Original research

# Ideal cardiovascular health duration and risk of chronic kidney disease and cardiovascular disease

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## ABSTRACT

**Objective** Increasing number of clinical guidelines are adopting comprehensive cardiovascular risk assessment tools for treatment decision and disease management. Yet, little is known regarding cardiovascular risks associated with the length of favourable cardiometabolic profile. In this context, we examined whether the duration of strictly ideal cardiovascular health (CVH), based on body mass index, blood pressure, fasting glucose, total cholesterol, cigarette smoking, alcohol drinking and physical activity, in middle age is associated with risk of developing chronic kidney disease (CKD) and cardiovascular disease (CVD) in mid-to-late life.

**Methods** From the Korean Genome and Epidemiology Study Ansung-Ansan cohort, we included 8020 participants (median age 50.0 years, 47.9% male), of whom, 7854 without CKD and 7796 without CVD at baseline. Cox proportional hazards models were employed to assess CKD and CVD risks, adjusting for age, sex, education level, examination sites and renal markers.

**Results** Over a median follow-up of 15.0 years, 1401 cases of CKD and 493 cases of CVD were newly developed. Compared with participants with <5 years of ideal CVH duration, HR (95% CI) of those who maintained for 5–<10 years or ≥10 years had negatively graded risks for CKD (5–<10 years, 0.63 (0.39 to 0.93); ≥10 years, 0.33 (0.15 to 0.74)) and CVD (5–<10 years, 0.83 (0.54 to 1.27); ≥10 years, 0.22 (0.08 to 0.60)). In parallel, participants with delayed decline to suboptimal level had lower disease risks compared with counterparts with consistently suboptimal CVH.

**Conclusion** Our findings confer that maintaining favourable health behaviours and clinical risk factor levels in midlife will improve later-life cardiovascular outcomes.

## INTRODUCTION

In 2010, the American Heart Association has released cardiovascular health (CVH) metrics called the 'Life's Simple 7'[1] based on modifiable risk factors. Concordantly, international clinical guidelines[2 3] have adopted and actively used atherosclerotic cardiovascular disease (CVD) risk assessment algorithms that account for clinical and lifestyle risk factors. Such holistic tools are intended to aid surveillance and management of CVD, which remains the leading cause of mortality worldwide.[4] Beyond this, timely and sustained management is expected to curtail life-years lost, to improve quality of life and to conserve healthcare costs.[5]

Previous literature has demonstrated the individual benefit of curbing obesity pandemic,[6] blood pressure,[7] cholesterol,[8] and blood sugar[9] lowering, smoking cessation,[10] moderate alcohol consumption[11] and regular physical activity[12] in the context of primary and secondary prevention of CVD. Recent observational studies have illustrated the association between a single-occasion CVH measure and subclinical atherosclerosis based on coronary artery calcium progression[13] and cardiac troponin T reduction.[14] However, growing evidence underscores the novelty of repeated measures to capture lifetime burden.[15]

Little is known on the risk magnitude associated with duration spent in ideal CVH in middle-age, Asian population. Age-adjusted CVD mortality has declined significantly in the high-income, western and Asia-Pacific regions over the past decades, but the decline has relatively plateaued in recent years.[4] Evaluating whether longer time spent in ideal CVH is associated with lower risk of target organ damage and cardiovascular events may improve the stagnant heart diseases hospitalisation and mortality rates.

In this context, we examined whether the duration of ideal CVH, based on body mass index, blood pressure, blood glucose, total cholesterol, cigarette smoking, alcohol drinking and physical activity, in middle age is associated with risk of developing chronic kidney disease (CKD) and CVD in mid-to-late life. To address this aim, we analysed data from the Korean Genome and Epidemiology Study (KoGES) Ansung-Ansan, an ongoing, prospective cohort in Republic of Korea.

## METHODS

### Study population

The KoGES consortium is a platform designated to investigate the genetic, social and environmental aetiology of chronic diseases in Republic of Korea.[16] It collected detailed information on demographics, lifestyle and healthcare utilisation and provided on-site anthropometric, blood and urine examinations.[16]

For this study, we selected the KoGES Ansung-Ansan, a community-based, prospective cohort in two suburban cities. Based on a two-stage cluster sampling recruitment, 10 030 participants, aged 40–69 years, underwent baseline examination between 2001 and 2002. Onwards, seven follow-up examinations were conducted every 2 years until 2015–2016. The KoGES Ansung-Ansan was administered, reviewed and approved by the Korea Center

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**Table 1** Definition and scoring of cardiovascular health components

| Metrics | Poor (0 point) | Intermediate (1 point) | Ideal (2 points) |
|---|---|---|---|
| Cigarette smoking | Current smoker | Former smoker | Never smoker |
| Alcohol drinking | ≥3 drinks/week | 1–2 drink(s)/week | Non-drinker |
| Physical activity | 0 min | More than 0 min but less than the recommendations | 75+ min of vigorous activity or 150+ min of moderate-to-vigorous activity |
| Body mass index | ≥25 kg/m$^2$ | 23–25 kg/m$^2$ | <23 kg/m$^2$ |
| Blood pressure | SBP ≥140 mm Hg or DBP ≥90 mm Hg | SBP 120–139 mm Hg, DBP <90 mm Hg, or treated to ideal | <120/80 mm Hg (untreated) |
| Fasting plasma glucose | ≥126 mg/dL | 100–126 mg/dL or treated to ideal | <100 mg/dL (untreated) |
| Total cholesterol | ≥240 mg/dL | 200–240 mg/dL or treated to ideal | <200 mg/dL (untreated) |

DBP, diastolic blood pressure; SBP, systolic blood pressure.

for Disease Control and Prevention. The present study was approved by the Institutional Review Board of Yonsei University Health System (Y-2020–0007). All participants provided written informed consent, and the study was conducted with strict adherence to the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines.

Among the 10 030 participants, 912 participants who had not attended any follow-up examinations were excluded. Additionally, 1098 participants with incomplete CVH measurements were excluded (online supplementary table S1). Of the remaining 8020 participants, 166 participants with CKD at baseline were excluded in the final analyses with CKD as the outcome; likewise, 224 participants with CVD at baseline were excluded with CVD as the outcome (online supplementary figures 1 and 2).

### Ideal CVH duration

Each clinical and lifestyle CVH metric was assigned 0 (poor), 1 (intermediate) or 2 (ideal) points to yield a composite CVH score for each examination (table 1). Scores of 0–7, 8–11 or 12–14 points were regarded as having poor, intermediate or ideal CVH, respectively. The number of years lived in ideal CVH was calculated as a sum of duration with CVH score ≥12 between each examination. If a participant had not attended a particular follow-up examination, the ideal duration was calculated based on the most recently attended examination prior to the absent one by linearly regressing the score—referred to as the *regressed model* (online supplementary figure S3). For example, if person B scored 14 (ideal) at the second follow-up, did not attend the third follow-up, and scored 11 (intermediate) at the fourth follow-up (60 months from the second follow-up), he/she would hypothetically maintain ideal CVH for 40 months since the second follow-up, which thereafter, the score deteriorates below the ideal threshold. For all follow-up examinations, there was no partially incomplete CVH measurement.

### Outcomes

CKD was defined as having an estimated glomerular filtration rate (eGFR) <60 mL/min/1.73 m$^2$ or self-reported diagnosis.[17] Urine albumin-to-creatinine ratio (UACR) was defined as the ratio of the urine albumin (mg/dL) to creatinine (g/dL) concentrations. CVD was defined based on a self-reported diagnosis for coronary artery disease, cerebrovascular disease or heart failure. If a participant had >1 different type of event, the first event of each type was counted as an outcome.

### Statistical analyses

Baseline characteristics of the study participants were reported as frequency and percentage or mean and SD then compared across the duration lived in ideal CVH.

The HR and 95% CI associated with each ideal CVH duration category were calculated using Cox proportional hazards models with discrete time intervals. The end of observation was defined as the date of event, last follow-up or 31 December 2016, whichever came first. HRs were adjusted for age, sex, education level, examination site; baseline eGFR and UACR were additionally adjusted with CKD as outcome. The proportional hazards assumption was not violated according to graphical inspection of log-minus-log plot and Schoenfeld residuals. Effect modification by cross-categories of sex and age (ie, male <50 years, female ≥50 years) was assessed using multiplicative interaction terms.

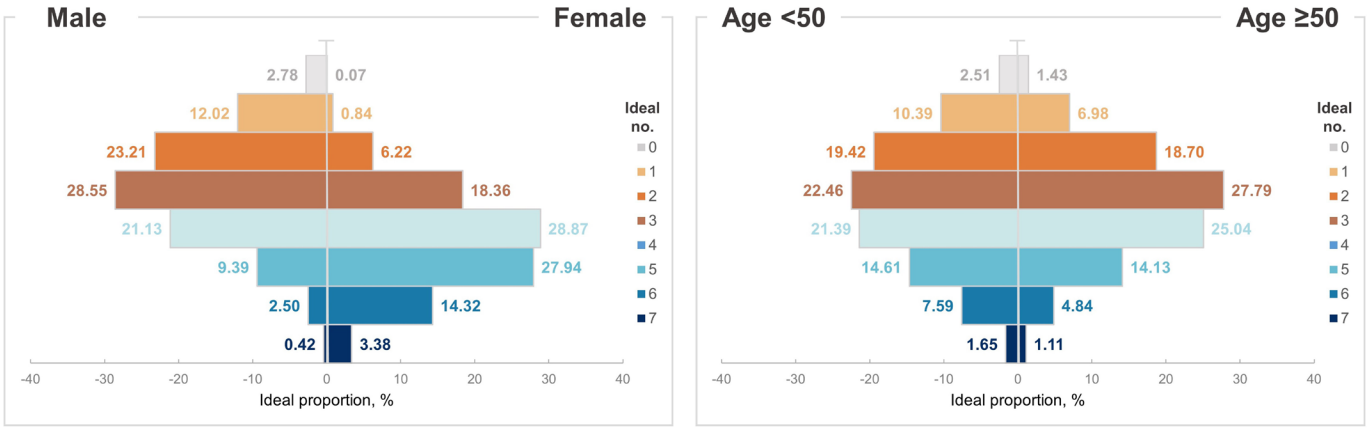
As a secondary analysis, we examined whether different rates at which ideal CVH deteriorates to suboptimal (intermediate or poor) levels are associated with CKD and CVD risks. In reference to participants with persistently suboptimal CVH, we assessed the risk differences across participants with early, incremental or no decline to suboptimal state based on latent class trajectory modelling (online supplemental methods).

Seven sensitivity analyses were performed. First, we examined the association of maintaining individual ideal CVH component for ≥5 years with CKD and CVD alongside their precursors—namely, hypertension, diabetes mellitus and hypercholesterolaemia. Second, we excluded incidence during the first follow-up to account for potential risk carryover. Third, to account for varied follow-up duration among participants, we examined the effects of relative CVH duration on outcomes by dividing the number of years lived in ideal CVH by total follow-up duration. Fourth, we assessed risks assuming no changes in CVH scores for missing examinations, referred to as the *stagnant model*; here, the most recent score is carried over and maintained until the subsequent follow-up attendance. Fifth, due to known J-shaped associations of very low clinical risk factor levels with CVD and all-cause mortality,[18–21] we further excluded participants with (1) body mass index <18.5 kg/m$^2$; (2) diastolic blood pressure <60 mm Hg; (3) low-density lipoprotein cholesterol <25 mg/dL; or (4) fasting glucose <70 mg/dL. Sixth, we examined whether the association persists for eGFR decline by 30% or greater from the baseline level in substitution for CKD. Lastly, we examined whether maintaining ideal or intermediate CVH (score ≥8) is also associated with CKD or CVD.

All statistical tests were two-sided, and statistical significance was set at a p value <0.05. All analyses were performed using R V.4.1.0 (R Foundation for Statistical Computing, Vienna, Austria) and SAS V.9.4 (SAS Institute).

### Patient and public involvement

No participants were involved in design nor execution of the research. Results from the KoGES are publicly available through




*P* value for sex difference <0.0001

*P* value for age difference=0.3587

**Figure 1** Baseline number of ideal cardiovascular health (CVH) components by sex (left) and median age (right). The ideal level of each CVH component includes (1) never-smoking; (2) non-drinking; (3) ≥75 min of vigorous activity or ≥150 min of moderate-to-vigorous activity per week; (4) body mass index <23 kg/m$^2$; (5) untreated systolic blood pressure <120 mm Hg and diastolic blood pressure <80 mm Hg; (6) untreated total cholesterol <200 mg/dL; and (7) untreated fasting glucose <100 mg/dL. P value for sex or age difference in the distributions of ideal number of CVH components were obtained from $\chi^2$ test.

the Korea Disease Control and Prevention Agency website and routinely disseminated in media outlets.

## RESULTS

The study included 8020 participants (median age 50.0 years, 47.9% male), of whom, 7854 without CKD and 7796 without CVD at baseline. Among them, 110 (1.4%) had zero ideal CVH components, followed by 497 (6.2%) with one, 1152 (14.4%) with two, 1864 (23.2%) with three, 2018 (25.2%) with four, 1528 (19.1%) with five, 694 (8.7%) with six and 157 (2.0%) with seven ideal CVH components, respectively (online supplementary table S2). Participants with greater number of ideal CVH components at baseline were distinguishably of female sex (p value for sex difference <0.0001; figure 1, online supplementary tables S2 and S3).

Overall, 7156 (89.2%) participants had less than 5 years of ideal CVH, 525 (6.5%) had 5– <10 years of ideal CVH, and 339 (2.1%) had 10 or greater years of ideal CVH, respectively (table 2). Compared with participants with shorter ideal CVH duration, those who maintained ideal CVH for ≥10 years were more likely to be female, to attain high school degree, non-smokers and non-drinkers and less likely to have metabolic abnormalities.

During a median follow-up of 15.0 (25th–75th percentile, 14.2–15.6; minimum–maximum, 1.6–15.6) years, 1401 CKD events occurred (online supplementary figure S4). CKD incidence largely varied by the ideal number of clinical and lifestyle CVH components. Age- and sex-adjusted CKD incidence rates per 1000 person-years were 30.1 among participants with 0 vs 10.6 with seven ideal CVH components at baseline.

During a median follow-up of 15.1 (25th–75th percentile, 14.3–15.6; minimum–maximum, 1.7–15.6) years, 493 new CVD events occurred (online supplementary figure S5). Likewise, age- and sex-adjusted CVD incidence rates differed from 6.5 among participants with 0–2.7 per 1000 person-years with seven ideal CVH components at baseline.

Figure 2 illustrates disease risks associated with ideal CVH duration. CKD event rates were incrementally lower by the longer duration lived with ideal CVH (less than 5 years, 19.0%; 5– <10 years, 9.5%; ≥10 years, 6.9%). In fully adjusted model, 5– <10 (HR 0.63 (95% CI 0.39 to 0.93)) and ≥10 years (HR

**Table 2** Baseline characteristics by the duration lived in ideal cardiovascular health

| Characteristics | Duration of ideal CVH, n (%) of participants | | |
|---|---|---|---|
| | ≥10 years (n=339) | 5–10 years (n=525) | <5 years (n=7156) |
| Age, years | 48.4±8.1 | 48.6±7.9 | 52.2±8.8 |
| Male sex | 51 (15.0) | 82 (15.6) | 3710 (51.8) |
| Attained high school degree | 192 (56.6) | 268 (51.1) | 3209 (44.8) |
| BMI, kg/m$^2$ | 21.8±2.1 | 22.5±2.2 | 24.9±3.1 |
| Current smoker | 9 (2.7) | 20 (3.8) | 1985 (27.7) |
| Current drinker | 38 (11.2) | 100 (19.1) | 3739 (52.3) |
| MVPA 150+ min/week | 181 (53.4) | 331 (63.1) | 4240 (59.3) |
| Systolic blood pressure, mm Hg | 107.0±13.3 | 109.8±13.5 | 123.2±18.5 |
| Diastolic blood pressure, mm Hg | 70.8±9.1 | 73.0±9.6 | 81.7±11.6 |
| Hypertension | 16 (4.7) | 42 (8.0) | 2676 (37.4) |
| Total cholesterol, mg/dL | 180.0±27.3 | 183.3±29.6 | 201.3±36.5 |
| HDL cholesterol, mg/dL | 53.3±11.6 | 51.9±11.3 | 49.1±11.7 |
| Fasting glucose level, mg/dL | 84.5±8.2 | 86.0±15.2 | 93.1±22.9 |
| Diabetes mellitus | 2 (0.6) | 7 (1.3) | 347 (4.9) |
| eGFR, mL/min/1.73 m$^2$ | 98.7±15.1 | 97.9±15.0 | 92.7±15.3 |
| Chronic kidney disease | 3 (0.9) | 7 (1.3) | 156 (2.2) |
| Cardiovascular disease | 5 (1.5) | 2 (0.4) | 217 (3.0) |
| Coronary artery disease | 2 (0.6) | 1 (0.2) | 125 (1.8) |
| Cerebrovascular disease | 4 (1.2) | 1 (0.2) | 86 (1.2) |
| Heart failure | 0 (0.0) | 0 (0.0) | 18 (0.3) |
| CVH score | 12.0±1.6 | 11.6±1.6 | 8.4±2.3 |
| CVH score category | | | |
| Ideal (12–14) | 234 (69.0) | 330 (62.9) | 573 (8.0) |
| Intermediate (8–11) | 104 (30.7) | 185 (35.2) | 4182 (58.4) |
| Poor (0–7) | 1 (0.3) | 10 (1.9) | 2401 (33.6) |

Values are presented as mean±standard deviation or number (%).
BMI, body mass index; CVD, cardiovascular disease; CVH, cardiovascular health; eGFR, estimated glomerular filtration rate; HDL, high-density lipoprotein; MVPA, moderate-to-vigorous physical activity.

| Outcome | Ideal CVH duration | No. at risk | No. (%) of events | HR (95% CI) | P Trend |
|---|---|---|---|---|---|
| Chronic kidney disease | <5 years | 7,000 | 1,329 (18.99) | 1.00 Reference | 0.0057 |
| | 5 to 10 years | 518 | 49 (9.46) | 0.63 (0.39-0.93) | |
| | ≥10 years | 336 | 23 (6.85) | 0.33 (0.15-0.74) | |
| Cardiovascular disease | <5 years | 6,939 | 466 (6.72) | 1.00 Reference | 0.0087 |
| | 5 to 10 years | 523 | 23 (4.40) | 0.83 (0.54-1.27) | |
| | ≥10 years | 334 | 4 (1.20) | 0.22 (0.08-0.60) | |
| Coronary artery disease | <5 years | 6,939 | 266 (3.83) | 1.00 Reference | 0.0239 |
| | 5 to 10 years | 523 | 7 (1.34) | 0.42 (0.20-0.89) | |
| | ≥10 years | 334 | 2 (0.60) | 0.19 (0.05-0.75) | |
| Cerebrovascular disease | <5 years | 6,939 | 210 (3.03) | 1.00 Reference | 0.0514 |
| | 5 to 10 years | 523 | 16 (3.06) | 1.43 (0.85-2.41) | |
| | ≥10 years | 334 | 2 (0.60) | 0.28 (0.07-1.12) | |
| Heart failure | <5 years | 6,939 | 9 (0.13) | 1.00 Reference | 0.8429 |
| | 5 to 10 years | 523 | 1 (0.19) | 1.24 (0.15-10.29) | |
| | ≥10 years | 334 | 0 (0.0) | N/A | |

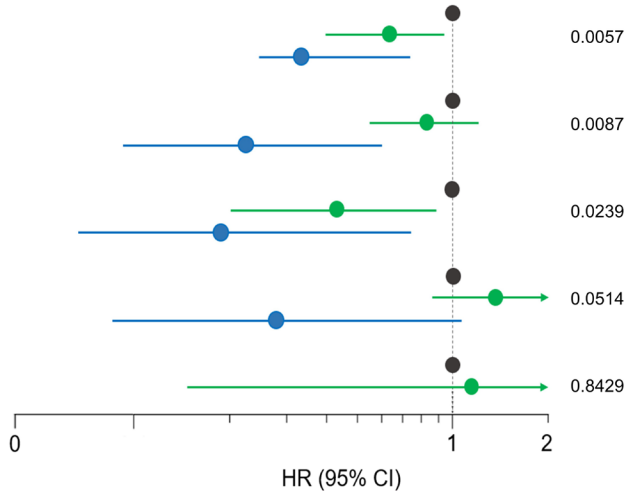



**Figure 2** Association of ideal cardiovascular health (CVH) duration and risk of chronic kidney disease and cardiovascular disease

0.33 (95% CI 0.15 to 0.74)) lived in ideal CVH were associated with lower CKD risk in reference to <5 years of maintenance (p trend, 0.0057).

Similarly, CVD event rates were the highest among participants lived with <5 years of ideal CVH (6.7%), followed by 5– <10 years (4.4%) and ≥10 years (1.2%) groups. In reference to the <5 years group, participants lived with 5– <10 years of ideal CVH had lower CVD risk (HR 0.83 (95% CI 0.54 to 1.27)) yet without statistical significance. However, living in ideal CVH for ≥10 years was associated with significantly lower CVD risk (HR 0.22 (95% CI 0.08 to 0.60)). By CVD subtypes, longer ideal CVH duration was associated with significantly lower risk for coronary artery disease (5– <10 years: HR 0.42 (95% CI 0.20 to 0.89), ≥10 years: HR 0.19 (95% CI 0.05 to 0.75)) and marginally lower risk for cerebrovascular disease (p trend, 0.0514). No significant effect measure modification by sex and age group was observed.

## SECONDARY ANALYSIS

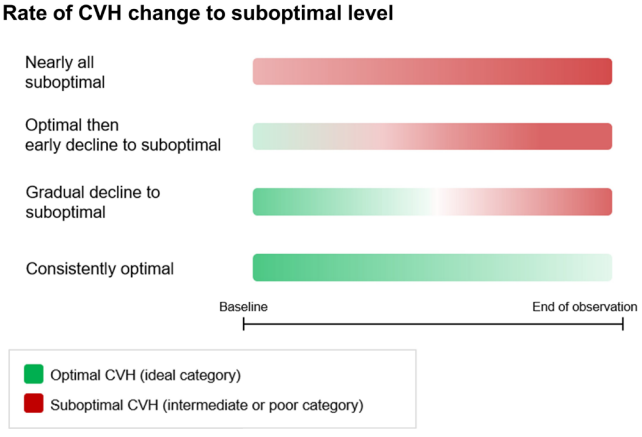
As a proxy to duration, we explored whether different rates at which optimal (ideal) CVH deteriorates to suboptimal (intermediate or poor) CVH are also meaningfully associated with both outcomes (figure 3). Compared with participants who mostly remained in suboptimal CVH, those who gradually declined to suboptimal CVH category had lower risk for CKD (HR 0.69 (95% CI 0.54 to 0.81)) and CVD (HR 0.65 (95% CI 0.51 to 0.79)). The risks were exceptionally lower among participants who consistently maintained optimal CVH.

## SENSITIVITY ANALYSES

We examined the association of maintaining ideal level of individual clinical and lifestyle risk factors for ≥5 years with CKD and CVD, alongside their established precursors (online supplementary table S4). In general, maintaining ideal clinical CVH for ≥5 years was consistently associated with lowered risks for all outcomes in reference to <5 years of maintenance. A notable exception was total cholesterol, which, alone, demonstrated no lowered effect on CKD (HR 0.94 (95% CI 0.79 to 1.13)) nor CVD (HR 1.01 (95% CI 0.84 to 1.22)).

After excluding events from the first follow-up, longer ideal CVH duration maintained negative associations with CKD (p trend, 0.0071) and CVD—specifically coronary artery disease (p trend, 0.0182) (online supplementary table S5). Furthermore, ideal CVH duration remained robustly associated with CKD and composite CVD events regardless of follow-up duration (online supplementary table S6).

Based on the stagnant model (online supplementary figure S6), no significant changes in the associations were observed




| Chronic kidney disease | | | Cardiovascular disease | | |
|---|---|---|---|---|---|
| At risk | Events (%) | HR (95% CI) | At risk | Events (%) | HR (95% CI) |
| 3,772 | 730 (19.35) | 1.00 (Ref) | 3,762 | 284 (7.55) | 1.00 (Ref) |
| 2,000 | 348 (17.40) | 0.89 (0.73-1.09) | 1,977 | 124 (6.27) | 0.84 (0.71-1.03) |
| 2,006 | 320 (15.95) | 0.69 (0.54-0.81) | 1,989 | 83 (4.17) | 0.65 (0.51-0.79) |
| 76 | 3 (3.95) | 0.43 (0.12-0.80) | 68 | 2 (2.94) | 0.38 (0.07-0.85) |

**Figure 3** Association of rate of cardiovascular health (CVH) change and risk of chronic kidney disease and cardiovascular disease.

(online supplementary table S7) despite moderate left-skewing of the CVH scores. We also restricted the analyses to participants within normal or high clinical risk factors range (online supplementary table S8). Notwithstanding blunted risk gradation, no significant changes were observed.

With 30% or greater eGFR decline as the outcome, the results were comparable to those of CKD (online supplementary table S9). Participants maintaining ideal CVH for 5– <10 years (HR 0.87 (95% CI 0.76 to 1.05)) or ≥10 years (HR 0.66 (95% CI 0.49 to 0.88)) had lower risk for adverse renal outcome.

We further expanded the analyses to more lenient definition of favourable CVH. Extending to ideal or intermediate level of CVH diminished the association strengths for all outcomes (online supplementary table S10). In reference to the <5 years group, those maintaining ideal or intermediate CVH for ≥10 years had significantly lower risk for composite (HR 0.61 (95% CI 0.49 to 0.75)) and all subtypes of CVD. However, maintaining ideal or intermediate CVH for 5– <10 years was not significantly associated with CKD nor CVD.

## DISCUSSION

In this study of middle-aged Korean adults, longer duration spent in ideal CVH was associated with incrementally lower CKD and CVD risks over a median follow-up of 15.0 years. Our findings bolster the utility of repeated CVH assessments to be incorporated into clinical guidelines and public health policies in devising long-term cardiometabolic health management strategies.

Our findings are consistent with previous literature. In the Framingham Offspring Study, worsening CVH over 20 years was associated with adverse echocardiographic atherosclerotic measures.[22] Similarly, in a Korean hospital-based cohort of low-risk adults, higher baseline CVH score was negatively associated with coronary artery calcium development and progression.[13] The maintenance of ideal CVH in midlife extends to favourable cardiovascular structure and function in later life. Compared with participants who had undergone ≥0.5 point/decade of CVH score increase, those with >1 point/decade decrease exhibited worse left ventricular structure, arterial function and myocardial stress.[23] The benefits of sustained CVH are also projected to all CVD subtypes, regardless of age, sex, race and comorbidity.[23 24] However, the aforementioned studies had a number of differences compared with the present analysis: (1) the participants were predominantly of non-Hispanic white/black race[22 23]; (2) a considerable proportion already had atherosclerotic lesion[13]; (3) outcomes were assessed in late life[22]; (4) a high proportion of participants had pre-diabetes/diabetes[24]; and (5) a single or very few CVH scores were considered with limited follow-up duration.[13 22] Considering the heterogeneous distributions of each CVH component across sociodemographics,[25] the current study advances the prior work by demonstrating that long-term CVH is associated with CVD and its preceding target organ damage in a low-risk, community-dwelling population.

To consider cumulative CVH, the Framingham Offspring Study team has investigated the association between duration of fair CVH and cardiometabolic outcomes. Among 1445 participants (mean age 60 years, 48% male), each 5-year duration with intermediate or ideal CVH was associated with lowered HRs (95% CIs) for CKD (0.75 (0.63 to 0.89)) and CVD (0.73 (0.63 to 0.85))[26]—analogous to our supplementary analyses of combined ideal and intermediate categories. However, several differences should be noted. First, our study substituted the traditional Life Simple 7's diet score with alcohol drinking, as a nationwide study[27] has reported age-varying rate of excessive alcohol consumption. Importantly, our primary analysis quantified the benefits of strictly ideal CVH duration, as our participants had significantly lower prevalence of hypertension (37% vs 67%) and diabetes mellitus (5% vs 21%) than the Framingham Offspring cohort[26] even in the shortest ideal CVH duration category. Therefore, our results reflect promising cardiovascular outcomes in general population with predominantly low-to-moderate cardiometabolic risk. Regarding methodology, the aforementioned study[26] calculated the duration by multiplying the number of examination cycles with available CVH score with mean interval (4 years) between follow-ups, whereas we summed the exact years between each examination. However, it remains undetermined whether deterioration or improvement in CVH can best be projected assuming linearity.

Nonetheless, our results illustrate how critical comprehensive lifestyle modification and pharmacological interventions in midlife are. Indeed, the absence of risk factors at 50 years of age was associated with very low lifetime CVD risk, longer survival and improved physical, mental and social functioning in older age.[15] Beyond, prolongation of ideal CVH deems essential. Whereas maintaining ideal CVH for ≥5 years was associated with lower CKD risk, a brief maintenance was not meaningful. In light of these findings, public health programmes should aim to deter risk factor manifestation and progression earlier in life.

A major strength of our investigation was repeated assessments of CVH in general population. However, several limitations should be noted. Due to the nature of CVH scoring system, we were unable to pinpoint specific CVH component attributable for varied risks. As a previous study[28] reported age-varying effects of CVD risk factors in both independent and interactive manner, a larger study is needed to adequately assess differential contributions of each component. As an observational study, we were unable to calculate absolute risk reduction from ideal CVH maintenance. Pragmatic trials may adequately yield real-world benefits of sustained CVH. Lastly, our findings may not be generalisable to populations with different age or race structure. Considering the geographic

### Key messages

**What is already known on this subject?**

- Single-occasion cardiovascular health (CVH) index is associated with subclinical atherosclerosis.

**What might this study add?**

- Prolonged duration, but not brief maintenance, of ideal CVH is associated with lowered risks of chronic kidney disease and cardiovascular disease in healthy, middle-age, Korean population.
- Routine CVH assessments and sustained lifestyle and pharmacological interventions in midlife can lower mid-to-late life cardiovascular risk.

**How might this impact on clinical practice?**

- Nationwide public health programmes should widen the opportunity window for early diagnosis across all age spectra.
- Health practitioners should actively cooperate with patients to evaluate their circumstances for lifestyle and treatment modifications, to identify potential barriers, to implement measurable goals and to monitor their progress throughout lifetime.

and racial/ethnic variations in CVH management status, population-specific metrics and cut-offs should be developed and validated.

In summary, our findings suggest that longer maintenance of ideal CVH in midlife is associated with lower CKD and CVD risks in mid-to-late life. Nationwide public health programmes should widen the opportunity window for early diagnosis across all age spectra. In healthcare settings, practitioners should actively cooperate with patients to evaluate their circumstances for lifestyle modifications, to identify potential barriers, to implement measurable goals and to monitor their progress.

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**Contributors** SMJC and HCK conceived and designed the study. SMJC performed statistical analyses. SMJC, JYJ, T-HY, H-YL, Y-HL and HCK interpreted the findings. SMJC drafted the manuscript. SMJC, JYJ, T-HY, H-YL, Y-HL and HCK made critical revision of the manuscript for key intellectual content. HCK takes full responsibility for the content of the manuscript, including data and analysis. All authors approved the final manuscript. HCK is the guarantor.

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**Patient consent for publication** Not applicable.

**Ethics approval** This study involved human participants and was approved by The KoGES Ansung-Ansan, and was administered, reviewed and approved by the Korea Center for Disease Control and Prevention. The present study was approved by the Institutional Review Board of Yonsei University Health System (Y-2020-0007). Participants gave informed consent to participate in the study before taking part.

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**Data availability statement** Data are available upon reasonable request. The KoGES Ansung-Ansan data are available on reasonable request from the Korea Center for Disease Control and Prevention website.



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## REFERENCES

1 Lloyd-Jones DM, Hong Y, Labarthe D, *et al*. Defining and setting national goals for cardiovascular health promotion and disease reduction: the American heart association's strategic impact goal through 2020 and beyond. *Circulation* 2010;121:586–613.
2 Goff DC, Lloyd-Jones DM, Bennett G. ACC/AHA guideline on the assessment of cardiovascular risk: a report of the American College of cardiology/American heart association Task force on practice guidelines. *Circulation* 2013;2014:S49–73.
3 Conroy RM, Pyörälä K, Fitzgerald AP, *et al*. Estimation of ten-year risk of fatal cardiovascular disease in Europe: the score project. *Eur Heart J* 2003;24:987–1003.
4 GBD 2017 Risk Factor Collaborators. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: a systematic analysis for the global burden of disease study 2017. *Lancet* 2018;392:1923–94.
5 Virani SS, Alonso A, Benjamin EJ. Heart disease and stroke statistics—2020 update: a report from the American heart association. *Circ Res* 2020;141:e139–596.
6 Ortega FB, Lavie CJ, Blair SN. Obesity and cardiovascular disease. *Circ Res* 2016;118:1752–70.
7 Lee H, Cho SMJ, Park JH, *et al*. 2017 ACC/AHA blood pressure classification and cardiovascular disease in 15 million adults of age 20-94 years. *J Clin Med* 2019;8:1832.
8 Cannon CP, Braunwald E, McCabe CH, *et al*. Intensive versus moderate lipid lowering with statins after acute coronary syndromes. *N Engl J Med* 2004;350:1495–504.
9 Lawes CMM, Parag V, Bennett DA, *et al*. Blood glucose and risk of cardiovascular disease in the Asia Pacific region. *Diabetes Care* 2004;27:2836–42.
10 Ockene IS, Miller NH. Cigarette smoking, cardiovascular disease, and stroke: a statement for healthcare professionals from the American heart association. American heart association Task force on risk reduction. *Circulation* 1997;96:3243–7.
11 Abramson JL, Williams SA, Krumholz HM, *et al*. Moderate alcohol consumption and risk of heart failure among older persons. *JAMA* 2001;285:1971–7.
12 Jeong S-W, Kim S-H, Kang S-H, *et al*. Mortality reduction with physical activity in patients with and without cardiovascular disease. *Eur Heart J* 2019;40:3547–55.
13 Kim S, Chang Y, Cho J, *et al*. Life's simple 7 cardiovascular health metrics and progression of coronary artery calcium in a low-risk population. *Arterioscler Thromb Vasc Biol* 2019;39:826–33.
14 Fretz A, McEvoy JW, Rebholz CM, *et al*. Relation of lifestyle factors and life's simple 7 score to temporal reduction in troponin levels measured by a high-sensitivity assay (from the Atherosclerosis risk in Communities study). *Am J Cardiol* 2018;121:430–6.
15 Lloyd-Jones DM, Leip EP, Larson MG, *et al*. Prediction of lifetime risk for cardiovascular disease by risk factor burden at 50 years of age. *Circulation* 2006;113:791–8.
16 Kim Y, Han B-G, KoGES group. Cohort profile: the Korean genome and epidemiology study (KoGES) Consortium. *Int J Epidemiol* 2017;46:e20.
17 Kidney disease: improving global outcomes (KDIGO) hepatitis C work group. KDIGO 2018 Clinical Practice Guideline for the Prevention, Diagnosis, Evaluation, and Treatment of Hepatitis C in Chronic Kidney Disease. *Kidney Int Suppl* 2018;8:91–165.
18 Zheng W, McLerran DF, Rolland B, *et al*. Association between body-mass index and risk of death in more than 1 million Asians. *N Engl J Med* 2011;364:719–29.
19 Kang Y-Y, Wang J-G. The J-Curve phenomenon in hypertension. *Pulse* 2016;4:49–60.
20 Furtado RHM, Giugliano RP. What lessons have we learned and what remains to be clarified for PCSK9 inhibitors? A review of Fourier and odyssey outcomes trials. *Cardiol Ther* 2020;9:59–73.
21 Park C, Guallar E, Linton JA, *et al*. Fasting glucose level and the risk of incident atherosclerotic cardiovascular diseases. *Diabetes Care* 2013;36:1988–93.
22 Enserro DM, Vasan RS, Xanthakis V. Twenty-year trends in the American heart association cardiovascular health score and impact on subclinical and clinical cardiovascular disease: the Framingham offspring study. *J Am Heart Assoc* 2018;7:e008741.
23 Shah AM, Claggett B, Folsom AR, *et al*. Ideal cardiovascular health during adult life and cardiovascular structure and function among the elderly. *Circulation* 2015;132:1979–89.
24 Wang T, Lu J, Su Q, *et al*. Ideal cardiovascular health metrics and major cardiovascular events in patients with prediabetes and diabetes. *JAMA Cardiol* 2019;4:874–83.
25 Rana JS, Tabada GH, Solomon MD, *et al*. Accuracy of the Atherosclerotic Cardiovascular Risk Equation in a Large Contemporary, Multiethnic Population. *J Am Coll Cardiol* 2016;67:2118–30.
26 Corlin L, Short MI, Vasan RS, *et al*. Association of the duration of ideal cardiovascular health through adulthood with cardiometabolic outcomes and mortality in the Framingham offspring study. *JAMA Cardiol* 2020;5:549–56.
27 Choe SA, Yoo S, JeKarl J, *et al*. Recent trend and associated factors of harmful alcohol use based on age and gender in Korea. *J Korean Med Sci* 2018;33:e23.
28 Lind L, Sundström J, Ärnlöv J, *et al*. Impact of aging on the strength of cardiovascular risk factors: a longitudinal study over 40 years. *J Am Heart Assoc* 2018;7:e007061.

**Supplemental Methods**

To examine whether different rates of cardiovascular health (CVH) decline are associated with chronic kidney disease and cardiovascular risks, latent class trajectory was modeled using the SAS procedure *PROC TRAJ*.[1] Based on the previous literature,[2] we identified distinct patterns of CVH change based on 1) the Bayesian information criterion; 2) the average posterior predictive probability of group membership after 20 multiple imputations; and 3) modification of number of clusters from 3 to 5 with various combinations of polynomial functions (linear, quadratic, and tertiary). Specifically, trajectories were largely characterized as 1) having consistently suboptimal (intermediate or poor category) CVH; 2) early decline to suboptimal CVH; 3) gradual decline to suboptimal CVH; and 4) consistently optimal (ideal) CVH.

After confirming the satisfaction of proportional hazards assumption, we set the trajectory group membership as an independent variable in multivariate Cox hazards regression model. The final model was adjusted for baseline age, sex, examination site, and education level; we additionally adjusted for baseline estimated glomerular filtration rate and urine albumin-to-creatinine ratio for chronic kidney disease as an outcome. Model calibration was ensured based on the Hosmer-Lemeshow goodness-of-fit statistics.

*References*

1. Jones BL, Nagin D, Roeder K. A SAS procedure based on mixture models for e stimating developmental trajectories. *Sociol Methods Res* 2001;29:374-393.

2. Allen NB, Siddique J, Wilkins J, et al. Blood pressure trajectories in early adulth ood and subclinical atherosclerosis in middle age. *JAMA* 2014;311(5):490-497.

Table S1. Comparison of baseline characteristics between included versus excluded participants

| Characteristic | Included (n=8,020) | Excluded (n=1,098) | *p*-value |
|---|---|---|---|
| Male sex | 3,843 (47.92) | 493 (44.90) | 0.0604 |
| Age, year | 51.83±8.82 | 55.86±8.76 | <0.0001 |
| Attained high school degree | 3,669 (45.75) | 255 (23.22) | <0.0001 |
| Body mass index, kg/m$^2$ | 24.61±3.14 | 24.41±3.18 | 0.0422 |
| Current smoker | 2,014 (25.11) | 275 (27.98) | 0.3616 |
| Current drinker | 3,877 (48.34) | 410 (40.39) | <0.0001 |
| MVPA 150+ min/week | 4,752 (59.25) | 558 (71.81) | <0.0001 |
| Systolic blood pressure, mm Hg | 121.65±18.58 | 126.21±18.33 | <0.0001 |
| Diastolic blood pressure, mm Hg | 80.64±11.74 | 81.19±11.08 | 0.1388 |
| Hypertension | 2,734 (34.09) | 244 (44.77) | <0.0001 |
| Total cholesterol, mg/dL | 199.21±36.20 | 192.08±37.27 | <0.0001 |
| HDL cholesterol, mg/dL | 49.43±11.72 | 49.71±12.19 | 0.4689 |
| Fasting glucose level, mg/dL | 92.30±22.21 | 91.30±19.25 | 0.2119 |
| Diabetes mellitus | 356 (4.44) | 21 (7.42) | 0.0546 |
| eGFR, ml/min/1.73m$^2$ | 93.30±15.35 | 94.34±14.29 | 0.0340 |
| Chronic kidney disease | 166 (2.07) | 25 (2.28) | 0.6470 |
| Cardiovascular disease | 224 (2.79) | 42 (3.83) | 0.0567 |
| Coronary artery disease | 128 (1.60) | 22 (2.01) | 0.3182 |
| Cerebrovascular disease | 91 (1.14) | 15 (1.37) | 0.5010 |
| Heart failure | 18 (0.22) | 5 (0.46) | 0.1522 |

*Values are presented as mean±standard deviation or number (%).

Abbreviations: eGFR, estimated glomerular filtration rate; HDL, high-density lipoprotein; MVPA, moderate-to-vigorous physical activity

Table S2. Baseline characteristics of participants according to the number of ideal cardiovascular health components

| | Number of ideal cardiovascular health components | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Characteristic | 0<br>n=110 | 1<br>n=497 | 2<br>n=1,152 | 3<br>n=1,864 | 4<br>n=2,018 | 5<br>n=1,528 | 6<br>n=694 | 7<br>n=157 |
| Age, years | 50.1±8.4 | 49.7±7.9 | 51.5±8.4 | 52.6±8.9 | 52.9±9.0 | 51.6±8.9 | 50.2±8.9 | 49.3±8.3 |
| Male sex | 107 (97.3) | 462 (93.0) | 892 (77.4) | 1,097 (58.9) | 812 (40.2) | 361 (23.6) | 96 (13.8) | 16 (10.2) |
| Attained high school degree | 83 (75.5) | 336 (67.6) | 618 (53.7) | 874 (46.9) | 779 (38.6) | 603 (39.5) | 303 (43.7) | 73 (46.5) |
| Body mass index, kg/m$^2$ | 26.5±2.5 | 26.2±2.4 | 25.7±2.7 | 25.2±3.0 | 24.6±3.2 | 23.8±3.1 | 22.4±2.6 | 21.1±1.5 |
| Triglyceride, mg/dL | 269.7±194.5 | 219.3±148.9 | 193.0±138.0 | 164.6±112.4 | 138.3±79.3 | 121.5±73.3 | 104.7±63.6 | 94.8±44.6 |
| HDL-cholesterol, mg/dL | 45.8±8.00 | 46.5±9.9 | 47.6±11.4 | 49.2±12.1 | 49.9±11.9 | 50.2±11.8 | 52.0±11.4 | 51.6±10.6 |
| eGFR, ml/min/1.73m$^2$ | 88.1±14.9 | 88.9±14.9 | 90.1±15.1 | 91.7±15.3 | 93.8±15.4 | 96.0±15.2 | 98.1±14.0 | 99.8±14.4 |
| Cigarette smoking status | | | | | | | | |
| Never smoker | 0 (0.0) | 31 (6.2) | 294 (25.5) | 911 (48.9) | 1,389 (68.8) | 1,285 (84.1) | 655 (94.4) | 157 (100.0) |
| Former smoker | 52 (47.3) | 193 (38.8) | 356 (30.9) | 368 (19.7) | 236 (11.7) | 71 (4.7) | 8 (1.2) | 0 (0.0) |
| Current smoker | 58 (52.7) | 273 (54.9) | 502 (43.6) | 585 (31.4) | 393 (19.5) | 172 (11.3) | 31 (4.5) | 0 (0.0) |
| Alcohol drinking status | | | | | | | | |
| Non-drinker | 0 (0.0) | 10 (2.0) | 143 (12.4) | 583 (31.3) | 1,050 (52.0) | 1,096 (71.7) | 609 (87.8) | 157 (100.0) |
| Former drinker | 13 (11.8) | 40 (8.1) | 133 (11.6) | 145 (7.8) | 106 (5.3) | 52 (3.4) | 6 (0.9) | 0 (0.0) |
| Current drinker | 97 (88.2) | 447 (89.9) | 876 (76.0) | 1,136 (60.9) | 862 (42.7) | 380 (24.9) | 79 (11.4) | 0 (0.0) |
| Physical activity | | | | | | | | |
| 75+ min of vigorous or 150+ min of moderate activity | 0 (0.0) | 112 (22.5) | 498 (43.2) | 1,017 (54.6) | 1,333 (66.1) | 1,090 (71.3) | 545 (78.5) | 157 (100.0) |
| More than 0 min but less than the recommendation | 26 (23.6) | 86 (17.3) | 165 (14.3) | 177 (9.5) | 145 (7.2) | 82 (5.4) | 35 (5.0) | 0 (0.0) |
| 0 minutes | 84 (76.4) | 299 (60.2) | 489 (42.5) | 670 (35.9) | 540 (26.8) | 356 (23.3) | 114 (16.4) | 0 (0.0) |
| Body mass index, kg/m$^2$ | | | | | | | | |
| <23 | 0 (0.0) | 16 (3.2) | 139 (12.1) | 379 (20.3) | 602 (29.8) | 665 (43.5) | 498 (71.8) | 157 (100.0) |
| 23-24.9 | 34 (30.9) | 153 (30.8) | 341 (29.6) | 542 (29.1) | 567 (28.1) | 368 (24.1) | 105 (15.1) | 0 (0.0) |
| ≥25 | 76 (69.1) | 328 (66.0) | 672 (58.3) | 943 (50.6) | 849 (42.1) | 495 (32.4) | 91 (13.1) | 0 (0.0) |
| Total cholesterol, mg/dL | | | | | | | | |
| <200 (Untreated) | 0 (0.0) | 51 (10.3) | 292 (25.4) | 802 (43.0) | 1,131 (56.1) | 1,168 (76.4) | 632 (91.1) | 157 (100.0) |
| 200-239 or treated to ideal | 62 (56.4) | 308 (62.0) | 594 (51.6) | 722 (38.7) | 671 (33.3) | 287 (18.8) | 54 (7.8) | 0 (0.0) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ≥240 | 48 (43.6) | 138 (27.8) | 266 (23.1) | 340 (18.2) | 216 (10.7) | 73 (4.8) | 8 (1.2) | 0 (0.0) |
| Blood pressure, mmHg | | | | | | | | |
| <120/80 (Untreated) | 0 (0.0) | 33 (6.6) | 159 (13.8) | 375 (20.1) | 693 (34.3) | 852 (55.8) | 540 (77.8) | 157 (100.0) |
| SBP 120-139 or DBP <90 or treated to ideal | 60 (54.6) | 312 (62.8) | 663 (57.6) | 1,025 (55.0) | 880 (43.6) | 468 (30.6) | 111 (16.0) | 0 (0.0) |
| SBP ≥140 or DBP ≥90 | 50 (45.5) | 152 (30.6) | 330 (28.7) | 464 (24.9) | 445 (22.1) | 208 (13.6) | 43 (6.2) | 0 (0.0) |
| Fasting glucose, mg/dL | | | | | | | | |
| <100 (Untreated) | 0 (0.0) | 244 (49.1) | 779 (67.6) | 1,525 (81.8) | 1,874 (92.9) | 1,484 (97.1) | 685 (98.7) | 157 (100.0) |
| 100-125 or treated to ideal | 77 (70.0) | 184 (37.0) | 270 (23.4) | 253 (13.6) | 104 (5.2) | 33 (2.2) | 4 (0.6) | 0 (0.0) |
| ≥126 | 33 (30.0) | 69 (13.9) | 103 (8.9) | 86 (4.6) | 40 (2.0) | 11 (0.7) | 5 (0.7) | 0 (0.0) |

*Values are presented as mean±standard deviation or number (%).

†Abbreviations: DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; HDL, high-density lipoprotein; SBP, systolic blood pressure

Table S3. Baseline characteristics of study participants by sex

| Characteristic | Male (n=3,843) | Female (n=4,177) |
|---|---|---|
| Age, year | 51.3±8.6 | 52.3±9.0 |
| Attained high school degree | 1,555 (40.5) | 1,381 (33.1) |
| Body mass index, kg/m$^2$ | 24.3±2.9 | 24.9±3.3 |
| Current smoker | 1,856 (48.3) | 158 (3.8) |
| Current drinker | 2,754 (71.7) | 1,123 (26.9) |
| MVPA 150+ min/week | 2,331 (60.7) | 2,421 (58.0) |
| Systolic blood pressure, mmHg | 122.3±17.1 | 121.1±19.9 |
| Diastolic blood pressure, mmHg | 82.3±11.2 | 79.1±12.0 |
| Hypertension | 1,374 (35.8) | 1,360 (32.6) |
| Total cholesterol, mg/dL | 199.3±36.2 | 199.2±36.3 |
| HDL cholesterol, mg/dL | 47.5±11.4 | 51.2±11.8 |
| Fasting blood glucose level, mg/dL | 94.8±24.5 | 90.0±19.6 |
| Diabetes mellitus | 212 (5.5) | 144 (3.5) |
| eGFR, ml/min/1.73m$^2$ | 91.0±14.5 | 95.5±15.8 |
| Chronic kidney disease | 70 (1.8) | 96 (2.3) |
| Cardiovascular disease | 124 (3.2) | 100 (2.4) |
| Coronary artery disease | 74 (1.9) | 54 (1.3) |
| Cerebrovascular disease | 50 (1.3) | 41 (1.0) |
| Heart failure | 9 (0.2) | 9 (0.2) |
| Cardiovascular health score category | | |
| Ideal (12-14) | 164 (4.3) | 973 (23.3) |
| Intermediate (8-11) | 1,870 (48.7) | 2,601 (62.3) |
| Poor (0-7) | 1,809 (47.1) | 603 (14.4) |
| Cardiovascular health score (%) | | |
| 0 points | 1 (0.0) | 1 (0.0) |
| 1 point | 15 (0.4) | 0 (0.0) |
| 2 points | 29 (0.8) | 2 (0.1) |
| 3 points | 93 (2.4) | 9 (0.2) |
| 4 points | 209 (5.4) | 30 (0.7) |
| 5 points | 335 (8.7) | 78 (1.9) |
| 6 points | 485 (12.6) | 184 (4.4) |
| 7 points | 642 (16.1) | 299 (7.2) |
| 8 points | 650 (16.9) | 475 (11.4) |
| 9 points | 579 (15.1) | 641 (15.4) |
| 10 points | 409 (10.6) | 760 (18.2) |
| 11 points | 232 (6.0) | 725 (17.4) |
| 12 points | 113 (2.9) | 544 (13.0) |
| 13 points | 35 (0.9) | 288 (6.9) |
| 14 points | 16 (0.4) | 141 (3.4) |

*Values are presented as mean±standard deviation or number (%).

†Abbreviations: eGFR, estimated glomerular filtration rate; HDL, high-density lipoprotein; MVPA, moderate-to-vigorous physical activity

Table S4. Association of maintaining ideal cardiovascular health components for 5 years or longer with risk of developing hypertension, diabetes mellitus, hypercholesterolemia, chronic kidney disease, or cardiovascular disease on follow-up

| Outcome | No. of Events/No. at Risk (%) | Ideal CVH component | HR (95% CI) | *p*-value |
|---|---|---|---|---|
| [‡]Hypertension | | | | |
| | 2,072/5,286 (39.20) | Cigarette smoking | 1.00 (0.87-1.15) | 0.9889 |
| | | Physical activity | 0.96 (0.88-1.05) | 0.3435 |
| | | Alcohol drinking | 0.96 (0.87-1.07) | 0.4824 |
| | | Body mass index | 0.67 (0.61-0.73) | <0.0001 |
| | | Blood pressure | 0.16 (0.14-0.18) | <0.0001 |
| | | Fasting glucose | 0.87 (0.77-0.97) | 0.0121 |
| | | Total cholesterol | 0.98 (0.89-1.07) | 0.6327 |
| [§]Diabetes mellitus | | | | |
| | 796/7,664 (10.39) | Cigarette smoking | 0.88 (0.71-1.08) | 0.2133 |
| | | Physical activity | 1.00 (0.86-1.15) | 0.9713 |
| | | Alcohol drinking | 1.07 (0.90-1.28) | 0.4326 |
| | | Body mass index | 0.54 (0.46-0.65) | <0.0001 |
| | | Blood pressure | 0.57 (0.48-0.68) | <0.0001 |
| | | Fasting glucose | 0.13 (0.11-0.16) | <0.0001 |
| | | Total cholesterol | 1.04 (0.90-1.20) | 0.6059 |
| [¶]Hypercholesterolemia | | | | |
| | 1,902/6,919 (27.49) | Cigarette smoking | 1.07 (0.92-1.25) | 0.3750 |
| | | Physical activity | 1.05 (0.95-1.15) | 0.3346 |
| | | Alcohol drinking | 1.24 (1.11-1.39) | 0.0001 |
| | | Body mass index | 0.83 (0.75-0.91) | 0.0001 |
| | | Blood pressure | 0.78 (0.71-0.86) | <0.0001 |
| | | Fasting glucose | 0.89 (0.79-0.99) | 0.0455 |
| | | Total cholesterol | 0.28 (0.25-0.31) | <0.0001 |
| [#]Chronic kidney disease | | | | |
| | 1,401/7,854 (17.84) | Cigarette smoking | 1.04 (0.78-1.39) | 0.7995 |
| | | Physical activity | 1.29 (1.07-1.56) | 0.0069 |
| | | Alcohol drinking | 1.12 (0.89-1.42) | 0.3433 |
| | | Body mass index | 0.73 (0.60-0.89) | 0.0021 |
| | | Blood pressure | 0.72 (0.59-0.88) | 0.0016 |
| | | Fasting glucose | 0.73 (0.59-0.90) | 0.0037 |

| | | | | |
|---|---|---|---|---|
| | | Total cholesterol | 0.94 (0.79-1.13) | 0.5304 |
| [**]Cardiovascular disease | 493/7,796 (6.32) | Cigarette smoking | 0.79 (0.60-1.03) | 0.0835 |
| | | Physical activity | 1.02 (0.84-1.22) | 0.8730 |
| | | Alcohol drinking | 1.25 (1.00-1.56) | 0.0490 |
| | | Body mass index | 0.66 (0.54-0.80) | <0.0001 |
| | | Blood pressure | 0.59 (0.48-0.72) | <0.0001 |
| | | Fasting glucose | 0.70 (0.57-0.86) | 0.0007 |
| | | Total cholesterol | 1.01 (0.84-1.22) | 0.9218 |

[*]The HRs are in reference to participants with less than 5 years of ideal CVH components.

[†]All models are adjusted for age, sex, education level, and examination site.

[‡]Additionally adjusted for baseline SBP and DBP

[§]Additionally adjusted for baseline fasting glucose

[¶]Additionally adjusted for baseline total cholesterol

[#]Additionally adjusted for baseline eGFR and UACR

[**]First cardiovascular disease event: coronary artery disease, cerebrovascular disease, or heart failure

[††]Abbreviations: CI, confidence interval; CKD, chronic kidney disease; CVH, cardiovascular health; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; HR, hazard ratio; SBP, systolic blood pressure; UACR, urine albumin-to-creatinine ratio

Table S5. Association of maintaining ideal cardiovascular health with risk of developing chronic kidney disease or cardiovascular disease on follow-up, excluding incidence during the first follow-up wave

| Outcome | Ideal CVH Duration | No. of Events/No. at Risk (%) | HR (95% CI) | *P* trend |
|---|---|---|---|---|
| [†]Chronic kidney disease | <5 years | 1,255/7,000 (17.93) | 1.00 Reference | |
| | 5 to 10 years | 47/518 (9.07) | 0.67 (0.41-0.98) | 0.0071 |
| | ≥10 years | 21/336 (6.25) | 0.29 (0.12-0.71) | |
| [‡]Cardiovascular disease | <5 years | 404/6,939 (5.82) | 1.00 Reference | |
| | 5 to 10 years | 20/523 (3.82) | 0.85 (0.54-1.35) | 0.0245 |
| | ≥10 years | 4/334 (1.20) | 0.26 (0.10-0.70) | |
| Coronary artery disease | <5 years | 229/7,031 (3.26) | 1.00 Reference | |
| | 5 to 10 years | 6/524 (1.15) | 0.44 (0.19-0.99) | 0.0182 |
| | ≥10 years | 2/337 (0.59) | 0.23 (0.06-0.92) | |
| Cerebrovascular disease | <5 years | 193/7,070 (2.73) | 1.00 Reference | |
| | 5 to 10 years | 14/524 (2.67) | 1.41 (0.81-2.45) | 0.2302 |
| | ≥10 years | 2/335 (0.60) | 0.31 (0.08-1.25) | |
| Heart failure | <5 years | 8/6,939 (0.12) | 1.00 Reference | |
| | 5 to 10 years | 1/523 (0.19) | 1.32 (0.16-11.04) | 0.8010 |
| | ≥10 years | 0/334 (0.0) | N/A | |

[*]All models adjusted for age, sex, education level, and examination site.

[†]Additionally adjusted for baseline estimated glomerular filtration rate and urine albumin-to-creatinine ratio

[‡]First cardiovascular disease event: coronary artery disease, cerebrovascular disease, or heart failure

[§]Abbreviations: CI, confidence interval; CVH, cardiovascular health; HR, hazard ratio

Table S6. Association of relative ideal cardiovascular health duration with risk of developing chronic kidney disease or cardiovascular disease on follow-up

| Outcome | *Relative Ideal CVH Duration | No. of Events/No. at Risk (%) | HR (95% CI) | *P* trend |
|---|---|---|---|---|
| ‡Chronic kidney disease | <33.33% | 1,329/7,000 (18.99) | 1.00 Reference | |
| | 33.34% to 66.67% | 46/490 (9.39) | 0.68 (0.42-1.11) | 0.0045 |
| | ≥66.67% | 26/364 (7.14) | 0.30 (0.13-0.66) | |
| §Cardiovascular disease | <33.33% | 466/6,939 (6.72) | 1.00 Reference | |
| | 33.34% to 66.67% | 22/494 (4.45) | 0.83 (0.54-1.27) | 0.0092 |
| | ≥66.67% | 5/363 (1.38) | 0.26 (0.11-0.64) | |
| Coronary artery disease | <33.33% | 266/6,939 (3.83) | 1.00 Reference | |
| | 33.34% to 66.67% | 7/494 (1.42) | 0.44 (0.20-0.93) | 0.0056 |
| | ≥66.67% | 2/363 (0.55) | 0.18 (0.04-0.71) | |
| Cerebrovascular disease | <33.33% | 210/6,939 (3.03) | 1.00 Reference | |
| | 33.34% to 66.67% | 15/494 (3.04) | 1.38 (0.81-2.36) | 0.1259 |
| | ≥66.67% | 3/363 (0.83) | 0.39 (0.13-1.24) | |
| Heart failure | <33.33% | 9/6,939 (0.13) | 1.00 Reference | |
| | 33.34% to 66.67% | 1/494 (0.20) | 1.31 (0.16-10.82) | 0.9693 |
| | ≥66.67% | 0/363 (0.0) | N/A | |

*Relative CVH duration is calculated as years live in ideal CVH divided by total follow-up years.

†All models adjusted for age, sex, education level, and examination site.

‡Additionally adjusted for baseline estimated glomerular filtration rate and urine albumin-to-creatinine ratio.

§First cardiovascular disease event: coronary artery disease, cerebrovascular disease, or heart failure

Abbreviations: CI, confidence interval; CVH, cardiovascular health; HR, hazard ratio

Table S7. Association of maintaining ideal cardiovascular health with risk of developing chronic kidney disease or cardiovascular disease on follow-up based on the stagnant model

| Outcome | Ideal CVH Duration | No. of Events/No. at Risk (%) | HR (95% CI) | *P* trend |
|---|---|---|---|---|
| | <5 years | 1,298/6,819 (19.04) | 1.00 Reference | |
| [†]Chronic kidney disease | 5 to 10 years | 70/651 (10.75) | 0.68 (0.42-0.87) | 0.0027 |
| | ≥10 years | 33/384 (4.82) | 0.24 (0.07-0.69) | |
| | <5 years | 460/6,830 (6.73) | 1.00 Reference | |
| [‡]Cardiovascular disease | 5 to 10 years | 28/595 (4.71) | 0.85 (0.57-1.22) | 0.0108 |
| | ≥10 years | 5/371 (1.35) | 0.26 (0.09-0.58) | |
| | <5 years | 260/6,830 (3.82) | 1.00 Reference | |
| Coronary artery disease | 5 to 10 years | 11/595 (1.85) | 0.48 (0.23-0.88) | 0.0402 |
| | ≥10 years | 3/371 (0.81) | 0.23 (0.08-0.73) | |
| | <5 years | 210/6,830 (3.07) | 1.00 Reference | |
| Cerebrovascular disease | 5 to 10 years | 17/595 (2.86) | 0.96 (0.38-1.81) | 0.0387 |
| | ≥10 years | 2/371 (0.54) | 0.24 (0.01-1.03) | |
| | <5 years | 9/6,830 (0.13) | 1.00 Reference | |
| Heart failure | 5 to 10 years | 1/595 (0.17) | 1.04 (0.07-9.63) | 0.9657 |
| | ≥10 years | 0/371 (0.0) | N/A | |

[*]All models adjusted for age, sex, education level, and examination site.

[†]Additionally adjusted for baseline estimated glomerular filtration rate and urine albumin-to-creatinine ratio

[‡]First cardiovascular disease event: coronary artery disease, cerebrovascular disease, or heart failure

[§]Abbreviations: CI, confidence interval; CVH, cardiovascular health; HR, hazard ratio

Table S8. Association of maintaining ideal cardiovascular health with risk of developing chronic kidney disease or cardiovascular disease on follow-up, excluding participants with very low clinical risk factor levels

| Outcome | Ideal CVH Duration | No. of Events/No. at Risk (%) | HR (95% CI) | *P* trend |
|---|---|---|---|---|
| | <5 years | 1,246/6,565 (18.98) | 1.00 Reference | |
| †Chronic kidney disease | 5 to 10 years | 42/476 (8.82) | 0.61 (0.34-0.96) | 0.0068 |
| | ≥10 years | 20/296 (6.76) | 0.36 (0.16-0.80) | |
| | <5 years | 437/6,503 (6.72) | 1.00 Reference | |
| ‡Cardiovascular disease | 5 to 10 years | 20/480 (4.17) | 0.81 (0.51-1.24) | 0.0106 |
| | ≥10 years | 4/294 (1.36) | 0.25 (0.09-0.64) | |
| | <5 years | 253/6,503 (3.89) | 1.00 Reference | |
| Coronary artery disease | 5 to 10 years | 5/480 (1.04) | 0.32 (0.13-0.78) | 0.0042 |
| | ≥10 years | 2/294 (0.68) | 0.21 (0.05-0.84) | |
| | <5 years | 191/6,503 (2.94) | 1.00 Reference | |
| Cerebrovascular disease | 5 to 10 years | 15/480 (3.13) | 1.51 (0.88-2.59) | 0.0812 |
| | ≥10 years | 2/294 (0.68) | 0.32 (0.08-1.30) | |
| | <5 years | 8/6,503 (0.12) | 1.00 Reference | |
| Heart failure | 5 to 10 years | 0/480 (0.0) | N/A | N/A |
| | ≥10 years | 0/294 (0.0) | N/A | |

*All models adjusted for age, sex, education level, and examination site.

†Additionally adjusted for baseline estimated glomerular filtration rate and urine albumin-to-creatinine ratio

‡First cardiovascular disease event: coronary artery disease, cerebrovascular disease, or heart failure

§Very low clinical CVH risk factor levels include body mass index <18.5 kg/m$^2$, low-density lipoprotein cholesterol <25 mg/dL, diastolic blood pressure <60 mm-Hg, or fasting glucose <70 mg/dL.

¶Abbreviations: CI, confidence interval; CVH, cardiovascular health; HR, hazard ratio

Table S9. Association of maintaining ideal cardiovascular health with risk of estimated glomerular filtration rate decline by 30% or greater on follow-up

| Outcome | Ideal CVH Duration | No. of Events/No. at Risk (%) | HR (95% CI) | *P* trend |
|---|---|---|---|---|
| eGFR decline | <5 years | 2,564/7,000 (36.63) | 1.00 Reference | 0.0478 |
| | ≥5 years | 365/854 (42.74) | 0.85 (0.72-0.98) | |
| | <10 years | 2,796/7,504 (37.26) | 1.00 Reference | 0.0049 |
| | ≥10 years | 133/350 (38.00) | 0.66 (0.50-0.88) | |
| | <5 years | 2,564/7,000 (36.63) | 1.00 Reference | |
| | 5 to 10 years | 239/518 (46.14) | 0.87 (0.76-1.05) | 0.0170 |
| | ≥10 years | 126/336 (37.50) | 0.66 (0.49-0.88) | |

*The models adjusted for age, sex, education level, examination site, and baseline eGFR and UACR.

†Abbreviations: CI, confidence interval; CVH, cardiovascular health; eGFR, estimated glomerular filtration rate; HR, hazard ratio; UACR, urine albumin-to-creatinine-ratio

Table S10. Association of maintaining ideal or intermediate cardiovascular health with risk of developing chronic kidney disease or cardiovascular disease on follow-up

| Outcome | Ideal CVH Duration | No. of Events/No. at Risk (%) | HR (95% CI) | *P* trend |
|---|---|---|---|---|
| | <5 years | 413/2,285 (18.07) | 1.00 Reference | |
| [†]Chronic kidney disease | 5 to 10 years | 319/1,348 (23.66) | 1.16 (0.91-1.48) | 0.0001 |
| | ≥10 years | 669/4,221 (15.85) | 0.73 (0.58-0.91) | |
| | <5 years | 181/2,265 (7.99) | 1.00 Reference | |
| [‡]Cardiovascular disease | 5 to 10 years | 114/1,344 (8.48) | 1.06 (0.83-1.34) | <0.0001 |
| | ≥10 years | 198/4,187 (4.73) | 0.61 (0.49-0.75) | |
| | <5 years | 68/2,323 (2.93) | 1.00 Reference | |
| Coronary artery disease | 5 to 10 years | 47/1,369 (3.43) | 0.89 (0.78-1.07) | 0.0082 |
| | ≥10 years | 104/4,265 (2.44) | 0.74 (0.61-0.97) | |
| | <5 years | 99/2,321 (4.27) | 1.00 Reference | |
| Cerebrovascular disease | 5 to 10 years | 48/1,363 (3.52) | 0.83 (0.59-1.18) | 0.0702 |
| | ≥10 years | 88/4,245 (2.07) | 0.53 (0.39-0.72) | |
| | <5 years | 6/2,340 (0.26) | 1.00 Reference | |
| Heart failure | 5 to 10 years | 4/1,378 (0.29) | 0.82 (0.22-3.01) | 0.0264 |
| | ≥10 years | 2/4,248 (0.05) | 0.11 (0.02-0.58) | |

[*]All models adjusted for age, sex, education level, and examination site.

[†]Additionally adjusted for baseline estimated glomerular filtration rate and urine albumin-to-creatinine ratio

[‡]First cardiovascular disease event: coronary artery disease, cerebrovascular disease, or heart failure

[§]Abbreviations: CI, confidence interval; CVH, cardiovascular health; HR, hazard ratio

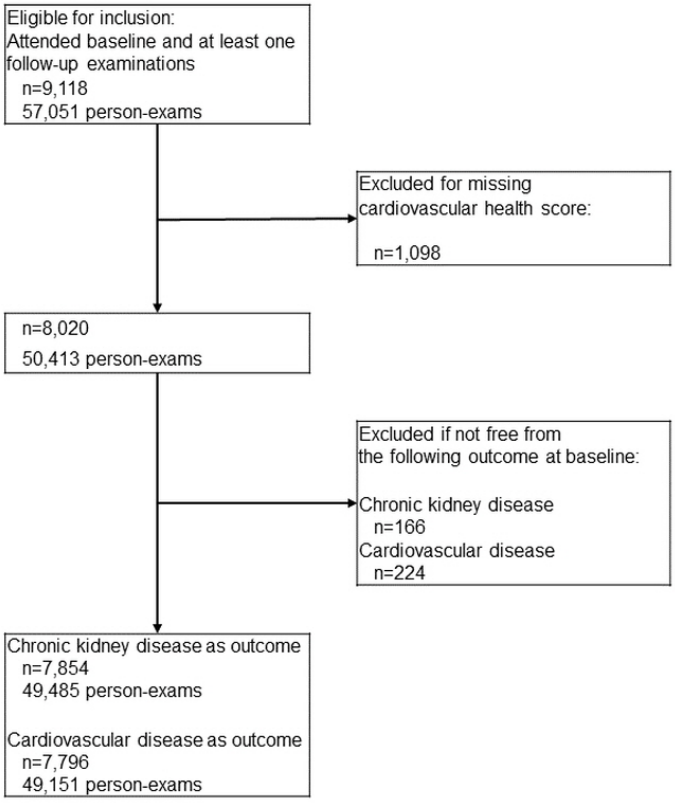


Figure S1. Derivation of study population

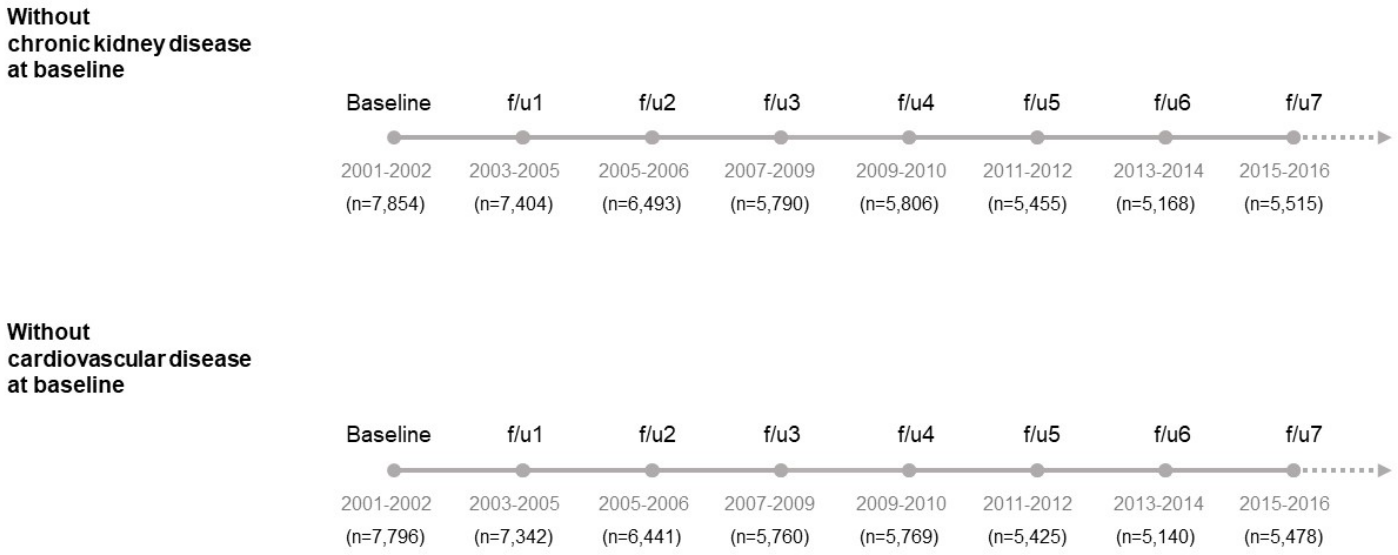


Figure S2. Attendance at baseline and follow-up examinations among participants without (top) chronic kidney disease or (bottom) cardiovascular disease at baseline.

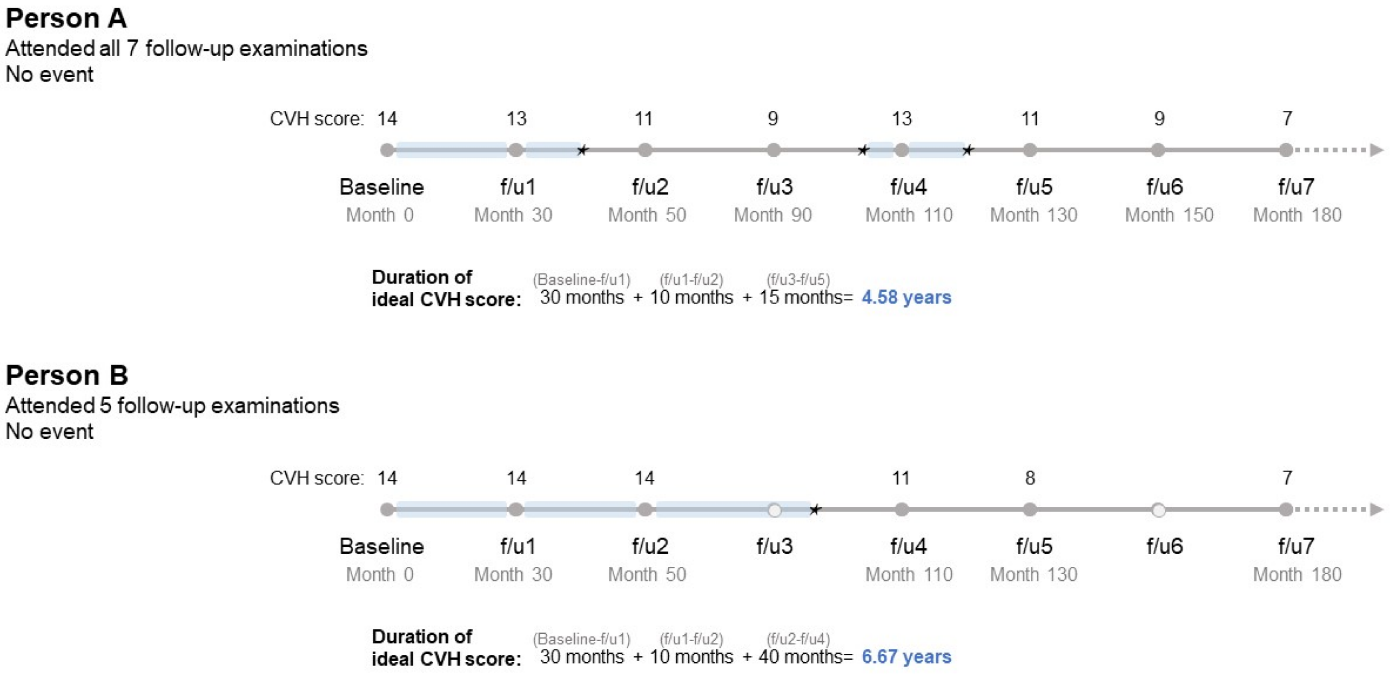


Figure S3. Example of ideal cardiovascular health duration calculation based on the *regressed* model
Blue line highlights the duration lived with ideal CVH.
Abbreviation: CVH, cardiovascular health

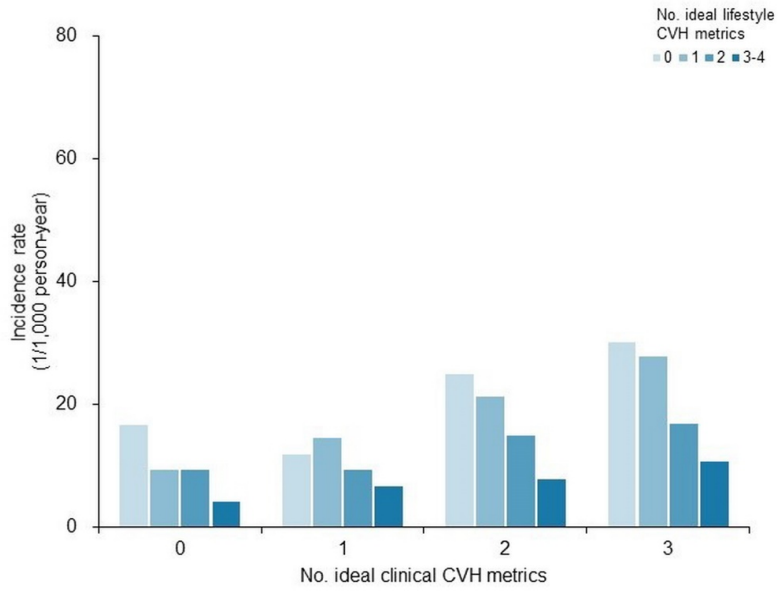


Figure S4. Age- and sex-adjusted chronic kidney disease incidence by the number of ideal cardiovascular health components
Abbreviation: CVH, cardiovascular health

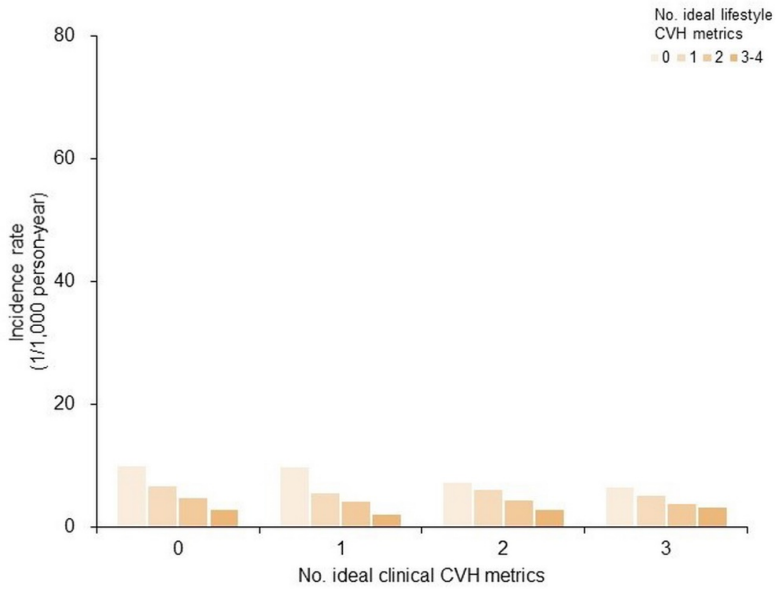


Figure S5. Age- and sex-adjusted cardiovascular disease incidence by the number of ideal cardiovascular health components
Abbreviation: CVH, cardiovascular health

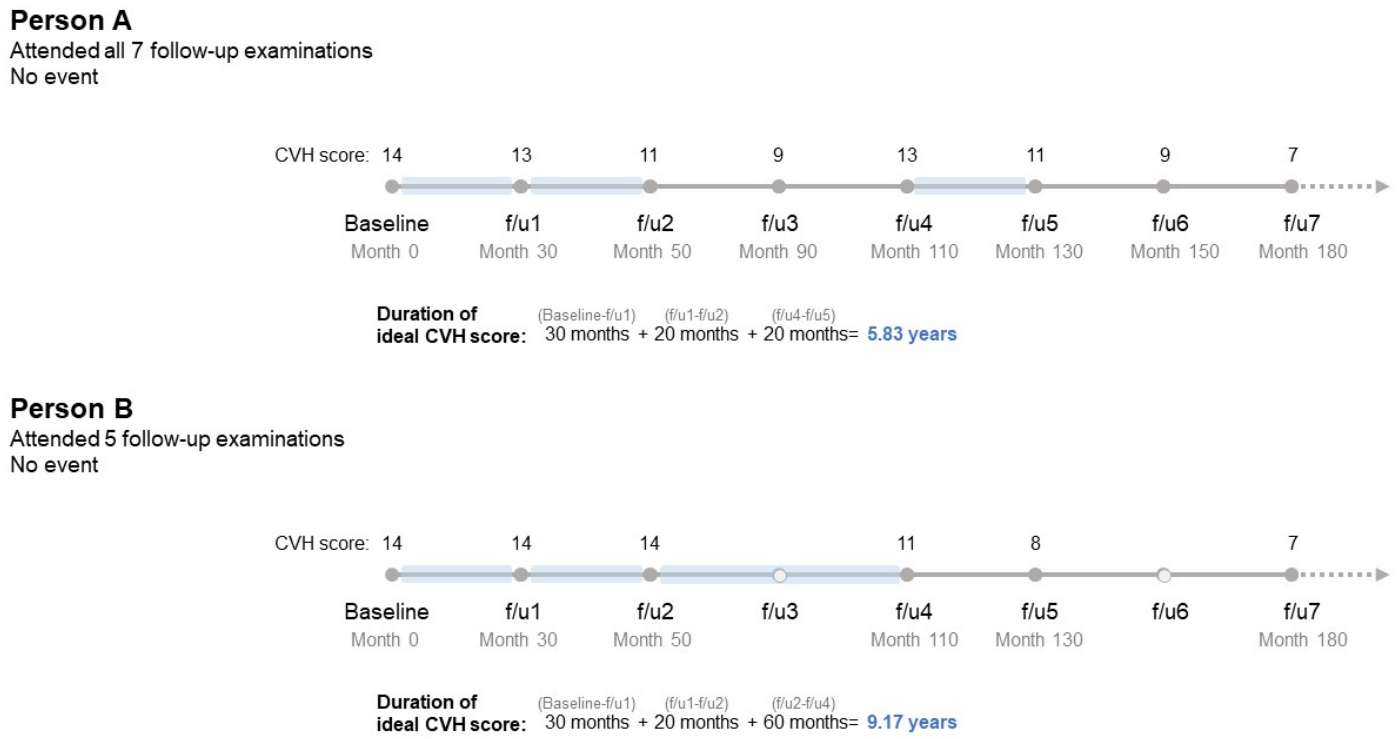


Figure S6. Example of ideal cardiovascular health duration calculation based on the *stagnant* model
Blue line highlights the duration lived with ideal CVH.
Abbreviation: CVH, cardiovascular health