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Association of diabetes with age-related macular degeneration in the EUREYE study

F Topouzis,1 E Anastasopoulos,1 C Augood,2 G C Bentham,3 U Chakravarthy,4 P T V M de Jong,5 M Rahu,6 J Seland,7 G Soubrane,8 L Tomazzoli,9 J R Vingerling,5 J Vioque,10 I S Young,11 A E Fletcher2

ABSTRACT
Objective: To examine the association between self-reported diabetes history and early or late age-related macular degeneration (AMD) in the European population. Methods: Participants aged 65 years and over in the cross-sectional population-based EUREYE study underwent an eye examination including digital retinal photography. The images were graded at a single centre. A structured questionnaire was administered by trained field workers for putative risk factors for AMD including history of diabetes mellitus. Logistic regression models were used to examine the association between diabetes and stages of AMD, taking account of potential demographic, behavioural, dietary and medical (history of cardiovascular disease) confounders. Main outcome measures: Photographic images were graded according to the modified International Classification System for AMD and stratified into five exclusive stages from no signs of AMD (AMD stage 0), early AMD (Stages 1–3) and late AMD (Stage 4). Late AMD was subdivided in neovascular AMD (NV-AMD) or geographic atrophy (GA). Results: Data on diabetes history and potential founders were available in 2117 control subjects without AMD, 2182 with early AMD, 49 with GA and 101 with NV-AMD. Of all participants, 13.1% reported a history of diabetes. After adjusting for potential founders, subjects with neovascular AMD compared with controls had increased odds for diabetes (odds ratio 1.81; 95% confidence interval, 1.10 to 2.98, p = 0.02). Subjects with AMD grades 1 to 3 or GA had no increased odds for diabetes compared with those without AMD. Conclusions: In the EUREYE study, after multiple adjustments, positive association of diabetes mellitus with neovascular AMD was found. The hypothesis that diabetes is associated with neovascular AMD but not with geographic atrophy may suggest a different pathogenesis of the two advanced forms of the disease and needs to be further evaluated.

Age-related macular degeneration (AMD) is an important cause of irreversible visual impairment or blindness in the adult Western World. The prevalence of AMD and the subsequent burden in public health are expected to rise as a result of the progressive increase in the life expectancy and the proportion of elderly persons in the population. The identification and modification of risk factors may have the potential for improving knowledge of pathogenetic mechanisms, facilitating prevention and subsequently reducing the morbidity associated with the disease.

The pathogenesis of AMD is considered to be multifactorial. Although many previous studies assessed a considerable number of demographic, environmental, genetic or medical risk factors for AMD, the majority remain controversial. AMD and cardiovascular disease have been hypothesised to share common pathways. Diabetes mellitus as a major cause of cardiovascular disease has been linked also with AMD. However, to date, most of the epidemiological data have not been consistent regarding the association of diabetes with AMD, with some studies finding an association, others not, while one study reported an inverse relationship between diabetes and incident reticular drusen. In addition, even in studies that found an association of diabetes with AMD, the specific association with types of late AMD (neovascular AMD or geographic atrophy) was also inconsistent.

The EUREYE study is a multicentre, population-based, analytical cross-sectional study of risk factors for AMD with retrospective and current exposure measurements. The study centres (Estonia, France, Greece, Italy, Norway, Spain, UK) were chosen to maximise the range of geographical latitude and lifestyle behaviours, including diet since primary hypotheses were related to sunlight exposure and antioxidants. We examined the association of diabetes with AMD stages and late AMD types in the EUREYE study.

MATERIALS AND METHODS
Population
The methods used to identify and describe this population have been published previously. In brief, participants were recruited from random sampling of the population aged over 65 years and attended the examination centre where they were first interviewed by trained field workers and then underwent an ophthalmological examination and provided a non-fasting blood sample.

Risk-factor assessment
Measurement of general lifestyle and medical history risk factors
Sociodemographic details and educational level were recorded. Self-reported data on current and past smoking, alcohol consumption habits, history of cardiovascular disease (stroke or heart attack), angina and use of aspirin were collected. A history of diabetes mellitus was defined as a positive answer to the question: “Have you ever been told by a doctor that you have diabetes (sugar in the blood)?” For each study centre, the years of education were
classified into tertiles: low education group (for the lower third), middle (the middle third) and high (upper third).

Measurement of other risk factors
We measured weight and demispan (the distance between the sternal notch and the finger roots with the arm out-stretched laterally). The demisquet index was calculated as weight/ demispan². For comparison with other studies, we also calculated the body mass index (BMI) as weight/(kg)/height (m)² in which height was calculated from demispan using equations derived from a sub study in the Alicante population.17 Systolic and diastolic blood pressures were measured with the arm in the seated position after 3–5 minutes' rest. Two readings were taken with a 5-min interval, and the average of the two values recorded was used. Field workers in all centres followed the same protocol and used the same type of sphygmomanometer (OMRON HEM 705 CP).

Fundus photography and grading
Following pupillary dilation with tropicamide 0.5% and phenylephrine 5%, two 35° non-simultaneous stereoscopic colour fundus images were taken of each eye, centred on the fovea. Images from participants were saved without manipulation as raw TIFF files to compact discs and sent to the grading centre in Rotterdam. The fundus images were graded according to a modification of the International Classification and Grading System for AMD.35 In this system, all AMD fundus signs within a standard circle (diameter 6 mm) around the fovea are recorded. Two highly experienced staff in the Rotterdam Fundus Photography Reading Centre undertook grading of the fundus. We next categorised eyes into five mutually exclusive stages from 0 to 4 according to fundus signs that had an increasing risk of late AMD. No AMD was defined as stage 0, meaning no signs of AMD at all or only hard drusen (<63 μm). Stage 1 was defined as soft distinct drusen (≥63 μm) or pigmentary abnormalities, stage 2 as soft indistinct drusen (≥125 μm) or reticular drusen only or soft distinct drusen (≥63 μm) with pigmentary abnormalities and stage 3 as soft indistinct drusen (≥125 μm) or reticular drusen with pigmentary abnormalities. Stage 4 was similar to late AMD subdivided into geographic atrophy or neovascular AMD. Geographic atrophy (GA) was defined as any sharply demarcated round or oval area of apparent absence of the RPE, larger than 175 μm, with visible choroidal vessels, and no wet AMD. Neovascular (NV) AMD was defined as the presence of a serous or haemorrhagic detachment of the RPE and/or a subretinal neovascular membrane and/or subretinal haemorrhage, and/or periretinal fibrous scarring, even with patches of GA.35 Out of the total sample size of 4753 participants with gradable fundus images, there were 2262 controls persons with grade 0, 2333 early AMD (1734 grade 1, 482 grade 2, 117 grade 3) and 158 late images, there were 2262 controls persons with grade 0, 2333 the total sample size of 4753 participants with gradable fundus periretinal fibrous scarring, even with patches of GA.19 Out of

RESULTS
Overall, the prevalence of self-reported diabetes was 13.1% (n = 616). Compared with those without diabetes, people with diabetes were more likely to be male, to have a lower level of education, to report a positive history of cardiovascular disease or angina, to report a regular use of aspirin, to have a higher BMI, to have a higher systolic blood pressure (SBP), to have a lower blood level of total cholesterol, lower level of vitamin C and to have a higher alpha-tocopherol-to-cholesterol ratio (table 1).

Diabetes was strongly associated with the presence of retinal haemorrhages as identified by the fundus images grading (table 1). In analyses adjusted for age, sex, systolic pressure and history of cardiovascular disease, people with diabetes were significantly more likely to have retinal haemorrhages (OR 4.37, 95% CI 3.77 to 5.08, p <0.0001). The association of diabetes with bilateral retinal haemorrhages was even stronger; the adjusted OR for diabetes was 22.64, 95% CI 14.89 to 34.46, p<0.0001.

The prevalence of diabetes among the five AMD groups is presented in table 2. The prevalence of diabetes among subjects with GA was 13.2%, while the prevalence of diabetes among subjects with neovascular AMD was 19.3%. In the regression analysis, the association of diabetes with grades of AMD was adjusted for age and sex. Diabetes was not associated with early AMD grades or with geographic atrophy. In contrast, subjects with neovascular AMD were 1.75 times more likely to have diabetes (p = 0.016) compared with those with AMD grade 0 (controls). The results were additionally adjusted for the following parameters: smoking, educational level, alcohol intake, body mass index (BMI), self-reported history of cardiovascular disease, regular aspirin intake, systolic blood pressure, serum alpha-tocopherol-to-cholesterol ratio, vitamin C and lutein level; the association did not change significance. After multiple adjustments, subjects with neovascular AMD were 1.81 times more likely to have diabetes (p = 0.02), compared with those without AMD. Either AMD grades 1–3 or GA were not associated with diabetes in the fully adjusted model (table 3).
DISCUSSION

In the EUREYE Study, an association between self-reported diabetes mellitus and neovascular AMD was observed. This association remained significant after adjusting for potential confounders. No association was found for diabetes history with any stage of early AMD (stages 1–3) or GA.

Diabetes-related changes in the function and structure of the retinal pigment epithelium, Bruch membrane and the choroidal circulation have been hypothesised to increase the risk of AMD. Histopathological studies in eyes of subjects with diabetes of long duration have shown thickening of the basement membrane of the choriocapillaries walls, luminal narrowing, dropout of the choriocapillaries and thickening of the Bruch membrane, factors that may predispose to the development of AMD. However, there is poor evidence for a common pathogenetic pathway since data from epidemiological studies are inconsistent.

There is limited population-based evidence supporting a clear association between diabetes and AMD. In the Beaver Dam Eye Study, diabetes was not associated with early AMD. However, in persons older than 75 years, those with diabetes had a higher frequency of neovascular AMD (9.4%) than those without diabetes (4.7%), but both groups had similar frequencies of geographic atrophy. The relative risk of neovascular AMD in diabetic men over 75 years of age was 10.2 (95% CI 2.4 to 43.7); for women it was 1.1 (95% CI 0.4 to 3.0). The authors noted that they were unable to explain the observed relationship between neovascular AMD and diabetes in older men, but not women, and suggested that this might be the result of chance.

In this context, it is worth noting that among women who participated in the Women’s Health Initiative Sight Exam Ancillary study, a history of diabetes was associated with a 2.5-fold increased risk for neovascular AMD but not associated with either early AMD or GA. In contrary, the Blue Mountains Eye Study reported that diabetes was significantly associated with the prevalence of geographic atrophy (OR 4.0; 95% CI 1.6 to 10.3), but no association was found for either neovascular AMD (OR 1.2; 95% CI 0.4 to 3.5) or early AMD (OR 1.0; 95% CI 0.5 to 1.8). In the 5- and 10-year incidence studies of the same cohort, diabetes was also related to an increased risk of incident geographic atrophy (RR 8.3 and 3.9, respectively) but not to neovascular AMD. In a cohort study of a black population in Barbados, a 2.7-fold association of diabetes history with incident AMD was reported; however, a subtype analysis of AMD was not performed. Diabetes history was not associated with early AMD in this study either.

Table 1 Characteristics of people with and without a history of diabetes in the EUREYE Study (n = 4247 with data on full confounders)

<table>
<thead>
<tr>
<th></th>
<th>Diabetes (n = 561)</th>
<th>No diabetes (n = 3686)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age* (years)</td>
<td>72.86 (5.00)</td>
<td>73.09 (5.67)</td>
<td>0.3</td>
</tr>
<tr>
<td>Sex (n, % men)</td>
<td>284 (50.6)</td>
<td>1623 (44.0)</td>
<td>0.04</td>
</tr>
<tr>
<td>Lowest tertile of education (n, %)</td>
<td>229 (40.8)</td>
<td>1370 (37.2)</td>
<td>0.02</td>
</tr>
<tr>
<td>Smoking (n, %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>289 (51.5)</td>
<td>1965 (53.3)</td>
<td>0.4</td>
</tr>
<tr>
<td>Ex</td>
<td>199 (35.5)</td>
<td>1188 (32.2)</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>73 (13.0)</td>
<td>533 (14.5)</td>
<td></td>
</tr>
<tr>
<td>Alcohol consumption (n, %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>114 (20.3)</td>
<td>567 (15.4)</td>
<td>0.08</td>
</tr>
<tr>
<td>Infrequent</td>
<td>223 (39.8)</td>
<td>1618 (43.9)</td>
<td></td>
</tr>
<tr>
<td>Weekly or more</td>
<td>224 (39.9)</td>
<td>1501 (40.7)</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular disease† (n, %)</td>
<td>124 (22.1)</td>
<td>461 (12.5)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Angina‡ (n, %)</td>
<td>143 (25.5)</td>
<td>450 (12.2)</td>
<td>0.001</td>
</tr>
<tr>
<td>Retinal haemorrhages either eye§</td>
<td>102 (18.6)</td>
<td>162 (4.5)</td>
<td>&lt;0.00001</td>
</tr>
<tr>
<td>Regular use of aspirin¶ (n, %)</td>
<td>143 (25.5)</td>
<td>739 (20.1)</td>
<td>0.06</td>
</tr>
<tr>
<td>BMI &gt;30 (n, %)</td>
<td>256 (45.6)</td>
<td>1273 (34.5)</td>
<td>0.002</td>
</tr>
<tr>
<td>SBP*, mm Hg</td>
<td>155.38 (22.40)</td>
<td>149.88 (22.34)</td>
<td>0.03</td>
</tr>
<tr>
<td>Total cholesterol*, µmol/l</td>
<td>5.35 (1.12)</td>
<td>5.77 (1.11)</td>
<td>0.02</td>
</tr>
<tr>
<td>Vitamin C**, µmol/l</td>
<td>40.0 (22.6 to 56.4)</td>
<td>45.4 (27.5 to 62.4)</td>
<td>0.02</td>
</tr>
<tr>
<td>Lutein** (µmol/l)</td>
<td>0.123 (0.049 to 0.286)</td>
<td>0.113 (0.047 to 0.276)</td>
<td>0.7</td>
</tr>
<tr>
<td>Zeaxanthin** (µmol/l)</td>
<td>0.029 (0.016 to 0.057)</td>
<td>0.021 (0.015 to 0.054)</td>
<td>0.7</td>
</tr>
<tr>
<td>Alpha-tocopherol*** †† (µmol/mmol cholesterol)</td>
<td>5.55 (4.85 to 6.47)</td>
<td>5.19 (4.49 to 5.94)</td>
<td>0.003</td>
</tr>
</tbody>
</table>

*Mean (standard deviation). †History of heart attack or stroke. ‡Information missing in seven people (one with diabetes and six without diabetes). §Information missing in 92 people (11 with diabetes and 81 without diabetes). ¶At least once a week. **Median (interquartile range). ***Ratio of alpha tocopherol to cholesterol.

Table 2 Prevalence of self-reported diabetes by age-related macular degeneration (AMD) grade in the EUREYE study (n = 4722, 31 subjects with missing data on diabetes)

<table>
<thead>
<tr>
<th>AMD grade</th>
<th>No diabetes n (%)</th>
<th>Diabetes n (%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No AMD</td>
<td>1954 (87.0)</td>
<td>292 (13.0)</td>
<td>2246</td>
</tr>
<tr>
<td>AMD grade 1</td>
<td>1491 (86.6)</td>
<td>231 (13.4)</td>
<td>1722</td>
</tr>
<tr>
<td>AMD grade 2</td>
<td>430 (89.6)</td>
<td>50 (10.4)</td>
<td>480</td>
</tr>
<tr>
<td>AMD grade 3</td>
<td>100 (86.5)</td>
<td>16 (13.8)</td>
<td>116</td>
</tr>
<tr>
<td>Late AMD</td>
<td>131 (82.9)</td>
<td>27 (17.1)</td>
<td>158</td>
</tr>
<tr>
<td>Total</td>
<td>4106 (87.0)</td>
<td>616 (13.1)</td>
<td>4722</td>
</tr>
</tbody>
</table>
self-reported diabetes have been found to be similar to those from clinical and laboratory evaluations. In our study, people with a self-reported history of diabetes were four times more likely to have retinal haemorrhages on fundus photography and 23 times more likely to have bilateral haemorrhages, lending strength to the the validity of the self-reported measure. In addition, we have no reason to believe that any misreporting was related to AMD status. We cannot exclude the possibility that people with AMD were more likely to be attending an ophthalmologist and therefore identified with diabetes earlier than the controls persons. However, the majority of people (69%) in our study did not report a history of AMD.

In conclusion, the EUREYE study results support a positive association between history of diabetes with neovascular AMD but not with geographic atrophy or early AMD. The hypothesis that diabetes mellitus is associated only with neovascular AMD may suggest a different pathogenesis of the two advanced forms of the disease and needs to be evaluated further.

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Competing interests: None.

Ethics approval: Ethics approval was obtained at each centre from the relevant ethics committee.

Patient consent: Obtained.

REFERENCES


Clinical science

Table 3  Association between diabetes mellitus and age-related macular degeneration (AMD) by grade and type of AMD in the EUREYE study

<table>
<thead>
<tr>
<th>AMD grade</th>
<th>OR* (95% CI)</th>
<th>OR* (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 1552</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 430</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 152</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 95</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*In all analyses, the comparison group are those with ARM grade 0, n = 2024 with data on all confounders.

<table>
<thead>
<tr>
<th>Geographic atrophy</th>
<th>OR (95% CI)</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 108</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 104</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 1040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 111 to 2.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Adjusted for age and sex.

**Adjusted for age, sex, smoking, education, BMI, alcohol consumption, cardiovascular disease, aspirin use, systolic blood pressure, alpha-tocopherol ratio, vitamin C and lutein.

Possible associations between diabetes and AMD have been identified by the Age-related Eye Disease Study (AREDS), a randomised, prospective, clinical trial. A history of diabetes was associated with increased risk for incident neovascular AMD (OR: 1.88) and not for GA in persons at risk of developing advanced AMD in one eye.7

Dietary glycaemic index (dGI) has been linked to AMD. A high dGI was found on a cross-sectional analysis of the AREDS cohort to be associated with an increased risk of early and late AMD in non-diabetic subjects.25 In another report of the same study, a high dGI was reported to be associated with an increased risk of AMD progression in persons with early stages of the disease.26 The dGI is a weighted average of the glycaemic index of foods in the diet. High dGI is an indicator of poor-quality dietary carbohydrate intake and has been implicated in the development of diabetes and cardiovascular disease. It may increase the risk of AMD through several common aetiological factors of diabetes and cardiovascular disease, including the formation of advanced glycation end products and increases in oxidative stress, inflammation and hyperlipidaemia.

A number of studies have suggested an association between AMD and history of cardiovascular disease. Since diabetes is a major risk factor for cardiovascular disease, the association of diabetes with AMD could be mediated by the presence of cardiovascular disease. However, in the EUREYE study, the association of diabetes with neovascular AMD was independent of a history of cardiovascular disease. After adjustment, cardiovascular disease was not significantly associated with neovascular AMD (OR: 1.48; 95% CI 0.83 to 2.64; p = 0.2).

The EUREYE study is population-based, and because the participants were aged 65 or older there were more cases of late AMD than previous epidemiological studies, thus giving it additional power to detect associations with risk factors. However, the study also has several limitations. Our results were based only on self-reported history of diabetes, and participants may have incorrectly reported their diabetes status. However, self-reports of certain chronic conditions like diabetes are considered reasonably accurate, and prevalence estimates of...


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