Ethnic Differences in Aortic Pulse Wave Velocity Occur in the Descending Aorta and May Be Related to Vitamin D

Mohammad-Reza Rezai, A. Michael Wallace, Naveed Sattar, Joseph D. Finn, Frederick C.W. Wu, J. Kennedy Cruickshank

Abstract—We studied aortic pulse wave velocity (aPWV), a predictor of cardiovascular events independent of blood pressure, in a multiethnic sample of British men, to investigate the roles for blood levels of vitamin D and aldosterone in total and regional aortic stiffness. Total aPWV was estimated noninvasively by the Arteriograph device (aPWVAG) in 198 men, with its length measure calibrated by magnetic resonance. PWVs over the aortic arch and descending aorta were measured by magnetic resonance in a subsample (n=47). Mean (SE) aPWVAG in South Asians (n=68; age 55±10 years), at known higher coronary disease risk than other groups, was 0.5 m/s (0.2 m/s) higher than in African Caribbeans (n=67; 55±10 years), at lowest coronary disease risk here, and Europeans (n=63; 57±8 years), adjusted for age, systolic blood pressure, and diabetes mellitus (P=0.01). By magnetic resonance, PWV over the descending aorta in South Asians was 0.7 m/s (0.3 m/s) and 0.8 m/s (0.3 m/s) higher than in African Caribbeans and Europeans, respectively; PWV over the aortic arch was not different. South Asians and African Caribbeans had 21 nmol/L (3 nmol/L) and 14 nmol/L (3 nmol/L) lower mean (SE) 25(OH)D than Europeans (P<0.001). Unlike aldosterone, 25(OH)D was negatively correlated with aPWVAG adjusted for age and systolic blood pressure, as well as weakened or removed ethnic differences in aPWVAG in regression models. These data suggest that aortic stiffness as aPWV parallels coronary disease risk in ethnic groups, descending aortic but not arch PWV has this feature, and serum 25(OH)D is an independent negative correlate of aPWV and may partly account for ethnicity-related differences in aPWV and coronary disease risk. (Hypertension. 2011;58:247-253.) • Online Data Supplement

Key Words: vitamin D • aorta • pulse wave velocity • ethnic groups • aldosterone

Cardiovascular morbidity and mortality vary among different ethnic groups. People of Indian subcontinental, or South Asian, origin (SA) in Britain and North America have higher coronary heart disease (CHD) prevalence and mortality, experiencing events at a younger age and slower declines in premature CHD mortality than other populations1–4 (Figure S1A, available in the online Data Supplement at http://hyper.ahajournals.org). Conventional risk factors, such as diabetes mellitus, obesity, and hypertension, fail to explain these ethnic differences fully.5 In contrast, African Caribbeans (AfCs) have lower CHD mortality than Europeans despite higher rates of hypertension, diabetes mellitus, and stroke2,6,7 (Figure S1B). Despite sharing excess hypertension and diabetes mellitus, a similar heritage, and genetic background with AfCs, blacks have a different vascular profile further along the epidemiological transition to atheromatous disease than AfCs.7,8

There has been little comparative data on arterial function of these populations. Aortic pulse wave velocity (aPWV), an index of arterial stiffness, is a powerful independent predictor of cardiovascular events and death.9–12 We studied aPWV and its determinants in a sample of men from 3 ethnic groups to investigate the following questions. First, do differences in aPWV across ethnic groups parallel their known coronary risk profiles, and, if so, do proximal and distal aPWVs measured by more precise magnetic resonance (MR) imaging differ similarly? Second, are serum vitamin D or aldosterone concentrations related to aPWV as a risk marker, and do they influence cross-ethnic aPWV differences?

Methods

Participants were 198 men aged 40 to 80 years of AfC, SA, and European origin in Manchester, United Kingdom, who had already been recruited to the European Male Ageing Study.13 The participants had to be free of severe chronic or acute disease of active malignant renal or liver origin. Ethnicity was defined by participants’ self-reporting and 3 of 4 grandparents being of the same ethnic origin. Original recruitment was through volunteers by advertising in community centers and media in Manchester for SA and AfC groups and by general practice register sampling for Europeans.

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Main Study
All of the participants had noninvasive oscillometric arterial stiffness and blood pressure (BP) measurement in the morning after avoiding caffeine, tobacco, and heavy meals 3 hours before their visit, as well as alcohol from the night before. Using a standard protocol, BP was measured using a validated Omron semiautomatic device on the left upper arm, sitting, 3 times after 5 minutes rest in a temperature-controlled room. The values from the last 2 measurements were averaged and recorded.

The Arteriograph (TensioMed, Budapest, Hungary) device was used to measure arterial stiffness indices, including total aPWV (aPWV), estimated central (aortic) augmentation index (aoAIx), and central systolic BP (SBP). The device records pressure waves in the brachial artery with an arm cuff and estimates the aortic pulse wave transit time between the aortic root and bifurcation from the time interval between the peaks of forward and reflection pressure waves in each cardiac cycle using a commercial algorithm. It assumes that the corresponding aortic path is approximated by a straight line from the sternal notch to pubis on body surface.

Arrival times of the aortic pulse waves were computed from the 3 time intervals between the peaks of forward and reflection waves for which the 3 pulse wave transit times could be derived for P1P2, P2P3, and P1P3. Magnetic resonance aortic sagittal view shows 3 aortic paths (P1,P2,P3, and P1P3), for which the 3 pulse wave velocities, pulse wave velocity (PWV) aortic arch segment (arch-PWVMR), PWV descending aorta segment (des-PWVMR), and PWV aortic overall segment (aoPWVMR), were measured in a subsample of 47 men. AV indicates aortic valve; Bif, aortic bifurcation.

Improving aPWVAG Estimation With MRI Aortic Lengths
Comparison of the MR-measured total aortic lengths (ie, aortic root to bifurcation) to the surface sternal notch-pubis length used by Arteriograph (as externally estimated arterial pathway) showed that the latter would overestimate the real aortic path and that it was possible to predict MR-measured total aortic lengths from a regression model derived from age and height. Consequently, the Arteriograph aPWVAG was recalculated using the transit time measured by the device and the length of aortic path estimated by the aforementioned regression model.

Statistical Analysis
Data were analyzed by R statistical package version 2.11.1. ANOVA was used to compare means of parametric (and transformed skewed) variables across ethnic groups. PWV and hormonal corre-
Table 1. General, Hemodynamic, and Metabolic Characteristics of the Participants With Univariate Analysis (n=198) in Mean±SD or Median (Interquartile Range)

<table>
<thead>
<tr>
<th>Variable</th>
<th>All (N=198)</th>
<th>MR Subsample (N=47)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AIC (N=67)</td>
<td>SA (N=68)</td>
</tr>
<tr>
<td>Age, y</td>
<td>55±10</td>
<td>55±10</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>8 (12%)</td>
<td>24 (35%)</td>
</tr>
<tr>
<td>Hypertension Tx</td>
<td>8 (12%)</td>
<td>10 (15%)</td>
</tr>
<tr>
<td>Dyslipidemia Tx</td>
<td>6 (9%)</td>
<td>13 (19%)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>12 (19%)</td>
<td>11 (17%)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>84±11.0</td>
<td>79±110</td>
</tr>
<tr>
<td>Height, cm</td>
<td>174±6</td>
<td>170±6</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>28±3</td>
<td>27±3</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>130±16</td>
<td>124±14</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>82±11</td>
<td>78±9</td>
</tr>
<tr>
<td>PP, mm Hg</td>
<td>48±10</td>
<td>46±9</td>
</tr>
<tr>
<td>MAP, mm Hg</td>
<td>98±12</td>
<td>94±11</td>
</tr>
<tr>
<td>cSBP, mm Hg</td>
<td>127±20</td>
<td>125±19</td>
</tr>
<tr>
<td>cPP, mm Hg</td>
<td>46±11</td>
<td>45±11</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>65±8</td>
<td>68±11</td>
</tr>
<tr>
<td>archPWVagr, m/s</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>desPWVagr, m/s</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>aPWVagr or MRI, m/s</td>
<td>6.8 (1.7)</td>
<td>7.6 (2.4)</td>
</tr>
<tr>
<td>aoAix, %</td>
<td>27±13</td>
<td>33±13</td>
</tr>
<tr>
<td>cAP, mm Hg</td>
<td>13±9</td>
<td>16±9</td>
</tr>
<tr>
<td>FPG, mmol/L</td>
<td>5.3 (0.9)</td>
<td>5.6 (1.5)</td>
</tr>
<tr>
<td>Creatinine, mmol/L</td>
<td>95±14</td>
<td>85±14</td>
</tr>
<tr>
<td>TC, mmol/L</td>
<td>5.0±1.1</td>
<td>4.7±0.8</td>
</tr>
<tr>
<td>HDL, mmol/L</td>
<td>1.4±0.5</td>
<td>1.1±0.3</td>
</tr>
<tr>
<td>TC/HDL ratio</td>
<td>3.6±0.9</td>
<td>4.4±1.1</td>
</tr>
<tr>
<td>25 (OH)D, nmol/L</td>
<td>30±16</td>
<td>18±15</td>
</tr>
<tr>
<td>Aldosterone, pmol/L</td>
<td>180 (137)</td>
<td>295 (160)</td>
</tr>
</tbody>
</table>

*P values are from ANOVA test unless otherwise specified. AIC indicates African Caribbean; SA, South Asian; Eu, European; Tx, treatment; FPG, fasting plasma glucose; TC and HDL, total and high-density lipoprotein cholesterol; IQR, interquartile range; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; PP, pulse pressure; MAP, mean arterial pressure; cSBP, central SBP; cPP, central PP; HR, heart rate; archPWVagr, pulse wave velocity aortic arch segment; desPWVagr, pulse wave velocity descending aorta segment; aPWVagr or MRI, aortic pulse wave velocity estimated noninvasively by the arteriograph device or magnetic resonance; aoAix, aortic augmentation index; cAP, central augmentation pressure; MR, magnetic resonance.

†Data show significant P values.
‡Data show empirical P values.

Adjusted mean (SE) aPWVagr in SAs was ~0.5 m/s (0.2 m/s) higher than in AfCs and Europeans (Table 2), whereas AIC adjusted aoAix and central augmentation pressure were 7% (2%) and 3.6 mm Hg (1.0 mm Hg) lower than SAs and 7% (2%) and 2.5 mm Hg (1.0 mm Hg) less than Europeans. Thus, SAs had higher aPWVagr for given levels of age and distending pressures. Excluding diabetes mellitus or replacing SBP with mean arterial pressure did not change the ethnic distribution of these variables.
effects for aPWVAG and aoAIx; entering heart rate in the aPWV model (Model A, Table 2) slightly weakened but did not remove them (data not shown).

Hormones
Vitamin D and aldosterone were significantly different across the groups (Table 1 and Figure 3A and 3B). Adjusted for age, weight, season of blood sampling, and vitamin D supplement use, mean (SE) 25(OH)D in SAs was 21 nmol/L (3 nmol/L) and AfCs 14 nmol/L (3 nmol/L) lower than Europeans and in SAs was lower by 7 nmol/L (2 nmol/L) than AfCs (P < 0.001 for all).

Compared with AfCs, aldosterone was 85 pmol/L (20 pmol/L) higher in SAs (P < 0.001) and 51 pmol/L (21 pmol/L) higher in Europeans (P = 0.015) after adjusting for antihypertensive use and body mass index. SAs had 34 pmol/L (22 pmol/L) higher aldosterone than Europeans, but this was not significant (P = 0.13) after adjustments. There was borderline inverse correlation between aldosterone and 25(OH)D (ρ = −0.14; P = 0.06).

Arterial Stiffness-Hormonal Relations
Neither hormone was correlated with BPs, PWV, and aoAIx in univariate analysis. Adjusted for age, SBP, and diabetes mellitus, 25(OH)D was inversely related to aPWVAG (B [SE] = −0.013 [0.004]; P < 0.001) but not aoAIx (data not shown). With similar adjustments, the participants in tertiles 2 and 3 of 25(OH)D had 0.3 m/s (0.2 m/s; P = 0.1) and 0.5 m/s (0.2 m/s; P = 0.015) lower aPWVAG, respectively, compared with tertile 1. The correlations between aldosterone and aPWVAG were insignificant in similar models. Entering 25(OH)D in the model removed statistical ethnic differences in aPWVAG; such results were not observed for aldosterone (Table 2). An interaction term between ethnicity and 25(OH)D was not significant (data not shown). Age adjustment was the main factor making the 25(OH)D-aPWVAG relationship significant, notably in those >50 years of age (Figure 3C).

MRI Substudy
MRI study participants consisted of 16 Caribbean, 13 Pakistani, and 18 European men whose age, body mass index, brachial BP, or central BP differed significantly with this relatively small sample size (Table 1). After adjusting for age and SBP, mean (SE) desPWVMR in SAs was 0.7 m/s (0.3 m/s) and 0.8 m/s (0.3 m/s) higher than in AfCs and Europeans, respectively; archPWVMR was not statistically different (Table 3). This pattern of ethnic difference in desPWVMR in the MR study replicates the result for the aPWVAG in the total sample (Figure 2A through 2B), but the pattern for archPWVMR is different (Figure 2C). Adjusted for age and SBP, higher aldosterone tertiles were associated with greater archPWVMR but not desPWVMR (Table 3); this remained significant after adjusting for ethnicity.

Discussion
The results suggest firstly that SA men had higher aPWV than AfCs and Europeans for the same levels of age and brachial/central distending pressures, thus reflecting the known CHD population risk differences across ethnic groups. Despite slightly higher peripheral BPs, AfCs had lower aPWV paralleling currently lower CHD risk in Britain and the Caribbean region. Second, the MR substudy showed that pathology in the more elastic descending aortic segment, but not that of the aortic arch, may be related to CHD risk. Third, serum 25(OH)D was inversely related to aPWV independent of age and SBP; hence, poor vitamin D status may account for some of the ethnic differences in aPWV and, potentially, therefore, some vascular disease in the population as a whole. Randomized trials to test that hypothesis are scarce.19

Studies comparing arterial stiffness in SAs, AfCs, and Europeans, particularly in community samples, are few. Our previous population-based work focused on comparing risks across glucose tolerance with relatively small numbers of controls found no difference in Doppler-measured aPWV down the descending aorta in AfC (10.1 m/s), Gujarati SA (10.5 m/s), and European (9.7 m/s) groups after adjusting for age and sex.9 However, those data were not adjusted for BPs, which were higher in AfCs. Two studies reported higher arterial stiffness estimated by reflection wave indices among

### Table 2. Regression Models Comparing Aortic Pulse Wave Velocity Estimated Noninvasively by the Arteriograph Device (m/s) Between Ethnic Groups in Total Sample (n=198)

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Model A, Ethnicty</th>
<th>Model B, Ethnicty+25(OH)D</th>
<th>Model C, Ethnicty+Aldosterone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B (SE)</td>
<td>P</td>
<td>B (SE)</td>
</tr>
<tr>
<td>Age, y</td>
<td>0.10 (0.009)</td>
<td>&lt;0.001*</td>
<td>0.11 (0.009)</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>0.02 (0.005)</td>
<td>&lt;0.001*</td>
<td>0.02 (0.005)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>0.43 (0.30)</td>
<td>0.15</td>
<td>0.42 (0.29)</td>
</tr>
<tr>
<td>AfC vs SA†</td>
<td>−0.56 (0.18)</td>
<td>0.002*</td>
<td>−0.33 (0.22)</td>
</tr>
<tr>
<td>Eu vs SA‡</td>
<td>0.10 (0.15)</td>
<td>0.52</td>
<td>−0.03 (0.17)</td>
</tr>
<tr>
<td>25(OH)D, nmol/L</td>
<td>…</td>
<td>…</td>
<td>−0.01 (0.004)</td>
</tr>
<tr>
<td>Aldosterone, pmol/L</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
</tbody>
</table>

Note the change in regression coefficients regarding ethnic difference in aPWVAG (†) before (Model A) and after entering vitamin D (Model B) or aldosterone (Model C). SBP indicates systolic blood pressure; AfC, African Caribbean; SA, South Asian; Eu, European.

*Data show significant P values.
†Data are for when the same model was run again with European as the reference group.
‡Significance level for ethnic group differences is <0.02 after multiple testing adjustment.
healthy\textsuperscript{20} and poststroke\textsuperscript{21} SA subjects compared with their European counterparts. Neither measured aPWV.

We found no significant aPWV differences between AfCs and Europeans. Similar results were found in different populations of black and white adults, using Doppler-measured aortic-femoral PWV,\textsuperscript{22} central aPWV,\textsuperscript{23} or arterial compliance by the Windkessel method.\textsuperscript{24} However, 2 other studies using the Complior device reported higher carotid-femoral PWV in younger Brazilians of African descent\textsuperscript{25} and for British AfCs compared with Europeans.\textsuperscript{26} The above inconsistencies may be attributed to different techniques, study populations, statistical approaches, and arterial paths or length estimation methods used for PWV measurement, as we found in a recent European pooling project.\textsuperscript{27} Here we measured aPWV over a central aortic path.

Data on the relationship between vitamin D and PWV is scarce and limited to chronic kidney disease patients, with inverse relationships found.\textsuperscript{28–30} Our study appears to be the first to report such an association in a community-dwelling, multiethnic sample. A recent randomized trial (n=49) found a fall in carotid-femoral PWV among black teenagers given 2000 IU/d of vitamin D\textsubscript{3} compared with those on 400 IU/d.\textsuperscript{31} These pilot results suggest promise for vitamin D as an intervention in black populations. Other data from disease-free or asymptomatic subjects primarily relate to endothelial function measured by brachial flow-mediated dilation,\textsuperscript{32} which was positively correlated with serum 25(OH)D and improved on supplementation in deficient cases.\textsuperscript{33}

In our data, vitamin D was also negatively related to total cholesterol/high-density lipoprotein cholesterol ratio, fasting plasma glucose, and aldosterone. Including these variables in the regressions did not remove the independent correlation of vitamin D and aPWV\textsubscript{AG} (data not shown).

Effects of vitamin D on arterial stiffness may be via a variety of mechanisms, including endothelial function, renin-angiotensin system inhibition, regulation of parathyroid hor-
mone, vascular calcification, and matrix metalloproteinase activity.\textsuperscript{34–38} Paradoxically, pharmacological doses of some vitamin D receptor activators (eg, calcitriol) may cause arterial calcification and stiffness in experimental models, whereas others (eg, paricalcitol) do not.\textsuperscript{35}

Arterial calcification and stiffness in experimental models, Europeans is also well established.\textsuperscript{46–49} The “high-aldosterone” SA group in the total sample had higher aPWV\textsubscript{AG} than the “low-aldosterone” AfCs, but without correlation between aldosterone and aPWV\textsubscript{AG}. Reports of an aldosterone and aPWV relationship are inconsistent.\textsuperscript{39–42} Circulating levels of aldosterone are variable, may not reflect local aldosterone inside the vascular wall,\textsuperscript{43} and are affected by diurnal variations and antihypertensive medications.

Almost all SAs and AfCs and half of Europeans were vitamin D “deficient” (\(<50 \text{ nmol/L}\)) here, as is described in Britain.\textsuperscript{45} Lower vitamin D among migrants of SA and African descent resident in temperate climates compared with Europeans is also well established.\textsuperscript{46–49}

**Study Limitations**

Although the participants were community-dwelling men, they were recruited as volunteers. The study sample is, therefore, not fully representative, although their BP and metabolic profiles are similar to those reported previously. Similarly, our MR substudy results should be interpreted with caution, because the numbers in each group are small. However, the MR subsamples were free of known vascular disease, so these novel data generate hypotheses on the relative roles of regional differences in aortic PWV in relation to vascular events. In cross-sectional data, cause and effect between low vitamin D or higher aldosterone levels and arterial stiffness cannot be assessed, and are in part confounded by the ethnic data. Participants were also not on standardized sodium diets.

**Perspectives**

Arterial stiffness here was greater among SA men, with lower aPWV values from both noninvasive and MR measures in AfCs despite slightly higher BPs. Because the data parallel CHD risk in these ethnic groups, aPWV may, therefore, add precision to risk estimation from BP alone. Vitamin D insufficiency may explain part of the ethnic differences in aPWV and cardiovascular risk.

**Acknowledgments**

The article is dedicated to the memory of Prof Mike Wallace, who died unexpectedly while this work was in progress. We wish to acknowledge the support of the Wellcome Trust Clinical Research Facility (Manchester, United Kingdom), where the fieldwork and MRI scans took place.

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**Disclosures**

None.

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Ethnic differences in aortic pulse wave velocity occur in the descending aorta and may be related to vitamin D

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Short title: Aortic stiffness & vitamin D, a multi-ethnic study

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Figure S1. a) Men’s CHD prevalence by age and three ethnic groups in England, 2008, (adapted from data in 1) and b) Men’s stroke mortality trends, 1979-2003 by country of birth in England and Wales (adapted from data in 1,2)