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Circulating soluble receptor for advanced glycation end product: Cross-sectional associations with cardiac markers and subclinical vascular disease in older men with and without diabetes

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Background and aims: The soluble receptor for advanced glycation end products (sRAGE) has been implicated in diabetic vascular complications. We have examined the association between sRAGE and cardiac markers [NT-proBNP and cardiac troponin T (cTnT)] and subclinical vascular markers in older men with and without diabetes.

Methods: We performed a cross-sectional study of 1159 men aged 71–92 years with no history of cardiovascular disease (myocardial infarction, stroke, heart failure, coronary artery bypass graft operation or angioplasty). Prevalent diabetes included men with a doctor diagnosis of diabetes, men with fasting glucose ≥7 mmol/l or HbA1c ≥6.5% (N = 180). Subclinical vascular measurements included carotid intima media thickness (cIMT), arterial stiffness [pulse wave velocity (PWV)], central aortic blood pressure and arterial wave reflections [central augmentation pressure (AP) and augmentation index (AIx)].

Results: sRAGE was strongly and positively associated with renal dysfunction in men with and without diabetes. sRAGE was significantly and positively associated with NT-proBNP (but not cTnT) and AP and AIx in both groups of men after adjustment for CVD risk and metabolic risk markers, renal function and inflammation. However, no association was seen between sRAGE and central aortic blood pressure, cIMT or arterial stiffness as determined by PWV in either group.

Conclusions: Higher plasma sRAGE was associated with increased NT-proBNP and markers of arterial wave reflections in men both with and without diabetes. Increased sRAGE may contribute to or be a marker of worsening cardiac dysfunction or HF. Further studies with cardiac imaging data are required to confirm this.

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1. Introduction

Advanced glycation end products (AGEs) are bioactive molecules found in high amounts in the western diet, which have been implicated in the pathogenesis of atherosclerosis and heart failure (HF), particularly in patients with diabetes [1–4]. Numerous studies highlight the interaction between AGEs with their receptor (RAGE), which is expressed in the vasculature, kidney and inflammatory cells, as a potential contributor to increased oxidative stress and inflammation, vascular endothelial dysfunction and arterial stiffening [1,2]. Enhanced accumulation of AGEs is not just restricted to diabetes but also occurs with natural aging [5]. AGEs may also contribute to the development of vascular disease in non-diabetic people through their pro-oxidant properties [5–7].

The soluble receptor for advanced glycation end products (sRAGE) is the isoform of RAGE found in serum and is formed by proteolytic cleavage of RAGE [1]. sRAGE appears to act as a decoy for capturing circulating AGEs, preventing them from binding to the...
cell surface receptor and protecting them from the pro-
inflammatory effect of RAGE signalling [1]. While infusion of
AGEs is thought to result in upregulation of cell-bound RAGE
expression in cardiac tissue, administration of recombinant sRAGE
has been shown to inhibit the development and progression of
atherosclerosis in animal models [1]. However, the role of sRAGE in
cardiovascular disease is still contentious. Circulating sRAGE is
strongly associated with increased circulating levels of AGEs in both
people with diabetes and without diabetes, and is shown to reflect
tissue RAGE expression [8]. Data predominantly from participants
in clinical trials have shown sRAGE to be associated with the
development of CVD complications and mortality in patients with
type-1 and type-2 diabetes [9–12]. It is suggested that sRAGE,
which is easily measured in plasma and serum, could be used to
monitor diabetic vascular disease risk as well as to evaluate the
effect of potential intervention with a view to modulating sRAGE
[13]. However, other studies, largely in people without diabetes,
have shown sRAGE to be inversely associated with CVD [14–17],
and less is known about the clinical significance of sRAGE in the
general aging population. Non-invasive vascular markers and
central haemodynamic measurements (including aortic PWV,
central aortic blood pressure and arterial wave reflection) are
important markers of early arterial or vascular damage and provide
potential proxy indicators of CVD risk [18–22]. To address the
controversy regarding the possible role of sRAGE in CVD, we have
investigated the association between circulating sRAGE and early
markers of vascular disease including arterial stiffness [pulse wave
velocity (PWV)], central aortic blood pressure, arterial wave reflections [central augmentation pressure (AP), augmentation index
(ABI)] and intima-media thickness (IMT), as well as biomarkers of
subclinical myocardial injury and stress [cardiac troponin T (cTnT)
and N-terminal pro B-type natriuretic peptide (NT-proBNP)],
separately in those with and without diabetes. We hypothesised
that sRAGE would be associated with myocardial damage/
dysfunction and subclinical vascular disease before the develop-
ment of overt cardiac disease and that these associations may
depend on the individual’s diabetic status.

2. Patients and methods

The British Regional Heart Study is a prospective study, which
recruited a socioeconomically and geographically representative
cohort of 7735 men from 24 British towns between 1978 and 1980.
In 2010–2012, all surviving men (n = 3137), aged between 71 and
92 years, were sent a postal questionnaire and invited for a 30th
year re-examination. 2137 (68%) men completed the postal ques-
tionnaire and 1722 (55%) men attended the re-examination [23].
Ethical approval has been obtained from all relevant local research
ethics committees. Blood samples were collected after fasting for
a minimum of 6 h and were stored at −70 °C. The men were asked
whether a doctor had ever told them that they had myocardial
infarction (heart attack, coronary thrombosis), stroke, heart failure
or diabetes and to bring their medication to the examination ses-
tion. They were also asked if they had been told by their doctor if
they had narrowing or hardening of the leg arteries (including
claudication) and whether they had ever had a coronary artery
bypass graft operation (CABG) or angioplasty (percutaneous coro-
nary intervention).

2.1. Cardiovascular risk factors

Anthropometric measurements including body weight and
height were carried out. Body mass index (BMI) was calculated as
weight/(height)² (kg/m²). Details of measurements and classifica-
tion methods for smoking status, alcohol intake and physical
activity have been described [24]. The use of antihypertensive
medication was based on self-reported medication history and
review of codes from the British National Formulary (BNF). Blood
pressure was measured using an Omron blood pressure recorder
twice in succession in the right arm, with the subject seated and the
arm supported, and the mean of the two blood pressure recordings
was used. Plasma glucose was measured by a glucose oxidase
method using a Falc or 600 automated analyser. HbA1c was
measured in whole blood using high performance liquid chroma-
tography. Serum insulin was measured using an ELISA assay, which
does not cross-react with proinsulin. Glucose and insulin concen-
trations were adjusted for the effects of fasting duration and time of
day [25]. Predicted glomerular filtration rate (eGFR) (measure of
renal function) was estimated from serum creatinine using the
equation eGFR = 186 × (Creatinine/88.4)^−1.154 × (Age)−0.203 [26]. C-
reactive protein (CRP) was assayed by ultra-sensitive nephelometry
(Dade Behring, Milton Keynes, UK). Plasma levels of IL-6 were
measured with ELISA (R&D Systems, Oxford, UK). Prevalent dia-
betes included men with a doctor-diagnosed diabetes and men
with fasting blood glucose ≥7 mmol/l or men with HbA1c ≥6.5.

2.2. NT-proBNP and cardiac troponin T

NT-proBNP and cTnT were measured in plasma samples on an
automated clinically validated immunoassay analyser (e411, Roche
Diagnostics, Burgess Hill, United Kingdom) using the manufac-
turers’ calibrators and quality control reagents [27]. The lower limit
of sensitivity was 5 pg/ml for NT-proBNP and 3 pg/ml for cTnT. Low
control coefficient of variation (CV) was 6.7% and high control CV
was 4.9%.

2.3. Plasma sRAGE

Plasma sRAGE was measured in samples stored at −80 °C until
assay, using a commercially available ELISA (R&D Systems, Oxon,
UK). The control intra-assay coefficient of variation (CV) was 2.7%,
and inter-assay CV was 9.3%.

2.4. Non-invasive cardiovascular markers

Measurements were measured by two vascular technicians in
series. Left and right carotid arteries were images using a Z.One
Ultra ultrasound system (Zonare Medical Systems, Mountain View,
CA) with a 5–10-mHz linear probe. A cross sectional sweep from
the base of the common carotid artery to the jaw bone and longi-
tudinal images of the common carotid artery approximately 1 cm
proximal to the carotid bifurcation were recorded. Peak systolic
and end-diastolic common carotid artery diameter and carotid intima
media thickness (cIMT) (the distance between the leading edge of
the intima and the media-adventitia interface) were measured
using the Carotid Analyser software (Medical Imaging Applications,
Iowa City, IA). From the longitudinal images, a region of interest
(5–10 mm) was selected in a plaque free area, at least 1 cm from the
bifurcation. cIMT was measured from three end-diastolic images on
each side and a mean of these measures was calculated. Maximum
and minimum carotid artery diameter was assessed from three
consecutive waveforms and mean distension was calculated. The
distensibility coefficient was then calculated using the following
formula, as described by Dijk et al.: distensibility coefficient
(DC) = [(2 × mean distension/baseline diameter)/mean pulse
pressure (kPa)]*1000 [28]. There was good agreement between the
vascular technicians in ultrasound-based measurements. With re-
gard to the inter- and intra-observer reproducibility, the coefficient
of variation (CV) for cIMT (n = 108) was 7.1% and 5.1% respectively.
The corresponding inter and intra-observer reproducibility CV for
distension (n = 109) was 9.2% and 11.9%, respectively.

The Vicorder (Skidmore Medical, Bristol UK) was used to assess brachial artery waveforms and carotid to femoral pulse wave velocity (PWV). Brachial artery waveforms were recorded with the participant seated with a Hokanson SC10 cuff positioned around the middle of the right upper arm. A blood pressure measurement was taken first and then the cuff was reinflated to diastolic pressure and, when a good quality stable waveform was achieved, the signal was recorded. Central blood pressure (BP), augmentation pressure (AP) and the augmentation index (AIx) were all derived from the pulse waveform using a brachial-aortic transfer function within the Vicorder software. Two readings of AP within ±5 mmHg and AIx within ±5% of each other were accepted and averaged. PWV was assessed with participants in a semi-supine position with their torso at approximately 30°. A 2 × 9 cm cuff was positioned around the neck with the bladder over the right carotid pulse, and a Hokanson SC10 cuff around the middle of the right thigh. Path length was measured from the sternal notch to the centre of the thigh cuff. The cuffs were simultaneously inflated and traces with a minimum of 3 good quality waveforms recorded. Two PWV measurements, within ±0.5 m/s of each other, were accepted and averaged.

2.5. Statistical analysis

Distributions of HbA1c, glucose, insulin, CRP, IL-6, NT-proBNP and cTnT were highly skewed and log transformation was used. The men were divided into equal quartiles based on the sRAGE distribution in all men (<6.65, 6.65–6.94, 6.95–7.23 and >7.24 pg/l). For comparisons of baseline characteristics, logistic regression and linear regression were used to test for trends, fitting sRAGE in its original continuous form. Multiple linear regression models were used to assess the association between sRAGE and cardiac markers and subclinical vascular disease measures. In multivariate analyses, use of antihypertensive treatment was fitted as a categorical variable whilst age, body mass index (BMI), eGFR, LDL-C, IL-6, insulin, heart rate and NT-proBNP were fitted as continuous variables. All analyses were performed using SAS version 9.3 (SAS, Cary, North Carolina).

2.6. Study sample

This present study is a cross-sectional analysis of the data from the 2010–2012 examination. Of the 1722 men who attended the re-examination, sRAGE measurements were available in 1603 men. Men with prior clinical diagnosis of CVD were defined as men with a self-reported doctor diagnosis of CHD, stroke, heart failure or men who had reported a CABG or angioplasty (n = 444). Patient recall of a doctor diagnosis of CHD has been shown to be a valid measure of recording diseases in this study population [29] and [30]. The kappa statistics comparing health record review with patient’s recall of CHD was 0.82 [29]. Men with prevalent CVD showed significantly higher mean sRAGE [mean (SD) 7.03 (0.60)] compared to those without prevalent CVD [mean (SD) 6.94 (0.49)] (p = 0.002) and were excluded, leaving 1159 men for analysis.

3. Results

In men with no prior clinical diagnosis of CVD, those with diabetes (N = 180) showed similar sRAGE (SD) compared to those with no diabetes (N = 979) [6.96 (0.52) vs. 6.94 (0.49)]. Fig. 1 shows the distribution of sRAGE in those with and without diabetes. Table 1 shows the baseline characteristics by quartiles of the sRAGE distribution, separately in men without CVD, with and without diabetes. In those without diabetes, sRAGE was positively and significantly associated with age and eGFR (renal dysfunction) but was inversely associated with BMI, blood glucose, insulin, heart rate, and to a lesser extent with IL-6. In men with diabetes, sRAGE also related positively to age and eGFR but weak positive associations were seen with IL-6, and a significant positive association was seen with use of antihypertensive treatment. In contrast to those without diabetes, no association was seen between sRAGE and BMI, glucose, insulin or heart rate.

3.1. sRAGE and vascular measurements

sRAGE was positively and significantly associated with the cardiac markers NT-proBNP and cTnT and the haemodynamic parameters central AP and AIx in both men with and without diabetes (Table 2). A weak positive association was seen with aortic central BP. No association was seen with aortic or carotid stiffness (PWV and distensibility respectively) or cIMT in either group. Fig. 2 shows the correlation and linear regression line between sRAGE and NT-proBNP, cTnT, central AP and AIx. The association between sRAGE and NT-pro-BNP (but not cTnT), AP and AIx remained after adjustment for factors shown to be associated with sRAGE in Table 1, and known to be associated with CVD including age, BMI, eGFR, antihypertensive treatment, LDL-C, insulin and IL-6. Results were similar if glucose was used instead of insulin. The adjusted β regression coefficients for sRAGE are presented in Table 3. Further adjustment for heart rate made only minor differences to the associations. The association between sRAGE and AP and AIx was attenuated, but remained significant after further adjustment for NT-proBNP (Table 3). In a sensitivity analysis, we further excluded 23 men who reported claudication. This made little difference to the findings.

Fig. 1. Histogram of the distribution of sRAGE in men with and without diabetes.
Table 1
Baseline demographic, clinical and metabolic characteristics by quartiles of SRAGE in 1159 men with and without diabetes.

| sRAGE (pg/l)       | 1 (lowest) | 2 (N = 243) | 3 (N = 244) | 4 (highest) | p-trend |
|--------------------|------------|-------------|-------------|-------------|---------|
| Age (years)        | 77.98 (4.44) | 77.87 (4.62) | 78.85 (4.84) | 79.05 (5.07) | <0.0002 |
| BMI (kg/m²)        | 27.21 (3.62) | 26.54 (3.80) | 26.44 (3.21) | 25.84 (3.47) | <0.0001 |
| % inactive         | 2.4         | 4.7          | 4.0          | 3.2          | 0.54    |
| % manual           | 38.03       | 46.5         | 46.3         | 41.9         | 0.50    |
| % moderate/heavy drinkers | 8.2      | 5.4          | 4.2          | 2.6          | 0.002   |
| % with PVD          | 0.8         | 2.9          | 3.0          | 1.3          | 0.96    |
| Antihypertensive treatment | 45.4      | 42.4         | 48.0         | 41.9         | 0.60    |
| SBP (mmHg)         | 147.9 (17.5) | 149.8 (18.0) | 147.6 (18.3) | 148.3 (19.1) | 0.67    |
| LDL-C (mmol/l)     | 2.86 (0.89)  | 2.89 (0.85)  | 2.93 (0.94)  | 2.99 (0.99)  | 0.05    |
| HDL-C (mmol/l)     | 1.53 (0.44)  | 1.56 (0.45)  | 1.46 (0.37)  | 1.49 (0.45)  | 0.14    |
| Glucose (mmol/l)   | 5.37 (4.98–5.76) | 5.37 (5.04–5.64) | 5.26 (4.95–5.58) | 5.26 (4.89–5.53) | 0.006  |
| Insulin (IU)       | 7.46 (5.16–10.92) | 7.69 (5.25–11.50) | 7.39 (5.91–10.70) | 6.04 (4.63–9.52) | 0.04    |
| eGFR (ml/min/1.73 m²) | 78.76 (15.93) | 76.36 (15.81) | 73.08 (16.93) | 68.79 (17.59) | <0.0001 |
| CRP (mg/l)         | 1.57 (0.65–3.36) | 1.30 (0.52–2.78) | 1.30 (0.71–2.62) | 1.30 (0.67–2.50) | 0.13    |
| IL-6 (ng/ml)       | 3.25 (1.97–4.64) | 2.80 (1.75–4.23) | 2.89 (1.73–4.18) | 2.77 (1.74–4.03) | 0.10    |
| Heart rate (beats/min) | 70.91 (14.35) | 67.27 (12.42) | 66.47 (12.58) | 66.87 (12.02) | 0.01    |

| sRAGE (pg/l)       | 1 (N = 46) | 2 (N = 42) | 3 (N = 45) | 4 (N = 47) | p-trend |
|--------------------|------------|------------|------------|------------|---------|
| SBP (mmHg)         | 145.2 (20.8) | 144.3 (20.9) | 140.9 (18.7) | 143.5 (22.3) | 0.95    |
| LDL-C (mmol/l)     | 2.46 (0.86)  | 1.90 (0.85)  | 2.03 (0.81)  | 2.01 (0.81)  | 0.03    |
| HDL-C (mmol/l)     | 1.35 (0.39)  | 1.28 (0.36)  | 1.40 (0.52)  | 1.22 (0.37)  | 0.87    |
| Glucose (mmol/l)   | 7.24 (5.99–8.06) | 7.02 (6.01–7.85) | 7.00 (6.15–8.03) | 7.39 (5.82–9.02) | 0.51    |
| Insulin (IU)       | 10.48 (6.08–18.00) | 9.03 (6.06–13.20) | 14.43 (9.30–22.84) | 14.30 (10.20–21.19) | 0.44    |
| eGFR (ml/min/1.73 m²) | 78.31 (14.83) | 75.36 (17.98) | 71.53 (16.93) | 57.42 (17.72) | <0.0001 |
| CRP (mg/l)         | 1.75 (0.85–3.58) | 1.01 (0.64–1.80) | 1.16 (0.49–2.48) | 1.63 (0.65–4.59) | 0.55    |
| IL-6 (ng/ml)       | 3.00 (1.88–4.77) | 3.00 (1.94–5.21) | 2.83 (1.65–4.85) | 3.97 (2.39–7.19) | 0.30    |
| Heart rate (beats/min) | 67.76 (11.16) | 65.95 (13.65) | 67.78 (11.23) | 70.15 (14.79) | 0.29    |

Mean and standard deviation unless specified.

a Geometric mean (interquartile range).

Table 2
Cardiac markers and subclinical vascular measurements by quartiles of SRAGE in men with and without diabetes.

| sRAGE (quartiles) | 1 (lowest) | 2 | 3 | 4 (highest) | p-trend |
|--------------------|------------|---|---|-------------|---------|
| Men with no diabetes |
| NT-proBNP (pg/ml)  | 104.6 (54–240) | 93.7 (57–187) | 129.0 (67–247) | 152.9 (68–345) | <0.0001 |
| cTNT (pg/ml)       | 8.94 (6.38–13.10) | 12.30 (8.19–18.52) | 11.25 (7.31–18.00) | 15.64 (10.36–26.84) | <0.0002 |
| Central aortic blood pressure (mmHg) | 59.93 (13.27) | 62.14 (13.57) | 59.80 (13.98) | 64.44 (12.72) | 0.25    |
| Central augmentation pressure (mmHg) | 11.58 (4.71) | 13.46 (4.91) | 12.16 (4.18) | 14.20 (6.36) | 0.02    |
| Men with diabetes  |
| NT-proBNP (pg/ml)  | 79.0 (50–140) | 111 (64–235) | 131.6 (71–343) | 164.0 (76–282) | 0.006   |
| cTNT (pg/ml)       | 8.30 (0.22)  | 0.80 (0.15)  | 0.81 (0.16)  | 0.80 (0.15)  | 0.58    |

Mean and standard deviation unless specified.

a Geometric mean (interquartile range).
Men without diabetes: correlation coefficient (r) between sRAGE and (i) NT-proBNP (r = 0.15), (ii) AP (r = 0.11), (iii) AIx (r = 0.12) and (iv) cTnT (r = 0.09). Men with diabetes: correlation coefficient (r) between sRAGE and (i) NT-proBNP (r = 0.26), (ii) AP (r = 0.18), (iii) AIx (r = 0.16) and (iv) cTnT (r = 0.29).
In this study of older men without prevalent CVD, sRAGE was strongly and positively associated with renal function, as well as haemodynamic markers of arterial wave reflection (AP and AIx), which are known to predict CVD and HF [18–22,27]. Interestingly, levels of sRAGE were similar in men with and without diabetes and these associations with NT-proBNP, AP and AIx were seen in elderly men both with and without diabetes. To our knowledge, this is the first study to report on the association between sRAGE and both cardiac and vascular risk markers in those with and without diabetes from within the same population. Our findings of a positive association between sRAGE and both NT-proBNP and haemodynamic parameters known to be associated with CVD risk supports prospective studies that have shown sRAGE to be positively associated with increased risk of incident CVD in diabetes and in older adults and provides further insight into upstream pathways by which sRAGE may influence clinical development of CVD.

4.2. sRAGE, subclinical arterial disease and central haemodynamics

No association was seen between sRAGE and carotid atherosclerosis, which is consistent with findings from the NOMAS study of older adults [32]. We also found no association between sRAGE and arterial stiffness, as measured by carotid to femoral PWV and carotid distensibility, and only a weak positive association with central aortic pulse pressure. Previous work examining the relationship between sRAGE and arterial stiffness has been inconsistent, with some studies showing positive associations [33] and others finding inverse associations [34]. By contrast, a significant association was seen between sRAGE and AP and AIx, even after adjustment for CVD risk factors including BMI, renal function, metabolic risk markers, inflammation and heart rate. The association between sRAGE and both AP and AIx was partially accounted for by its relationship with NT-proBNP. Although AP and AIx have been used as indirect clinical indices of arterial stiffness, they are also importantly influenced by the timing and magnitude of wave reflections and are considered important measures of wave reflections [35]. Central AIx has also been shown to be affected by changes in LV ejection time and systolic loading [36]. The AIx, which may represent an increase in wave reflections and also serve as a marker of LV afterload, has been associated with impaired left ventricular systolic and diastolic function [37,38], which may herald the development of clinically overt heart failure. Data on the relationship between sRAGE and AP and AIx are limited and further studies are needed to confirm these findings and their clinical significance.

4.3. sRAGE and cardiac function

We have observed a positive association between sRAGE and NT-proBNP, a marker of left ventricular stress, but not with cTnT, a marker of myocardial damage. NT-proBNP is a cardiac hormone secreted from myocytes in response to ventricular and arterial wall stress and is predictive of CVD and HF [27]; circulating levels of NT-proBNP are increased in both LV systolic and diastolic dysfunction. Mechanical stress on cardiac myocytes stimulates secretion of NT-proBNP, and central haemodynamic indices may, at least in part, indicate left ventricular loading conditions. Several lines of evidence suggest that AGES are related to the development and progression of HF in both diabetic and non-diabetics patients [2]. Clinical studies in animals have also found that compliance of the left ventricle decreases with accumulation of AGES in the myocardium and implicated AGES in the development of both diastolic and systolic heart failure. The positive association we found between sRAGE and AP, AIx and NT-proBNP in men both with and without diabetes is consistent with these assertions and may reflect a direct effect of the AGE-RAGE system on left ventricular loading and function. This may explain why sRAGE is associated with the AP/AIx and NT-proBNP, but not large artery stiffness as characterised by aortic PWV, distensibility or cIMT in both men with and without diabetes in our study. Individuals with diabetes are at particularly high risk of CVD and HF [39] and RAGE may be a mechanism by which diabetes may lead to left ventricular dysfunction and eventually HF. Although sRAGE has been shown to be elevated in

### Table 3

Multivariate linear regression models of the relations of SRAGE with cardiac markers and subclinical vascular measurements in men with and without diabetes.

|                              | Men with no diabetes | Men with diabetes |
|------------------------------|----------------------|------------------|
|                              | Age-adjusted β Coefficient (se) | p-value | Model 1 | Age-adjusted β Coefficient (se) | p-value | Model 2 | Age-adjusted β Coefficient (se) | p-value | Model 3 |
| Log NT-proBNP                | 0.32 (0.08)          | 0.0002 | 0.30 (0.09) | 0.0007 | 0.29 (0.09) | 0.001 |
| Log cTnT                     | 0.05 (0.04)          | 0.20 | 0.04 (0.04) | 0.32 | 0.04 (0.04) | 0.35 |
| Augmentation pressure        | 0.99 (0.33)          | 0.003 | 1.08 (0.35) | 0.002 | 0.75 (0.33) | 0.02 |
| Augmentation index           | 1.37 (0.41)          | 0.0008 | 1.52 (0.43) | 0.0004 | 1.14 (0.40) | 0.005 |
| Log NT-proBNP                | 0.53 (0.18)          | 0.003 | 0.42 (0.20) | 0.04 | 0.41 (0.20) | 0.04 |
| Log cTnT                     | 0.31 (0.09)          | 0.0007 | 0.14 (0.09) | 0.13 | 0.14 (0.09) | 0.12 |
| Augmentation pressure        | 1.61 (0.75)          | 0.03 | 1.42 (0.79) | 0.07 | 1.59 (0.72) | 0.03 |
| Augmentation index           | 1.82 (0.92)          | 0.05 | 1.98 (0.99) | 0.04 | 2.21 (0.89) | 0.01 |

* Model 1: adjusted for age, BMI, eGFR, antihypertensive treatment, LDL-C, insulin and II-6.
* Model 2: Model 1 + heart rate.
* Model 3: Model 2 + NT-proBNP.
patients with HF [40], studies on sRAGE and incident HF risk are sparse, with only one prospective study conducted in middle-aged adults showing an inverse association between sRAGE and incident HF [41]. It is possible that sRAGE has differing relationships in differing states of increased AGEs; for example sRAGE in older adults and people with diabetes may reflect the level of RAGE expression.

4.4. Strengths and limitations

The study is a geographically representative sample of older British men and we are not aware of previous studies describing associations between sRAGE and a wide range of cardiovascular risk factors and vascular measurements in a large population-based sample of older people both with and without diabetes in whom AGEs are increased. The issue of survivor bias is inevitable in cohorts of ageing populations, with subjects with diabetes and CVD likely to have died at a higher rate. The results presented in this study are also subject to the sampling bias by the moderate response rate for the clinical examination (55%), which is also likely to have excluded participants in worse health; men who participated in our study were healthier than those who did not. These factors may have resulted in some of the null findings seen between sRAGE and vascular measurements such as cIMT and arterial stiffness. Nevertheless, we have observed significant associations between sRAGE and central haemodynamics (arterial wave reflections) and NT-proBNP in men with no prior clinical diagnosis of CVD. sRAGE was based on one measurement, however, concentrations of sRAGE within individuals have shown to be relatively stable over three years [42]. Another limitation of our study is that it comprises only white European men, and the generalizability of the study to women and other ethnic groups is limited. Our findings are based on associations with biological markers associated with cardiac dysfunction. Cardiac imaging measurements were not available and we do not have any direct data on LV systolic/diastolic function or ventricular-arterial interaction. We also acknowledge that our results are based on cross-sectional analyses, therefore, we cannot infer the direction of causation in the associations observed. Our study cannot address the question of whether sRAGE would be a useful clinical tool to assess CVD or HF risk based on cross sectional findings. Nevertheless, the association with wave reflection and cardiac dysfunction (NT-proBNP) may help towards understanding mechanisms and pathways by which elevated sRAGE is associated with increased risk of CVD/HF in diabetic patients. Further prospective studies and clinical studies are warranted to investigate the potential clinical usefulness of measuring sRAGE in clinical practice.

4.5. Conclusion

Higher plasma sRAGE is associated with increased NT-proBNP and arterial wave reflections (AP and AIx) in both older men with and without diabetes, but not with cIMT or arterial stiffness. These findings suggest that sRAGE as a marker of augmented AGE-RAGE signalling activity may contribute to or be a marker of worsening cardiac dysfunction and HF and thus may be a potential mechanism by which dysglycemia and diabetes lead to increased risk of HF. Cardiac imaging data are required to confirm these findings. Future prospective studies are warranted to investigate the association between sRAGE and development of HF in older adults with and without diabetes.

Conflict of interest

The authors declared they do not have anything to disclose regarding conflict of interest with respect to this manuscript.

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Author contributions

SGW initiated the concept and design of the paper, analysed the data and drafted the manuscript. JPJH, NS, PW and PHW contributed to the interpretation of data. OP contributed to the analysis of the paper. EAE, JPJH and PW contributed to the acquisition of the data. All authors revised it critically for important intellectual content and approved the final version of the manuscript. SGW is the guarantor and takes full responsibility for the work as a whole, including the study design, access to data, and the decision to submit and publish the manuscript.

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