9%)	<0.001
Anticoagulants	1335 (27.1%)	133 (41.6%)	1202 (26.1%)	<0.001
Statins	1716 (34.8%)	126 (39.4%)	1590 (34.5%)	0.08
Risk factors, mean±SD				
Systolic blood pressure, mmHg	138±17	140±16	138±17	0.06
Diastolic blood pressure, mmHg	83±9	82±9	83±9	0.06
Blood-glucose, mmol/L	5.7±1.0	5.7±1.1	5.7±1.0	0.38

Data are presented for the entire cohort and stratified by the occurrence of cardiovascular disease during follow-up. Continuous data are presented as means±SD.

of antihypertensive drugs and anticoagulants ($P<0.05$ for all). Balance was tested first with eyes open and then with eyes closed (Table 2). In general, women had worse balance for most of the tests performed compared with men, and balance measures were generally impaired during the eyes closed condition.

Incidence of Cardiovascular Disease During Follow-Up

Over a mean follow-up of 4.9 years (range, 0.0–10.6), 320 individuals experienced hospitalization for CVD. Individuals with higher lateral sway and higher variation in lateral sway during both eyes-open and eyes-closed tests at baseline were more likely to develop CVD ($P<0.05$ for all, Table 2). The association appeared to increase in a dose-dependent manner for quartiles of lateral sway (Figure 2). In addition, during the test with eyes closed at baseline, individuals with a higher sway velocity and variation in sway velocity in the anterior–posterior direction had a higher risk of CVD during follow-up (Table 2).

In the first unadjusted Cox regression model, individuals who were hospitalized for CVD during follow-up had higher lateral sway (hazard ratio [HR], 1.012 [95% CI, 1.002–1.022], per mm increase), anterior–posterior sway velocity (HR, 1.065 [95% CI, 1.012–1.121], per mm/s increase), and variation in anterior–posterior sway velocity (HR, 1.062 [95% CI, 1.005–1.121], per SD increase) during a test with eyes open at baseline (Table 3). During a test with eyes closed, individuals who were hospitalized for CVD during follow-up had higher variation in lateral sway (HR, 1.014 [95% CI, 1.004–1.024], per mm increase), higher variation anterior–posterior sway variation (HR, 1.022 [95% CI, 1.000–1.044], per SD increase), higher anterior–posterior sway velocity (HR, 1.011 [95% CI, 1.002–1.020], per mm/s increase), and higher variation in anterior–posterior sway velocity variation (HR, 1.014 [95% CI, 1.003–1.026], per SD increase) at baseline. In a second Cox regression model, adjusted for significant covariates according to Table 1, individuals with CVD during follow-up had a higher sway in the lateral direction at baseline (HR, 1.014 [95% CI, 1.004–1.025], $P=0.005$,

Table 2. Balance Test Results by Sex and Cardiovascular Disease Status

	Total cohort	Test with eyes open			Test with eyes open, CVD during follow-up			Test with eyes closed, CVD during follow-up		
		Men	Women		Yes	No		Yes	No	
	N=4927	N=2231	N=2696	*P* value	N=314	N=4524	*P* value	N=317	N=4516	*P* value
Balance measures										
Lateral										
Sway, mm	−2.8±11.4	−3.1±11.7	−2.6±11.0	0.14	−0.3±10.8	−3.0±11.4	<0.001	0.4±11.8	−2.7±11.6	<0.001
Sway mm variation, SD	2.5±1.6	2.7±1.5	2.4±1.6	<0.001	2.7±1.4	2.5±1.5	0.03	3.4±2.1	3.2±2.0	0.03
Sway velocity, mm/s	2.8±1.6	3.0±1.9	2.7±1.1	<0.001	2.8±1.0	2.8±1.3	0.88	4.5±3.2	4.3±2.8	0.16
Sway velocity variation, SD	2.3±1.4	2.5±1.6	2.2±1.2	<0.001	2.3±1.0	2.3±1.2	0.81	3.8±2.9	3.6±2.5	0.28
Anterior–posterior										
Sway, mm	−23.0±15.8	−22.3±15.6	−23.6±16.0	0.003	−23.3±15.6	−22.9±15.8	0.62	−22.4±14.3	−22.4±14.7	0.96
Sway mm variation, SD	3.8±1.6	4.2±1.7	3.6±1.5	<0.001	3.8±1.4	3.8±1.6	0.78	6.8±2.8	6.4±2.8	0.006
Sway velocity, mm/s	4.6±2.1	5.1±2.5	4.2±1.6	<0.001	4.7±1.6	4.5±1.9	0.22	11.7±7.2	10.4±6.0	0.02
Sway velocity variation, SD	3.8±1.9	4.2±2.2	3.4±1.5	<0.001	3.8±1.5	3.7±1.7	0.22	9.4±6.2	8.6±5.1	0.03
Trace length, mm±SD	351±159	386±193	322±117	<0.001	352±113	345±139	0.40	773±490	711±405	0.03
Safety limit of stability, mm±SD	44±20	47±21	42±19	<0.001	45±21	44±20	0.49	41±21	41±20	0.87

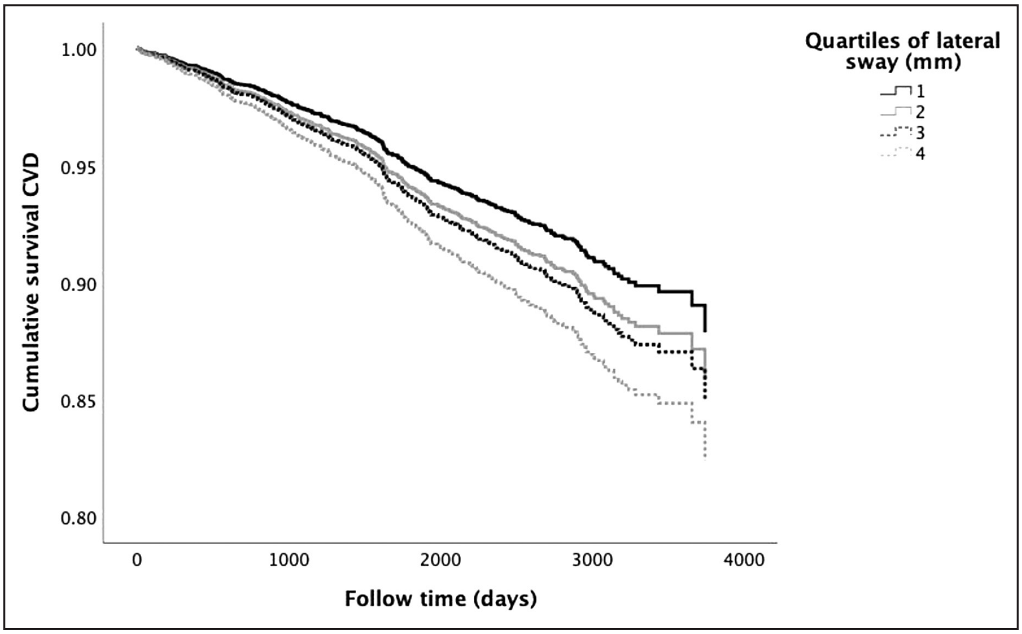

Figure 2. The associations for quartiles of lateral sway during a test with eyes open and incident cardiovascular disease.
CVD indicates cardiovascular disease.

per mm sway), during a test with eyes open (Table 3). Also, during a test with eyes closed, individuals with CVD during follow-up had a higher sway in the lateral direction at baseline (HR, 1.015 [95% CI, 1.005–1.025], *P*=0.002, per mm sway), after multivariable adjustment (Table 3). The 4 strongest independent predictors of CVD based on the *P* value included sex, lateral sway during the test with eyes closed, medication for hypertension, and anticoagulants (*P*<0.01 for all). Together, these risk factors were associated with a PAF of 61% (95% CI, 54–68). If lateral sway was removed from this model, PAF decreased to 57% (95% CI, 49–64). PAF for lateral sway alone was 10% (95% CI, 5–15).

Additional Analyses

In a first sensitivity analysis, individuals with <1 year of follow-up were excluded from the analysis, leaving 4327 individuals, 272 of whom were hospitalized for CVD during follow-up. Also in this cohort, higher lateral sway at baseline increased the risk of hospitalization for CVD during follow-up both in the test with eyes open (HR, 1.018 [95% CI, 1.008–1.029], *P*<0.001 per mm increase) and with eyes closed (HR, 1.016 [95% CI, 1.005–1.027], *P*=0.003 per mm increase), in the fully adjusted model. In an interaction analysis using the total cohort, the associations were similar for the significant covariates according to Table 1 for the main exposure of lateral sway tested with eyes closed (*P*>0.30 for all). Finally, when analyzing the separate outcomes in the total cohort, higher lateral sway at baseline tested with eyes closed showed a strong association with incident myocardial infarction (HR, 1.027 [95% CI, 1.010–1.043], *P*=0.002 per mm increase), intermediate with incident stroke (HR, 1.017 [95% CI, 1.03–1.032], *P*=0.02 per mm increase), and no association with incident angina pectoris (HR, 1.001 [95% CI, 0.984–1.019], *P*=0.90 per mm increase), in the fully adjusted model.

DISCUSSION

This investigation contributes novel insights into the intricate relationship between balance, specifically postural sway, and the risk of CVD within a population-based cohort of 70-year-old individuals. Balance was an independent predictor of later CVD, also after adjustment for traditional risk factors, such as body composition, diabetes, smoking, and blood pressure. The 4 strongest independent predictors of CVD included lateral sway, sex, anticoagulants, and medication for hypertension, which were associated with a PAF of 61%. The study's outcomes reveal compelling and significant discoveries of position balance as a potential early risk marker for underlying atherosclerotic disease, suggesting implications for prevention of manifest CVD.

Over an average follow-up period of approximately 5 years, about 6.5% of the individuals were diagnosed with CVD. Notably, lateral sway, assessed both with eyes open and closed, emerged as a critical predictor of the risk for CVD. A later sensitivity analysis suggested that the main results were applicable to both the risk of stroke and myocardial infarction. This discovery holds

Table 3. Association Between the Different Balance Measures and the Risk of Cardiovascular Disease During Follow-Up

	Test with eyes open						Test with eyes closed					
	Unadjusted model			Adjusted model*			Unadjusted model			Adjusted model*		
	HR	95% CI	*P* value	HR	95% CI	*P* value	HR	95% CI	*P* value	HR	95% CI	*P* value
Balance measures												
Lateral												
Sway, per mm	1.012	1.002–1.022	0.02	1.014	1.004–1.025	0.005	1.014	1.004–1.024	0.006	1.015	1.005–1.025	0.002
Sway mm variation, per SD	1.032	0.978–1.089	0.25	1.030	0.968–1.096	0.34	1.026	0.991–1.061	0.14	1.018	0.979–1.060	0.37
Sway velocity, per mm/s	1.023	0.942–1.110	0.59	1.000	0.913–1.094	0.99	1.021	0.991–1.053	0.17	1.004	0.968–1.041	0.83
Sway velocity variation, per SD	1.024	0.941–1.116	0.58	1.008	0.920–1.106	0.86	1.019	0.983–1.057	0.31	1.000	0.957–1.044	0.99
Anterior–posterior												
Sway per mm	0.998	0.991–1.005	0.53	0.997	0.990–1.004	0.39	0.999	0.991–1.006	0.77	0.998	0.991–1.006	0.67
Sway mm variation, per SD	1.014	0.949–1.084	0.69	0.994	0.925–1.067	0.86	1.022	1.000–1.044	0.04	1.009	0.981–1.039	0.53
Sway velocity, per mm/s	1.065	1.012–1.121	0.02	1.020	0.964–1.083	0.47	1.011	1.002–1.020	0.01	1.006	0.994–1.018	0.36
Sway velocity variation, per SD	1.062	1.005–1.121	0.03	1.008	0.920–1.106	0.86	1.014	1.003–1.026	0.02	1.007	0.992–1.022	0.36
Trace length, per mm	1.001	1.000–1.001	0.06	1.000	0.999–1.001	0.63	1.000	1.000–1.000	0.02	1.000	1.000–1.000	0.45
Safety limit of stability, per mm	1.024	0.941–1.116	0.58	1.000	0.994–1.007	0.87	1.000	0.994–1.006	0.99	1.000	0.994–1.006	1.00

Hazard ratios per unit increase, 95% CI, and *P* values are presented, HR indicates hazard ratio.
*Adjusted for the influence of age, sex, weight, height, education, and use of antihypertensives and anticoagulants at baseline.

particular significance as it implies that disturbances in balance, specifically lateral postural sway, can manifest years before the manifest disease of stroke or myocardial infarction. To our knowledge, there are no previous studies to support our results. Importantly, this association persisted independently of traditional risk factors, such as age, sex, smoking, diabetes, body composition, and blood pressure, highlighting the unique predictive value of impaired balance. Interestingly, increased lateral sway was the fourth strongest predictor of CVD, which, together with sex and medication for hypertension and anticoagulants, was associated with a PAF >60%. In comparison, a recent international study showed that the 5 risk factors, body mass index, smoking, non-high-density lipoprotein, systolic blood pressure, and diabetes, were associated with a PAF of 57% and 53%, in women and men, respectively.[18] The connection between balance and cardiovascular health has been explored in previous studies to some extent, revealing that individuals with balance deficits often exhibit elevated risk factors for cardiovascular diseases, including hypertension and diabetes.[11,12] Hence, recognizing this early and strong risk marker also for manifest CVD opens opportunities for timely interventions that encompass managing cardiovascular risk factors. Early interventions may include traditional strategies for enhancing cardiovascular health, such as improved control of hypertension and diabetes.

Objective measures assessing parameters such as sway magnitude and sway velocity during quiet standing provide additional insights into the underlying abnormalities in postural control and their contribution to other diagnoses, such as falls and imbalance.[16,19] Notably, in healthy elderly individuals, studies have established associations between falls and increased mediolateral sway and enhanced sway velocity during quiet standing, both with eyes open and closed.[16,19] Comparatively, people with stroke exhibit differences in weight-bearing symmetry and postural sway parameters, characterized by larger and faster sway, especially in the frontal plane.[20–22] It is therefore of interest that the present study shows that the impaired balance demonstrated in survivors of stroke may be present already before the stroke occurred, perhaps as a sign of subclinical disease, atherosclerosis, and other diagnoses.

The present study has some limitations to consider. It would have been of value to have an even larger cohort with more outcomes during follow-up. Yet, lateral sway was associated with stroke and myocardial infarction, also when analyzed separately. Furthermore, although we had access to the most important risk factors for CVD, such as blood pressure, medications, and smoking habits, there could be other important confounders that could have influenced the associations found. It should also be noted that the present study could not elucidate the underlying mechanisms linking impaired balance to CVD and whether increased lateral sway is a reflection of a general burden of atherosclerosis. Strengths include the population-based cohort, with objective measures of balance and virtually no loss to follow-up given that outcomes were collected in nationwide registers, although the generalizability may be limited to individuals who are 70 years of age.

CONCLUSIONS

In conclusion, this study emphasizes the predictive significance of balance, particularly lateral postural sway, as a marker for CVD risk in older individuals residing in the community. The findings shed light on distinctive balance patterns among individuals at an increased risk of future stroke and ischemic heart disease. Future investigations should aim to unravel the mechanistic links between impaired balance and CVD. Acknowledging the importance of balance assessments in predicting CVD risk opens avenues for early interventions and preventive strategies, which might mitigate the impact of CVD on individuals and health care systems.

ARTICLE INFORMATION

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Disclosures

None.

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