Coronary calcification is a risk factor for cardiovascular morbidity and mortality in the general population, independent of traditional cardiovascular risk factors. Similarly, calcification of other vascular beds, including the thoracic and abdominal aorta, and the breast artery, has been independently associated with cardiovascular morbidity and mortality. The susceptibility to vascular calcification and the strength of the relationship with outcomes may vary among vascular beds. In addition, different types of vascular calcification can...
An in vitro blood test has been developed that quantifies calcification propensity in serum. Under physiological circumstances, the precipitation of supersaturated calcium and phosphate in serum is prevented by the formation of primary calciprotein particles (CPP), which may subsequently transform to more harmful, secondary CPP. The transformation time from primary to secondary CPP, known as the serum T50, reflects the endogenous defense capacity against calcium-phosphate precipitation. In patients prone to vascular calcification, such as patients with CKD, circulating CPP has been associated with aortic stiffness and vascular calcification. Moreover, a shorter serum T50 (ie, accelerated precipitation time) has been associated with all-cause mortality in patients with CKD and hemodialysis, and with all-cause and cardiovascular mortality in renal transplant recipients, independent of established cardiovascular risk factors. However, recently, it was shown in patients with CKD (stage 2–4), that the association of T50 with cardiovascular and all-cause mortality was not independent of renal function.

To extend these findings, we broadened the research field of calcification propensity to the general population. We investigated the relationship between serum T50, established cardiovascular risk factors and other relevant clinical and biochemical parameters, and whether serum T50 is independently associated with the risk of cardiovascular mortality and all-cause mortality in a large, general population-based cohort.

### METHODS

The data that support the findings of this study are available from the corresponding author upon reasonable request. The article is written in compliance with the STROBE guidelines for observational studies.

### Study Population

The PREVEND study (Prevention of Renal and Vascular End-Stage Disease) is a prospective cohort that was designed to study the association of microalbuminuria with renal and cardiovascular disease in the general population. Details of the PREVEND study have been published previously. In brief, between 1997 and 1998, inhabitants of the city of Groningen, The Netherlands, aged 28 to 75 years (n=85,421), received a questionnaire and a vial to collect an early morning urinary sample. Of these subjects, 40,856 responded (47.8%) and sent back their vial to a central laboratory where urinary albumin and creatinine concentrations were measured. Two subgroups were derived from this population: 9966 individuals with a urinary albumin concentration ≥10 mg/L and 30,890 subjects with urinary albumin concentration <10 mg/L. After the exclusion of subjects with insulin-dependent diabetes mellitus and pregnant women, 7768 subjects with a urinary albumin concentration ≥10 mg/L were invited to participate (n=6000 enrolled) and a randomly selected control group with a urinary albumin concentration <10 mg/L was invited (n=2592 enrolled). These 8592 individuals form the PREVEND cohort and were further investigated in an outpatient clinic. The PREVEND study has been approved by the medical ethics committee of the University Medical Center Groningen and was performed in accordance with the declaration of Helsinki. All participants provided written informed consent.

For the measurement of serum T50 in this cohort, serum samples were available from the second examination round, which took place between April 2001 and November 2003. This resulted in data from 6231 participants for the current analysis.

### Measurements and Definitions

The procedures at each examination in the PREVEND study have been described in detail previously. In brief, each examination included 2 visits to an outpatient clinic separated by 3 weeks. For the baseline survey, participants completed
Clinical End Points

The primary outcome of our longitudinal analyses was cardiovascular mortality, whereas the secondary outcome of our study was all-cause mortality. We studied incident fatal or nonfatal cardiovascular events as an exploratory outcome. Information on hospitalization for cardiovascular morbidity was obtained from PRISMANT, the Dutch national registry of hospital discharge diagnoses. Clinical event data were coded according to the International Classification of Diseases, Ninth Revision (ICD-9) and the classification of health interventions. Incident coronary artery disease was defined as fatal or nonfatal acute myocardial infarction (ICD-9 code 410), acute and subacute ischemic heart disease (code 411), coronary artery bypass grafting (code 414), or percutaneous transluminal coronary angioplasty. Stroke events were defined as subarachnoid hemorrhage (code 430), intracerebral hemorrhage (code 431), other intracranial hemorrhage (code 432), or occlusion or stenosis of the precerebral (code 433) or cerebral (code 434) arteries. Peripheral artery disease was defined as vascular interventions such as percutaneous transluminal angioplasty or bypass grafting of aorta and peripheral vessels. From the time of recruitment, the vital status of the participants was checked through the municipal register. The cause of death was obtained by linking the number of the death certificate to the primary cause of death as coded by a physician from the Central Bureau of Statistics in The Netherlands. The survival time was defined as the period from the date of serum collection of the participant until the date of first cardiovascular event, date of death, or end of follow-up.

Statistical Analyses

Continuous variables with a normal distribution are expressed as mean with SD. Variables with a skewed distribution are shown as median (interquartile range) and were normalized using natural logarithmic transformation before use in parametric tests. P trend over the quintiles of serum T50 (based on the median T50 values for each quintile) was calculated by linear regression analysis for continuous variables or χ2 linear-by-linear association for categorical data.

For the screening of the PREVEND study, subjects with an elevated albuminuria were oversampled to acquire sufficient subjects with microalbuminuria. To overcome the effect of oversampling of subjects with elevated albuminuria, all models took the sampling design into account by specifying stratum-specific baseline hazard functions. Owing to this statistical weighing method, our conclusions may also be generalized to subjects with normal levels of albuminuria.

Our study cohort was used to examine the association of T50 with traditional cardiovascular risk factors, renal function, and other relevant clinical and biochemical parameters. Main determinants of serum T50 were evaluated using a backwards linear regression model in which variables were included that were significantly associated with T50 upon univariable linear regression. In longitudinal primary analyses, the association of T50 with cardiovascular mortality was investigated using Cox proportional hazard models. Model 1 is a basic model adjusted for age and sex. In model 2, we further adjusted for cardiovascular risk factors (smoking, systolic blood pressure, use of antihypertensive medication, plasma glucose, use of glucose-lowering medication, total cholesterol, use of lipid-lowering medication, history of cardiovascular events, body mass index [BMI], and hsCRP). In model 3, we additionally adjusted for alcohol consumption and eGFR, representing the determinants of serum T50 (derived from the backwards linear regression model) without a known direct (in vitro) accelerating (eg, phosphate) or delaying (eg, magnesium) effect on T50. Using the same Cox regression models, we conducted secondary analysis to investigate the association of T50 with all-cause mortality.

To investigate the value of serum T50 over plasma phosphate as a risk marker for (cardiovascular) mortality, the same models were used replacing T50 with phosphate. In additional exploratory...
analyses, we studied the association of decreasing serum $T_{50}$ with incident fatal or nonfatal cardiovascular events using the Cox regression models described above (except for adjustment for history of cardiovascular events). For these analyses, subjects with a history of the studied cardiovascular event outcome (eg, incident cardiovascular events, coronary artery disease, stroke, heart failure, and peripheral artery disease) were excluded beforehand.

To retain the number of events in adjusted Cox models, missing data in covariables (for details see Table I in the Data Supplement) were handled by multiple (n=5) imputations\(^31,32\) using the linear regression method in SPSS.

The ability of the models to distinguish those with an event from those without, was evaluated with Harrell C index. Harrell C index is analogous to the area under the receiver operating characteristic curve, for which larger values indicate better discrimination. We examined potential nonlinear relationships by fitting restricted cubic spline transformations with 3 knots on a Cox model adjusted for age and sex and comparing them with linear splines. We explored possible effect modification by age, sex, BMI, eGFR, diabetes mellitus, plasma magnesium, and plasma phosphate for the association between $T_{50}$ and cardiovascular and all-cause mortality by using multiplicative interaction terms (where applicable with continuous data), followed by stratified Cox regression analysis based on median values.

Statistical analyses were performed using SPSS version 23.0 for Windows (IBM Corporation, Chicago, IL) and STATA Statistical Software: Release 14 (StataCorp, College Station, TX); Figures were made using GraphPad Prism 7.02 (GraphPad Software, San Diego, CA) and R version 3.5.1 (Vienna, Austria; http://cran.r-project.org/).

RESULTS

Subjects
The mean age of participants was 53.5±12.0 years, 49.9% were male, and mean serum $T_{50}$ was 329±58 minutes. The prevalence of diabetes mellitus was 2.7%, 33.2% had hypertension, 18.5% were obese (BMI $\geq 30$ kg/m$^2$), 30.3% had hypercholesterolemia, and 28.2% were current smokers. Mean eGFR was 92.2±17.1 mL/min per 1.73 m$^2$, and 4.3% of the participants had an eGFR $<$60 mL/min per 1.73 m$^2$. Baseline characteristics of the 6231 participants, according to quintiles of $T_{50}$, are presented in Table 1. Subjects with a shorter $T_{50}$ (ie, higher calcification propensity) were more likely to be female, to consume more alcohol and to smoke (all $P<0.001$). The mean difference in serum $T_{50}$ between men and women was $\approx$20 minutes (339±58 and 320±56 minutes, respectively).

During follow-up for a median of 8.3 (7.8–8.9) years, 364 patients died (5.8%), of whom 95 (26.1%) from a cardiovascular cause.

Determinants of Serum $T_{50}$
Multivariable linear regression analysis (Table 2) showed that plasma phosphate, age, and plasma magnesium were the strongest determinants of serum $T_{50}$. Higher phosphate concentrations and older age were associated with a shorter $T_{50}$ whereas higher magnesium concentrations were associated with a longer $T_{50}$ (ie, lower calcification propensity). In addition, eGFR and alcohol intake were inversely associated with $T_{50}$ (ie, increased calcification propensity with higher eGFR and more alcohol consumption). Other determinants of serum $T_{50}$ in this population were albumin, smoking, calcium, cholesterol, glucose, parathyroid hormone, and systolic blood pressure (see Table 2 for directions of effects). The total multivariable model had an overall $R^2$ of 0.281.

$T_{50}$ and Cardiovascular Mortality
In a basic Cox regression model adjusted for age and sex, a shorter serum $T_{50}$ was associated with an increased risk of cardiovascular mortality (model 1, hazard ratio [HR; 95% CI], 1.24 [1.07–1.38], $P=0.007$; Table 3). This relationship is depicted as a linear spline curve in Figure 1A. Serum $T_{50}$ was associated with cardiovascular mortality independent of other cardiovascular risk factors (model 2), and independent of other possible confounders (model 3, fully adjusted HR, 1.22 [1.04–1.36], $P=0.021$).

For BMI, plasma magnesium, and diabetes mellitus significant effect modification was found in the association between $T_{50}$ and cardiovascular mortality ($P_{interaction} <0.1$). Stratified analyses indicated a more pronounced relationship between serum $T_{50}$ and the risk of cardiovascular mortality in subjects with diabetes mellitus (HR, 1.54 [1.15–1.76], $P=0.013$). In addition, the associations were mainly present for subjects with a higher BMI ($\geq 26.1$ kg/m$^2$) or lower plasma magnesium ($<0.82$ mmol/L; Figure 2).

$T_{50}$ and All-Cause Mortality
Multivariable Cox regression analysis also revealed that serum $T_{50}$ was associated with all-cause mortality in a basic model adjusted for age and sex (model 1, HR, 1.12 [1.03–1.21], $P=0.014$), depicted as a spline curve in Figure 1B. The association did not remain significant after adjustment for several cardiovascular risk factors and other potential confounders (fully adjusted HR [model 3], 1.10 [0.99–1.19], $P=0.064$).

Significant effect modification by diabetes mellitus was observed in the association between $T_{50}$ and all-cause mortality ($P_{interaction} <0.1$). Stratified analyses indicated that the increased risk for all-cause mortality per 60 minutes decrease in $T_{50}$ was most pronounced in participants with diabetes mellitus (HR, 1.43 [1.14–1.62], $P=0.007$; Figure I in the Data Supplement).

Exploratory Analyses–Phosphate and (Cardiovascular) Mortality
The value of serum $T_{50}$ over plasma phosphate as a risk marker for (cardiovascular) mortality was investigated
### Table 1. Baseline Characteristics of the Cohort Per Quintiles of Serum T50

| T50 (min) | Quintile 1  | Quintile 2  | Quintile 3  | Quintile 4  | Quintile 5  | P for Trend |
|-----------|-------------|-------------|-------------|-------------|-------------|-------------|
|           | N=1245; <284 | N=1243; 284–315 | N=1244; 315–344 | N=1249; 344–378 | N=1250; >378 |            |
| Demographics |             |             |             |             |             |            |
| Male sex, n (%) | 476 (38.2) | 574 (46.2) | 601 (48.3) | 667 (53.4) | 793 (63.4) | <0.001      |
| Age, y       | 54.0±11.7   | 53.5±11.7   | 54.2±12.0   | 52.7±12.0   | 53.1±12.7   | 0.024       |
| Current smoking | 459 (37.3) | 360 (29.1) | 322 (26.2) | 314 (25.5) | 283 (23.0) | <0.001      |
| Alcohol consumption |             |             |             |             |             | <0.001      |
| No, almost never | 265 (21.5) | 302 (24.5) | 308 (25.0) | 332 (26.8) | 334 (27.0) |             |
| 1–4 drinks/mo | 191 (15.5) | 198 (16.0) | 223 (18.1) | 214 (17.3) | 239 (19.3) |             |
| 2–7 drinks/wk | 351 (28.4) | 391 (31.7) | 399 (32.3) | 391 (31.6) | 418 (33.8) |             |
| >3 drinks/d | 80 (6.5) | 49 (4.0) | 49 (4.0) | 51 (4.1) | 33 (2.7) |             |
| History of CV events | 75 (6.0) | 86 (6.9) | 97 (7.8) | 74 (5.9) | 78 (6.2) | 0.861       |
| Body composition |             |             |             |             |             |            |
| BMI, kg/m² | 26.0±4.2 | 26.5±4.4 | 27.1±4.4 | 26.8±4.2 | 26.8±4.2 | <0.001      |
| Waist/hip, ratio | 0.88±0.09 | 0.90±0.09 | 0.90±0.08 | 0.90±0.08 | 0.92±0.08 | <0.001      |
| Blood pressure |             |             |             |             |             |            |
| Systolic BP, mm Hg | 123.2±18.9 | 125.2±18.8 | 126.2±18.3 | 126.9±18.6 | 129.1±18.9 | <0.001      |
| Diastolic BP, mm Hg | 72.4±9.3 | 73.1±8.9 | 73.2±8.9 | 73.7±9.2 | 74.5±9.3 | <0.001      |
| Renal function |             |             |             |             |             |            |
| eGFR, mL/min per 1.73 m² | 93.3±17.3 | 92.8±16.8 | 91.2±17.1 | 92.7±16.7 | 90.9±17.5 | 0.002       |
| Albuminuria, mg/24 h | 8.7 (6.0–15.4) | 9.0 (6.2–15.6) | 8.4 (6.0–15.6) | 8.7 (6.1–16.5) | 9.0 (6.2–16.5) | 0.186       |
| ACR, mg/mmol | 0.79 (0.54–1.36) | 0.77 (0.54–1.37) | 0.72 (0.50–1.37) | 0.71 (0.50–1.36) | 0.72 (0.48–1.37) | 0.064       |
| Other urinary parameter |             |             |             |             |             |            |
| Sodium excretion, mmol/24 h | 139±52 | 144±54 | 147±54 | 146±56 | 148±57 | <0.001      |
| Glucose |             |             |             |             |             |            |
| Type 2 diabetes mellitus, n (%) | 29 (2.3) | 34 (2.7) | 39 (3.1) | 31 (2.5) | 34 (2.7) | 0.681       |
| Glucose, mmol/L | 4.7 (4.4–5.2) | 4.7 (4.4–5.3) | 4.8 (4.4–5.3) | 4.8 (4.5–5.3) | 4.8 (4.5–5.3) | <0.001      |
| Lipids |             |             |             |             |             |            |
| Total cholesterol, mmol/L | 5.4±1.05 | 5.40±1.06 | 5.44±1.01 | 5.44±1.06 | 5.49±1.06 | 0.024       |
| HDL cholesterol, mmol/L | 1.32±0.34 | 1.27±0.30 | 1.24±0.31 | 1.23±0.30 | 1.23±0.31 | <0.001      |
| Triglycerides, mmol/L | 0.99 (0.73–1.40) | 1.07 (0.77–1.53) | 1.13 (0.83–1.65) | 1.15 (0.83–1.65) | 1.24 (0.88–1.76) | <0.001      |
| Other plasma parameters |             |             |             |             |             |            |
| Hemoglobin, mmol/L | 8.3±0.8 | 8.4±0.7 | 8.5±0.7 | 8.6±0.7 | 8.7±0.8 | <0.001      |
| Calcium (corrected), mmol/L | 2.23±0.08 | 2.23±0.07 | 2.23±0.07 | 2.23±0.08 | 2.24±0.07 | 0.021       |
| Phosphatate, mmol/L | 1.11±0.15 | 1.04±0.15 | 0.99±0.15 | 0.95±0.14 | 0.90±0.14 | <0.001      |
| Magnesium, mmol/L | 0.81±0.06 | 0.82±0.05 | 0.82±0.05 | 0.83±0.05 | 0.84±0.05 | <0.001      |
| PTH, pmol/L | 5.0±1.85 | 5.03±1.45 | 5.10±1.73 | 5.17±1.62 | 5.30±1.71 | <0.001      |
| Albumin, g/L | 43.4±2.5 | 43.5±2.6 | 43.5±2.5 | 43.9±2.7 | 44.3±2.9 | <0.001      |
| hsCRP, mg/L | 1.18 (0.56–2.73) | 1.37 (0.61–3.07) | 1.35 (0.63–3.19) | 1.40 (0.63–3.09) | 1.40 (0.65–2.96) | 0.069       |

**Medication use**

|                      | Aspirin | Vitamin K antagonist | Antihypertensive drug use | Diuretics | β-blocker | ACE inhibitors/ARBs | Lipid-lowering drug use |
|----------------------|---------|----------------------|---------------------------|-----------|-----------|---------------------|------------------------|
|                      | 28 (2.3) | 35 (2.9)             | 238 (19.1)                | 63 (5.3)  | 112 (9.4) | 108 (9.8)           | 105 (8.4)              |
|                      | 31 (2.6) | 22 (1.8)             | 260 (20.9)                | 70 (5.8)  | 126 (10.6)| 98 (8.1)            | 113 (9.1)              |
|                      | 37 (3.0) | 24 (2.0)             | 276 (22.2)                | 71 (6.0)  | 131 (11.1)| 114 (9.4)           | 137 (11.0)             |
|                      | 36 (2.9) | 16 (1.3)             | 259 (20.7)                | 71 (6.0)  | 116 (9.7) | 100 (8.2)           | 114 (9.1)              |
|                      | 33 (2.7) | 19 (1.6)             | 279 (22.3)                | 97 (8.2)  | 124 (10.5)| 106 (8.8)           | 113 (9.0)              |
|                      | 0.415    | 0.011                | 0.112                     | 0.006     | 0.555     | 0.753               | 0.626                  |

(Continued)
with the same Cox regression models. Circulating phosphate was not associated with cardiovascular mortality nor with all-cause mortality (Table II in the Data Supplement).

Exploratory Analyses—$T_{50}$ and Cardiovascular Events

Cox regression models exploring the possible association of serum $T_{50}$ with incident cardiovascular events, coronary artery disease, stroke, heart failure, or peripheral artery disease are shown in Table III in the Data Supplement. No significant associations were observed with the incidence of specific cardiovascular events.

DISCUSSION

In this prospective cohort study, we addressed the association between serum $T_{50}$ and the risk of cardiovascular mortality and all-cause mortality in the general population.

**DISCUSSION**

In this prospective cohort study, we addressed the association between serum $T_{50}$ and the risk of cardiovascular mortality and all-cause mortality in the general population.

Table 1. Continued

| $T_{50}$ (min) | Quintile 1 N=1245; <284 | Quintile 2 N=1243; 284–315 | Quintile 3 N=1244; 315–344 | Quintile 4 N=1249; 344–378 | Quintile 5 N=1250; >378 | $P$ for Trend |
|---------------|--------------------------|-----------------------------|-----------------------------|-----------------------------|--------------------------|----------------|
| Statines      | 83 (7.0)                 | 94 (7.9)                    | 114 (9.6)                   | 91 (7.6)                    | 88 (7.5)                 | 0.733          |
| Glucose-lowering drug use | 20 (1.6) | 26 (2.1) | 25 (2.0) | 19 (1.5) | 13 (1.0) | 0.151 |

ACE indicates angiotensin-converting enzyme; ACR, albumin creatinine ratio; ARBs, angiotensin receptor blockers; BMI, body mass index; BP, blood pressure; CV, cardiovascular; eGFR, estimated glomerular filtration rate; HDL, high-density lipoprotein; hsCRP, high-sensitivity C-reactive protein; IQR, interquartile range; and PTH, parathyroid hormone.

*Values are mean±SD if normally distributed, median (IQR) if non-normally distributed, or number (%) for categorical variables. $P$ value was calculated by linear regression analysis (after natural logarithmic transformation where applicable) for continuous variables or $\chi^2$ linear-by-linear association for categorical data.

The primary finding is that a shorter serum $T_{50}$, reflecting higher calcification propensity, is associated with a higher risk of cardiovascular mortality. This association was independent of established cardiovascular risk factors, and more pronounced in certain subgroups, such as participants with diabetes mellitus, overweight or low plasma magnesium. There was no association with all-cause mortality after multivariable adjustment.

The determination of calcification propensity, reflected by the serum $T_{50}$, is an increasingly used risk prediction tool in medicine, especially in the field of nephrology. When serum of individual subjects is challenged with supersaturated calcium and phosphate solutions, spontaneous formation of (additional) primary CPP, which contain amorphous calcium phosphate, is triggered. These nano-sized particles then undergo, at time point $T_{50}$, which is specific for individual serum samples, spontaneous conversion to more harmful crystalline calcium phosphate-containing secondary CPP. Thereby, calcification propensity, as measured by the $T_{50}$ test, reflects the functional integrity of a relevant protective physiological system, which so far has clinically not been...
taken into consideration. This system is thought to consist of calcification promoters and inhibitors, where an imbalance (eg, due to disease conditions such as kidney failure) of this dynamic system would lead to increased calcifications.14,15

From the multivariable regression analysis, phosphate appeared as the strongest determinant of $T_{50}$ showing an inverse association with serum $T_{50}$, as expected due to its prominent role in CPP formation. In a study in people with moderate CKD, higher serum phosphate concentrations, although still within the normal range, were previously associated with a greater prevalence of vascular calcification.33 Magnesium was also a strong determinant of serum $T_{50}$, with higher plasma magnesium concentrations being associated with a longer $T_{50}$ (eg, decreased calcification propensity), which is in line with results from the Framingham Heart Study, where magnesium intake was inversely associated with coronary artery calcification.34 This could imply that magnesium acts as an inhibitor of calcification, as observed in in vitro studies, where phosphate-induced calcification of vascular smooth muscle cells is prevented by magnesium, by interfering with secondary CPP crystal formation.35,36 Confirmatory ex vivo experiments in human serum demonstrated that the addition of 0.2 mmol/L Mg$^{2+}$ increased $T_{50}$ from both healthy controls and patients with CKD by ≈40 to 50 minutes.36 In addition, similar improvements of calcification propensity by magnesium was shown in randomized controlled intervention studies in CKD and dialysis patients.27,28 Multivariable regression analysis further indicated that age and alcohol use were independently associated with serum $T_{50}$. This latter observation can at least partly be reconciled with the established risk of cardiovascular events related to alcohol intake,39 although alcohol intake has not been consistently linked with vascular calcification.40,41 Together, these findings suggest that serum $T_{50}$ and the accompanying increased risks would be modifiable, for instance by changes in diet, but also by targeted therapeutic interventions aimed at, for example, magnesium and phosphate. It should, however, be noted that the variables remaining in the model (Table 2) only explain ≈28% of the variation in $T_{50}$.

The association between serum $T_{50}$ and the increased risk for cardiovascular mortality in the current population is in agreement with previous studies in renal transplant recipients18,19 but was so far not shown in the general population. If such an association would be confirmed in other general population-based cohorts, serum $T_{50}$ may prove useful as an independent cardiovascular risk marker in the general population. Nevertheless, serum $T_{50}$ may have a higher predictive value in subgroups that are at a higher risk of developing medial calcifications or cardiovascular disease. In line with this, we observed more pronounced associations between serum $T_{50}$ and cardiovascular mortality risk in subjects with diabetes mellitus, despite the small number of patients with diabetes mellitus in this cohort. Similarly, there was an interaction with BMI and plasma magnesium, showing more pronounced associations in subjects with a higher BMI and lower plasma magnesium, both characteristics that are also present in subjects with type 2 diabetes mellitus.42 Recently, in a study with type 1 diabetes mellitus patients serum $T_{50}$ was associated with indices of increased mineral stress, but not with the development of long-term macrovascular complications, possibly due to the small sample size.43 Future studies may clarify the role of $T_{50}$ as a marker of cardiovascular risk in persons with diabetes mellitus.

The association between serum $T_{50}$ and all-cause mortality was weaker and lost significance after multivariable adjustment. All-cause mortality includes, next to cardiovascular-related deaths, a substantial number of malignancy-related deaths ($n=185$), showing (as expected) no relation to serum $T_{50}$ (data not shown). In addition, given the associations with cardiovascular mortality, we expected to find relationships between serum $T_{50}$ and incident cardiovascular events in exploratory analyses, but these were not found in the present cohort. This may suggest that $T_{50}$ is linked with more severe cardiovascular events, leading to mortality.

It may be questioned whether the association between $T_{50}$ and cardiovascular mortality is not mainly driven by phosphate concentrations. Besides studies with CKD patients, another study in the general...
population found that fasting serum phosphate is associated with mortality, and phosphate is a strong determinant of \( T_{50} \). In an additional exploratory analysis, we, therefore, assessed whether phosphate is also associated with cardiovascular mortality and all-cause mortality, but these associations were absent in our cohort. This emphasizes that the \( T_{50} \) test gives additional, clinically relevant information over the measurement of phosphate concentrations.

In contrast to primary CPP, secondary CPP can induce calcification of vascular smooth muscle cells in vitro. Furthermore, exposure of macrophages or vascular smooth muscle cells to secondary CPP induces a strong proinflammatory response and oxidative stress. This inflammatory response was found to further enhance the calcification process. Therefore, secondary CPP may contribute to the formation of calcium-phosphate precipitation and inflammation of soft tissue, including the arterial wall. If substantiated in future studies, these proposed mechanisms may causally link the result of the \( T_{50} \) test with cardiovascular mortality in the general population.

To our knowledge, this is the first study to investigate the relationship between serum calcification propensity and outcomes in the general population. Other strengths of our study include the large sample size, the long duration of follow-up, the well-phenotyped cohort, allowing adjustment for relevant potential confounders, and the validated way in which causes of death were determined. A limitation is that serum \( T_{50} \) was measured only at a single visit; therefore, we could not take changes in calcification propensity over time into account.

**Figure 2. Forest plot of subanalyses for cardiovascular mortality.**

Stratification was based on median values for age (< or > 52.3 y), body mass index (BMI; < or > 26.1 kg/m²), estimated glomerular filtration rate (eGFR; < or > 93.9 mL/min per 1.73 m²), plasma magnesium (< or > 0.82 mmol/L), and plasma phosphate (< or > 1.00 mmol/L).
into account. However, the availability of a single measurement may lead to underestimation, rather than overestimation, of the true association between \(T_{50}\) and outcomes. Finally, as with any observational study, residual confounding could, in part, explain the association between serum \(T_{50}\) and the risk of cardiovascular mortality, despite the multivariable adjustment.

In conclusion, we found that a shorter serum \(T_{50}\), reflecting an increased calcification propensity, is associated with a higher risk of cardiovascular mortality in a large prospective general population-based cohort. Serum \(T_{50}\) may be considered a novel independent, and potentially modifiable, risk marker for cardiovascular mortality.

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**Affiliations**

From the Division of Nephrology (C.E., C.A.T.-V.K., R.T.G., S.J.L.B., M.H.V.), and Division of Endocrinology (P.R.V.D.), Department of Internal Medicine and Division of Pathology, Department of Pathology and Medical Biology (A.-R.S.F., J.-L.H., H.v.G.), University of Groningen, University Medical Center Groningen, The Netherlands; Department of Nephrology and Amsterdam Cardiovascular Sciences, Amsterdam University Medical Centers, Amsterdam, The Netherlands (E.A.V., M.G.V.); Department of Clinical Research, University Hospital Bern (Inselspital), Switzerland (M.B., P.A.); Department of Cardiovascular Medicine, University of Lausanne Medical School, Switzerland (P.A.); Calciscion AG, Nidau, Switzerland (A.P.); and Department of Physiology and Pathophysiology, Johannes Kepler University Linz, Austria (A.P.).

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**Disclosures**

A. Pasch holds stock in Calciscion, is an inventor of the \(T_{50}\) test, the founder, and employee of Calciscion AG, which commercializes the \(T_{50}\) test. The other authors report no conflicts.

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