Defined shapes of carotid artery calcifications on panoramic radiographs correlate with specific signs of cardiovascular disease on ultrasound examination

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Objective. The aim was to optimize diagnostics for carotid artery calcifications (CACs) on panoramic radiographs (PRs) to identify cardiovascular disease (CVD) by investigating how 4 defined CAC shapes are associated with ultrasound (US) findings indicating CVD.

Study Design. The study included 414 participants (802 neck sides) from the Malmö Offspring Dental Study, examined with PRs. The PRs were assessed for CAC shapes stratified into 4 categories: single, scattered, vessel-width defining, and vessel-outlining. The carotid arteries were examined with US for signs of CVD: the presence of plaques, largest individual area of a plaque, number of plaques, and percentage reduction of the lumen. Associations between the different CAC categories and US characteristics were analyzed.

Results. All categories of CAC were significantly associated with a higher degree of US findings indicating CVD compared with no CAC (P < .001). The most significant differences were found for vessel-outlining CAC, with the mean of the largest individual plaque area of 17.9 vs 2.3 mm², mean number of plaques 1.6 vs 0.2, and mean percentage reduction of the lumen 24.1% vs 3.5% (all P < .001).

Conclusions. Independent of shape, CACs detected on PRs were associated with a higher degree of US findings of CVD. This was most pronounced for vessel-outlining CAC. With refined differential diagnostics of CACs in PRs, dentists may contribute to improved identification of patients in need of cardiovascular prevention. (Oral Surg Oral Med Oral Pathol Oral Radiol 2023;000:1–13)

Atherosclerosis is characterized by lipid deposition in the walls of arteries, inflammation, and narrowing of the lumen. It is a risk factor for cardiovascular disease (CVD) events such as ischemic stroke and myocardial infarction, which are the leading causes of mortality globally. However, the risk of future events and early death can be reduced if atherosclerotic lesions are detected early and the affected subjects receive preventive treatment for CVD.

Panoramic radiography is a widely used imaging technique in dentistry and can be performed for various odontological indications in patients of different age groups. A panoramic radiograph (PR) is a type of tomographic image that depicts the teeth, jaws, facial skeleton, and often neighboring structures, such as the area of the bifurcation of the carotid arteries. In this area, PRs can depict carotid artery calcifications (CACs), a marker of atherosclerosis, as incidental findings.

Several studies have investigated the diagnostic value of detecting CACs on PRs, and in recent years the correlation between CACs and cardiovascular events has been strengthened. Therefore, patients with signs of CVD but without ongoing preventive treatment could be identified by dentists if the assessment of incidental findings of CACs on PRs is included in the diagnostic findings and reported to treating physicians.

Ultrasound (US) imaging is frequently performed to identify and quantify the characteristics of carotid plaques. It is favorable due to its high accuracy, low cost, and non-invasiveness without the use of radiation.

Statement of Clinical Relevance

Early signs of cardiovascular disease can be detected on panoramic radiographs with higher accuracy if the shape and bilateral occurrence of carotid artery calcifications are considered. Thereby, dentists can identify those patients who benefit most from prevention, decreasing the risk of cardiovascular-related morbidity.
Ultrasound has a sensitivity of 94% and specificity of 93% for the detection of unstable plaques compared with histologic assessment.6

In a previous study, bilateral vessel-outlining CACs were reported to be an independent risk marker for future CVD events,3 suggesting that detection of CACs with these specific features could identify patients with a higher risk of suffering a cardiovascular event.5,7 However, studies are lacking regarding the correlation between specific shapes of CACs and signs of CVD measured as different characteristics of US findings in the carotid arteries.

If specific shapes of CACs on PRs indicate a higher degree of early signs of CVD found during a carotid US, a dentist may contribute to optimized early detection of patients at increased cardiovascular risk and in need of preventive treatment.

Therefore, the objective of this population-based study was to optimize diagnostics for CACs visible on PRs for the identification of early signs of CVD by investigating how 4 defined shape categories of CACs are associated with the degree of US findings in the carotid artery, indicating atherosclerosis and CVD. We hypothesized that there would be significant differences in the distribution of the 4 calcification categories of CAC and the characteristics of plaque formation as detected by US.

MATERIALS AND METHODS
Participants
The Malmö Diet Cancer Study (MDCS) was initiated in 1991-1996 and the Cardiovascular Arm (MDCS-CVA) in 1992. The primary aim of MDCS-CVA was to examine the participants’ dietary habits, cancer risk factors, cardiovascular risk factors, and signs of early atherosclerosis by using carotid US.8-10 The Malmö Offspring Study (MOS) was initiated in 2013-2021 and is a population-based study including the children (G2) and grandchildren (G3) of the first generation (G1) of patients in the MDCS-CVA,11 with an attendance rate of 47% of all invited. A register-based follow-up study aims to investigate the risk of vascular disease, including the influence of genetic factors and biomarkers. Lifestyle and social aspects are also being evaluated.11 The following information was available regarding the participants in the present investigation: age, sex, education level, body mass index, smoking history, use of antihypertensive drugs, co-existing CVD, and diabetes.

The included participants were all aged ≥18 years and underwent a thorough assessment at the Clinical Research Unit, Skåne University Hospital, Malmö, Sweden, after signed informed consent. The appointment included a clinical examination measuring height, waist circumference, weight, and cardiovascular function. The MOS protocol was previously described in detail by Brunkwall et al.11 Potential patterns of early atherosclerosis in the carotid arteries were assessed by US. Due to the young mean age of the participants (28 years) and lack of clinical relevance among G3 participants (grandchildren), the US examinations were only carried out among G2 participants (children).

The Malmö Offspring Dental Study (MODS) is a sub-study of the MOS and was previously described by Jönsson et al.12 MODS aimed to examine possible correlations between oral and general health and included a thorough clinical examination and intraoral and panoramic radiographic examinations of the teeth and jaws for assessment of bone-affecting oral infections. The cohort included 1029 participants from G2 and G3, 999 of whom had PRs available. Of these, 773 participants from G2 had also been examined by US and were included in the present study (Figure 1).

Ultrasound examination
The G2 participants underwent a B-mode US examination of the carotid arteries using the Logiq E9 device (GE Healthcare). The examinations were performed by certified and experienced ultrasonographers and included the common carotid artery, the bifurcation, and the internal and external carotid arteries bilaterally, with a predefined 3 cm² window. The presence of a plaque was defined as a focal enlargement of the intima-media thickness (i.e., tunica intima and tunica media) >1.2 mm. In the presence of plaque formation, data were recorded regarding the largest individual area of a plaque (in mm²), the number of plaques, and the percentage reduction of the lumen. Each participant was examined by 1 ultrasonographer. However, an assessment of interobserver variability among all ultrasonographers was performed regularly. Interobserver variability for intima-media thickness was consistently <10%. A study of interobserver variability from online assessments of plaque area showed a mean absolute difference of 3.3 (SD: 2.2) mm² and an intraclass correlation coefficient of 0.79, indicating good reliability.13 The method was previously described in detail for G1 participants by Rosvall et al.14,15 Examples of US findings are shown in Figure 2.

Panoramic examination
The PRs were obtained using 2 different PR machines (Morita 3De-CP and Morita Veraviewepocs 3D F40, J. Morita, Corp., Kyoto, Japan).

Interpretation of panoramic radiographs
The presence of CACs on the PRs was assessed separately by a specialist (E.L.J.) and a resident with a PhD in oral and maxillofacial radiology (N.G.), both of
Fig. 1. Flowchart of included participants. MOS, Malmö Offspring Study; MODS, Malmö Offspring Dental Study; US, ultrasound; PR, panoramic radiograph; n, number of participants or neck sides.
whom had extensive experience in diagnosing CACs (more than 20 and 10 years, respectively). The PRs were assessed from the original database register in i-Dixel 2.0 (J. Morita, Corp.) to rule out data compression defects. The observers examined the images on high-resolution Barco Coronis Fusion 6MP LED 30” diagnostic displays in a room with dimmed light. The observers could adjust brightness, contrast, and magnification. The 2 observers were blinded to information about the participants, including medical history. According to Landis and Koch, the 2 observers exhibited “almost perfect” agreement (kappa value: 0.91, standard error of kappa = 0.02, 95% CI 0.74-0.94) on the interpretation of calcification presence and category of calcification.16 In case of disagreement, consensus was reached through discussion. The consensus was used as the basis of subsequent statistical analyses.

Of the 773 PRs for G2, 359 PRs were excluded due to the area of the carotid arteries not being depicted (n = 308), positioning errors (n = 25), overexposure (n = 23), and artifacts (n = 3). Of the remaining 414 PRs with a total of 828 neck sides, 26 neck sides were excluded due to the area of the carotid arteries not being depicted (n = 23), distortions (n = 2), and artifacts (n = 1). As a result, 414 PRs and 802 neck sides were included in the analysis (Figure 1).

The presence of CACs was determined for each neck side (right and left) on the PRs. If present, the CAC shape was stratified into 1 of 4 categories: single calcification (category 1), scattered calcifications (2 or more; category 2), vessel width-defining calcification (category 3), and vessel-outlining calcifications (category 4), as illustrated in Figure 3. DICOM data sets of cases exhibiting the 4 categories can be examined through the DICOM interactive viewer.

Statistical analyses

Statistical analyses were performed using SPSS Statistics for Windows version 28.0, released in 2021 (IBM SPSS, Inc.). Pertinent participant characteristics were analyzed with the Student t test for quantitative data or the chi-squared test for categorical data. The data were presented as mean values, SDs, and percentages. One-way analysis of variance was performed to analyze the relationship between the different CAC shapes and the degree of different characteristics in US examinations: the largest individual area of a plaque (mm²), number of plaques, and percentage reduction of the lumen of the carotid artery. In addition, 1-way analysis of variance was used when comparing bilateral plaques, including at least 1 category 4 calcification with the

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Fig. 2. Examples of ultrasound findings. (a) The largest individual area of a plaque measured in mm² (within the white line). (b) Number of plaques identified in the common carotid artery, the bifurcation, and the internal and external carotid arteries, marked at the level of the bifurcation (white arrowheads). (c) Percentage reduction of the lumen calculated as the ratio of the short double-headed arrow indicating plaque thickness to the long double-headed arrow indicating the lumen and expressed as a percentage. (d) Calcifications of larger size could also be detected in the plaque (white arrows); however, the resolution for the detection of calcifications in ultrasound imaging is lower than in panoramic radiographs, and therefore, the correlation between findings of calcifications when comparing the results of the 2 methods is low.
remaining unilateral and bilateral CAC shapes and US findings. The Bonferroni correction was used for multiple comparisons.

Accuracy, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and positive and negative likelihood ratios were calculated using MedCalc Statistical Software version 19.2.6, released in 2020 (MedCalc Software) based on an estimated prevalence of disease (CAC) of 10%. For all analyses, statistical significance was set at $P \leq .05$.

**Ethical considerations**

MODS was approved by the Ethical Review Board at Lund University (Dnr. 2013/761) before the study. All participants provided written informed consent. The study was conducted according to the principles outlined in the Helsinki Declaration.

**RESULTS**

The 414 participants had a mean age of 53.0 ± 7.8 years (min-max 29.8-70.0 years). The sex distribution was 265 women (64%) and 149 men (36%). Plaques were identified in 124 of the 414 participants for a prevalence of CAC in the study population of 30.0%.

Baseline characteristics of the participants, as listed in Table I, showed that compared with participants with no CACs, participants with CAC (any category) and bilateral CACs, including unilateral or bilateral

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Fig. 3. Illustrations of enhanced carotid artery calcification (CAC) categories 1-4, marked with circles. (a) Panoramic radiograph showing bilateral vessel-outlining CACs (category 4). (b) Single CAC (category 1). (c) Scattered CAC (category 2). (d) Vessel width-defining CAC (category 3). (e) Vessel-outlining CAC (category 4).
category 4, had a significantly higher mean age (57.6 and 58.8 vs 51.0 years, \( P < .001 \)) and greater use of hypertensive drugs (34% and 35% vs 14%, \( P < .001 \) and \( P = .011 \)). Furthermore, participants with CAC (any category) showed a higher prevalence of pre-existing CVD compared with participants with no CAC (38% vs 27%, \( P = .021 \)). Participants with bilateral CACs, including unilateral or bilateral category 4, had a significantly higher prevalence of diabetes compared with participants with no CAC (16% vs 4%, \( P = .014 \)). However, patient sex, tertiary education, BMI, and smoking history were not significantly different in either comparison (\( P \geq .289 \)).

When assessing the diagnostic values of CACs on PRs for detecting plaques in the carotid arteries, US was used as the reference standard. The accuracy of CAC detection on the neck side level was 86.6% (95% CI 84.0%-88.9%), sensitivity 54.4% (95% CI 48.1%-60.5%), and specificity 90.2% (95% CI 87.3%-92.6%). The PPV was 38.1% (95% CI 31.7%-44.8%) and NPV 94.7% (95% CI 94.0%-95.3%). The positive likelihood ratio was 5.5 (95% CI 4.2-7.3), and the negative likelihood ratio was 0.5 (95% CI 0.4-0.6; Table II).

The diagnostic values for detecting plaques in the carotid arteries were also assessed on the neck side level for CAC on PR divided into categories. The accuracy of detecting plaques in CAC categories 1-3 was 86.9% (95% CI 84.3%-89.3%), using US as the reference standard, which was lower than for CAC category 4 (91% [95% CI 88.6%-93.1]). The PPV for categories 1-3 was 37.7% (95% CI 30.8%-45.2%), which was also lower than for category 4 (64.4% [95% CI 45.1%-79.9%]; Table II).

Carotid artery calcifications on PRs were also compared with the detection of calcium in the carotid arteries using US as the reference standard. The accuracy of CAC detection on the neck side level was 52.2% (95% CI 46.0%-58.4%), sensitivity 73.9% (95% CI 58.9%-85.7%), and specificity 49.8% (95% CI 42.9%-56.6%). The PPV was 14.1% (95% CI 11.6%-16.9%) and NPV 94.5% (95% CI 91.2%-96.6%). The positive likelihood ratio was 1.5 (95% CI 1.2-1.8), and the negative likelihood ratio was 0.5 (95% CI 0.3-0.9; Table II).

When analyzing correlations on the neck side level, findings of CACs on the right side of a PR were compared with findings on the corresponding US examination of the right carotid artery; the same comparisons were made for the left side. The comparisons between any finding of CAC, independent of shape category, with the characteristics of US findings showed that the largest individual area of a plaque, number of plaques, and percentage reduction of the lumen were all significantly higher for neck sides with CAC on PRs than neck sides with no CAC (\( P < .001 \)), as shown in Table III and Figure 4. The most significant difference was found between US examinations of neck sides with vessel-outlining CAC (category 4) compared with neck sides without calcifications. The mean value of the largest individual area of a plaque was 17.9 mm\(^2\) vs 2.3 mm\(^2\) (\( P < .001 \)), the largest mean number of plaques was 1.6 vs 0.2 (\( P < .001 \)), and the largest mean percentage reduction in the carotid artery lumen was 24.1% vs 3.5% (\( P < .001 \); Table III and Figure 4).

### Table I. Baseline characteristics of the 414 participants when divided into groups with no CAC, with all categories of CAC, and the subgroup of participants with bilateral CAC, including unilateral or bilateral vessel-outlining CAC (category 4). Differences between the group with no CAC and the 2 groups with CAC were analyzed (\( P \) values)

<table>
<thead>
<tr>
<th>Pertinent characteristics</th>
<th>All included participants</th>
<th>Included, n (n = 290)</th>
<th>CAC all categories (n = 124)</th>
<th>( P ) value*</th>
<th>Bilateral CAC including unilateral or bilateral category 4 (n = 23)</th>
<th>( P ) value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y, mean (SD)</td>
<td>53.0 (7.80)</td>
<td>51.0 (7.55)</td>
<td>57.6 (6.35)</td>
<td>&lt; .001[2]</td>
<td>58.8 (7.37)</td>
<td>&lt; .001[2][4]</td>
</tr>
<tr>
<td>Sex, women, n (%)</td>
<td>265 (64)</td>
<td>266 (64)</td>
<td>79 (64)</td>
<td>.934[1]</td>
<td>15 (65)</td>
<td>.917[1][4]</td>
</tr>
<tr>
<td>Dementia, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m², mean (SD)</td>
<td>26.6 (4.71)</td>
<td>26.5 (4.63)</td>
<td>27.0 (4.89)</td>
<td>.289[2]</td>
<td>27.0 (4.82)</td>
<td>.624[2][4]</td>
</tr>
<tr>
<td>Smoking, current and former, n (%)</td>
<td>186 (49)</td>
<td>130 (48)</td>
<td>56 (50)</td>
<td>.606[2]</td>
<td>10 (50)</td>
<td>.861[2][4]</td>
</tr>
<tr>
<td>Use of antihypertensive drugs, n (%)</td>
<td>75 (20)</td>
<td>37 (14)</td>
<td>38 (34)</td>
<td>&lt; .001[1]</td>
<td>7 (35)</td>
<td>.011[1][4]</td>
</tr>
<tr>
<td>Pre-existing cardiovascular disease, n (%)</td>
<td>124 (30)</td>
<td>77 (27)</td>
<td>47 (38)</td>
<td>.021[1]</td>
<td>9 (39)</td>
<td>.193[1][4]</td>
</tr>
<tr>
<td>Diabetes, n (%)</td>
<td>19 (5)</td>
<td>10 (4)</td>
<td>9 (8)</td>
<td>.060[2]</td>
<td>3 (16)</td>
<td>.014[2][4]</td>
</tr>
</tbody>
</table>

*By comparison with No CAC group.
\[1\]Student \( t \) test.
\[2\]2-sided \( x^2 \) test.
\[3\]Completed college or university degree.
\[4\]Significant \( P \) value.

BMI, body mass index; CAC, carotid artery calcification; \( n \), number of participants.
Compared with categories 1 to 3, CAC category 4 also presented a significantly higher degree of US characteristics: largest individual area of a plaque \( (P < .001) \), number of plaques \( (P = .014) \), and percentage reduction of the lumen \( (P < .001) \). However, there were no significant differences in the degree of US characteristics between categories 1, 2, and 3.

When analyzing correlations on the participant level, including both neck sides, the participants were divided into 3 groups based on the findings on the PRs: (a) no CAC, (b) any unilateral CACs (categories 1-4) or bilateral CACs (categories 1-3), and (c) bilateral CACs with at least 1 neck side with a category 4 CAC. The 3 groups differed significantly, with the highest degree of all US characteristics among participants with bilateral CACs and at least 1 neck side with a category 4 lesion, which differed significantly from those with any unilateral CACs (category 1-4) or bilateral CACs (category 1-3). Furthermore, compared with the group with no CAC, both groups with findings of CAC had significantly greater mean values for largest individual area of a plaque (mean differences 16.8 mm² and 30.1 mm², respectively, \( P < .001 \)), number of plaques (mean differences 1.6 and 2.4, respectively, \( P < .001 \)), and percentage reduction of the lumen (mean differences 23.3% and 37.2%, respectively, \( P < .001 \)) as shown in Table IV and Figure 5.

**DISCUSSION**

The main finding of this population-based study was a strong correlation between the detection of CAC on PRs (independent of shape) and a higher degree of carotid atherosclerosis discovered on carotid US. Ultrasound-detected carotid atherosclerosis is a well-established risk marker for stroke, myocardial infarction, and cardiovascular death.\(^1,1^7\) The 3 analyzed characteristics of plaques in the US examinations were chosen because they all measure the degree of atherosclerosis. Our results suggest that CAC on PRs could be useful for identifying patients in general and specialized dentistry at increased risk of CVD who would benefit from early detection of CAC. These patients could be recommended to seek medical care for examination and, if necessary, appropriate preventive treatment to decrease the risk of CVD-related morbidity and death.

According to statistics from the Swedish Social Insurance Agency, one-third of the Swedish population receives an oral health care examination every year, and some patients visiting general dentists may not be aware of their cardiovascular risk. Therefore, diagnosing CAC on PRs performed for odontological indications could be cost-effective by reducing the risk of morbidity, hospitalization, or death.

Atherosclerosis is a progressive disease, and the prevalence, as well as the effects on the vessel walls,
increase with aging. Studies have shown an increasing prevalence of CAC on PR with increasing age: 31% at 62 ± 8 years and 39% in the age range of 60 to 96 years. The present investigation found a similar prevalence (30%), but the participants had a lower mean age (53 ± 7.8 years). This may partially be explained by the PRs not depicting the area of the carotid arteries (n = 308) being excluded from the investigation instead of being assessed as “without findings of CAC.” If these PRs had not been excluded, the prevalence would have been 17.1%, which is more comparable with the 14.9% previously reported in a Swedish population aged 18 to 74 years. If these participants had been included, the sensitivity of CAC on PR would have been lower and the associations weaker. This emphasizes that PR examinations should not be used as a screening tool and that a negative finding should not be interpreted as indicating vascular health. The exclusions due to awareness of the limitations of the PR represent a strength of the study.

The baseline comparison showed similar results of pertinent characteristics for participants with any category of CAC and the subgroup of participants with bilateral CACs where at least 1 side showed vessel-outlining CACs. Older age and the use of antihypertensive drugs were associated with significant differences between the participants with no CAC and both groups with CAC, whereas participant sex, tertiary education, BMI, and smoking history had no effect in either comparison. The exceptions were diabetes, which was significantly associated only with bilateral CACs, including vessel-outlining calcification, and pre-existing CVD, which was significantly associated with any type of CAC but not significantly with the bilateral subgroup. The differences between the CAC groups regarding pre-existing CVD might be a result of the low number of participants in the bilateral subgroup because both groups showed similar prevalence. Regarding the association between CAC and diabetes, the explanation for the differences could be that the subgroup with vessel-outlining CACs had a more severe vascular disease, and diabetes might have contributed to the severity.

The diagnostic accuracy of CAC in PR for detecting plaque was 86.6% when using the US assessment as the reference standard. This corresponds to Ertas and Sisman, who presented an accuracy of 80% to 82%.

### Table III. Carotid plaque categories according to carotid ultrasound by neck side with no CAC and different CAC categories detected on PRs

<table>
<thead>
<tr>
<th>CAC categories detected on PR</th>
<th>n</th>
<th>Mean (mm²)</th>
<th>Mean difference</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No CAC</td>
<td>606</td>
<td>2.3</td>
<td>Ref</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>1</td>
<td>92</td>
<td>11.6</td>
<td>9.3</td>
<td>6.9-11.8</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>7.8</td>
<td>5.6</td>
<td>1.8-9.4</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>9.6</td>
<td>7.4</td>
<td>3.0-11.7</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>17.9</td>
<td>15.6</td>
<td>12.2-19.1</td>
<td>&lt;.001*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CAC categories detected on PR</th>
<th>n</th>
<th>Mean (N)</th>
<th>Mean difference</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No CAC</td>
<td>606</td>
<td>0.2</td>
<td>Ref</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>1</td>
<td>92</td>
<td>1.1</td>
<td>0.8</td>
<td>0.6-1.0</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>0.9</td>
<td>0.7</td>
<td>0.4-0.9</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>1.1</td>
<td>0.9</td>
<td>0.5-1.2</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>1.6</td>
<td>1.4</td>
<td>1.1-1.7</td>
<td>&lt;.001*</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>CAC categories detected on PR</th>
<th>n</th>
<th>Mean (%)</th>
<th>Mean difference</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No CAC</td>
<td>606</td>
<td>3.5</td>
<td>Ref</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>1</td>
<td>92</td>
<td>16.6</td>
<td>13.1</td>
<td>10.0-16.1</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>12.3</td>
<td>8.7</td>
<td>3.9-13.5</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>14.2</td>
<td>10.7</td>
<td>5.2-16.2</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>4</td>
<td>43</td>
<td>24.1</td>
<td>20.5</td>
<td>16.2-24.9</td>
<td>&lt;.001*</td>
</tr>
</tbody>
</table>

*Significant P value.

CAC, carotid artery calcification; n, number of neck sides.
CAC categories 1-4 compared with no CAC: 1 = single calcification, 2 = scattered (2 or more) calcifications, 3 = vessel width-defining calcification, and 4 = vessel-outlining calcification.
Fig. 4. Neck side level findings on carotid ultrasound imaging in relation to findings on panoramic radiographs illustrated in box-plots for no carotid artery calcification (CAC) and CAC categories 1, 2, 3, and 4. The box indicates the interquartile range, the line in the box shows the median and X the mean, and the whiskers show the minimum and maximum values. The dots above the whiskers are outliers. (A) Largest individual area of a plaque; (B) number of plaques; (C) percentage reduction of the lumen.
Furthermore, PR assessments revealed a low sensitivity for the detection of plaques (54.4%, 95% CI 48.1%-60.5%) but a high specificity (90.2%, 95% CI 87.3%-92.6%). This can be explained by the fact that the comparison included all findings of plaques in the US examinations, independent of size and lumen reduction. Moreover, not all carotid plaques are calcified, and the bifurcations may be situated below the area depicted on the PR in some of the included cases, resulting in false negative findings. Independent of the exclusions, the high specificity of CAC on PR and the correlation with US results suggest that the findings on PR are important and should be considered because they may indicate CVD at an early stage.

Low to moderate conformity was found between CAC on PR and calcification of the carotid arteries detected by US evaluation. An explanation is that US examinations are mainly used for detecting changes in the soft tissues, and PR is more sensitive for calcifications with small volumes.24 Overall, there are differences between the modalities, as US has the ability to visualize the soft tissue part of the plaque, which is not visible on PRs, whereas PRs provide higher resolution and detection of calcifications down to a volume of 1 mm³.25 Therefore, the sensitivity of identifying CAC in PRs was higher (73.9% [95% CI 58.9%-85.7%]), but the specificity was low (49.8% [95% CI 42.9%-56.6%]) when using US-detected calcium as reference standard.

Vessel-outlining CACs (category 4) had significantly greater mean values for the largest individual area of a plaque, number of plaques, and percentage reduction of the lumen in the carotid arteries compared with any other shape of CAC. No significant differences were found between CAC categories 1, 2, and 3 and the degree of US findings. The interpretation is that patients with vessel-outlining CACs have the strongest association with and a higher degree of early signs of atherosclerosis and CVD risk, according to US findings. This target group may benefit to a higher degree from preventive treatment.

Compared with unilateral and other shapes of bilateral CAC on PR, bilateral CAC with at least one category 4 lesion had a significantly greater manifestation of all characteristics of carotid plaques on US. This is in accordance with previous studies showing significant associations between bilateral CAC and the risk of suffering from future cardiovascular events.4,5 Bilateral vessel-outlining CAC has also been shown to be an independent risk marker for vascular events.5 However, in prior research, the shape of the CAC did not increase the PPV for the detection of significant stenosis (i.e., a plaque exceeding 50% of the lumen).26 In this study, vessel-outlining CAC improved the PPV for the detection of plaques compared with the other shapes. However, all sizes of plaque were considered, and almost none of the participants had US findings in which the plaque exceeded 50% of the lumen, which may explain the difference in results.

Friedlander et al.27 showed that patients with CACs visible on PR present with pathologic findings in the

| Table IV. Carotid plaque characteristics according to ultrasound in relation to CAC groups detected on PRs |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| CAC groups according to PR      | n   | Mean (mm²) | Mean difference | 95% CI          | P value        |
| No CAC                         | 290 | 4.4          | Ref             | Ref             | Ref            |
| Unilateral (categories 1-4) or bilateral (categories 1-3) CAC | 101 | 21.2         | 16.8            | 13.0-20.6       | < .001*        |
| Bilateral CAC, including 1 or 2 category 4 | 23  | 34.4         | 30.1            | 23.0-37.1       | < .001*        |
| CAC groups according to PR      | n   | Mean (N)    | Mean difference | 95% CI          | P value        |
| No CAC                         | 290 | 0.4          | Ref             | Ref             | Ref            |
| Unilateral (categories 1-4) or bilateral (categories 1-3) CAC | 101 | 2.1          | 1.6             | 1.3-1.9         | < .001*        |
| Bilateral CAC, including 1 or 2 category 4 | 23  | 2.9          | 2.4             | 1.9-3.0         | < .001*        |
| CAC groups according to PR      | n   | Mean (%)     | Mean difference | 95% CI          | P value        |
| No CAC                         | 290 | 6.9          | Ref             | Ref             | Ref            |
| Unilateral (categories 1-4) or bilateral (categories 1-3) CAC | 101 | 30.1         | 23.3            | 18.7-27.8       | < .001*        |
| Bilateral CAC, including 1 or 2 category 4 | 23  | 44.0         | 37.2            | 28.6-45.7       | < .001*        |

*Significant P value.
CAC, carotid artery calcification; n, number of participants.
P values were obtained by 1-way analysis of variance and Bonferroni correction model.
Fig. 5. Participant-level findings on carotid ultrasound imaging in relation to findings on panoramic radiographs illustrated in boxplots for no carotid artery calcification (CAC), unilateral CAC categories 1-4 or bilateral CAC categories 1-3 and bilateral CAC including uni- or bilateral category 4. The box indicates the interquartile range, the line in the box shows the median and X the mean, and the whiskers show the minimum and maximum values. The dots above the whiskers are outliers. (A) Largest individual area of a plaque; (B) number of plaques; and (C) percentage reduction of the lumen.

Unilat., unilateral; Bilat., bilateral; cat., category.
carotid arteries upon US examination, which is consistent with the results of the present study. Overall, our results suggest that if CACs are detected on PRs, especially if they are bilateral and vessel-outlining, there is also a very high probability of vascular changes found by US. This supports the hypothesis that CAC corresponds with the findings in US examinations.

A limitation of the study is the high exclusion rate, mainly due to suboptimal PRs. However, the number of participants was still high (n = 414), making the statistical analyses valid. There is also a risk of health selection bias, suggesting that people who choose to participate in MOS and MODS are healthier than the general population. Therefore, a strength of the study is that the risk of type II errors is low. Furthermore, all assessments of the PRs and US examinations were performed by well-calibrated professionals.

CONCLUSION

Independent of shape, the presence of CACs on PRs is associated with a higher degree of atherosclerosis (plaques), according to carotid US, compared with participants with no CAC on PRs. The degree of US-detected atherosclerosis was most pronounced for vessel-outlining CAC, especially when included in bilateral findings. With refined differential diagnostics for CAC on PRs, dentists could more accurately identify patients who would benefit from cardiovascular prevention, thereby decreasing the risk of CVD-related morbidity and death.

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PRESENTATION

Preliminary results were presented during the Swedish Dental Association’s annual meeting in November 2022.

DECLARAITON OF INTEREST

None.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.ooom.2023.12.783.

REFERENCES


