Confirmation of association between the e4 allele of apolipoprotein E and Alzheimer’s disease

M Liddell, J Williams, A Bayer, F Kaiser, M Owen

Abstract
The Apo E genotype of 86 patients with Alzheimer’s disease (AD) and 77 age matched controls was determined by digestion of Apo E PCR products with the restriction enzyme CfoI. The frequency of the e4 allele was significantly increased in the patient group (0.33) as compared with controls (0.12). This effect was seen in patients with a family history and in sporadic cases. The odds ratio in homozygotes for the e4 allele was 11.24 (95% confidence interval 2.45-51.50). There was no relationship between age of onset and Apo E genotype. There was no linkage disequilibrium between the apolipoprotein E locus and a TaqI polymorphism at the Apo CII locus, and no allelic association between Apo CII and AD.

Methods
The patient group consisted of 95 subjects with AD (44 males and 51 females): 34 were obtained from the Cardiff Memory Clinic; 28 were the first sample members of families with more than one case of late onset AD and 33 were recruited from local psychogeriatric hospitals. The mean age of the patient group was 73.5 years (SD 10.1) with a mean age of onset of 67.5 years (SD 9.3). The majority of patients had an age of onset greater than 65 years (n = 56). Patients met the NINCDS criteria for probable AD. An age matched control group consisting of 86 subjects was obtained from the community with the help of a local general medical practice who identified elderly non-demented persons from their practice records. Potential controls were screened with the Mini mental State examination and included if they scored 28 or higher. The mean age of the control group was 73.2 years (SD 6.07). All patients and controls were white.

With the approval of the local ethics committee and the consent of the patient’s nearest relative, a sample of venous blood, anticoagulated with EDTA, was taken and DNA extracted from the white cells by a standard procedure. Digestion of the DNA and Southern blotting were also carried out by standard procedures. The Apo CII cDNA probe used was a 440 bp cDNA insert, which detects allelic fragments of 3.8 kb and 3.9 kb, designated A1 and A2 respectively, after digestion with TaqI. PCR analysis of apolipoprotein E genotypes was carried out by the method of Wenham et al.

Differences in allele and genotype frequencies were analysed by the method of Woolf. The observed and expected genotype frequencies were compared in order to determine that the loci were in Hardy-Weinberg equilibrium (HWE) using a χ² goodness of fit test. For the Apo E polymorphism, alleles 2 and 3 were collapsed because of small cell sizes. Haplo-type frequencies were estimated according to a

Department of Psychological Medicine, University of Wales College of Medicine, Heath Park, Cardiff CF4 4XN, UK
M Liddell
J Williams
F Kaiser
M Owen

Department of Medical Genetics, University of Wales College of Medicine, Heath Park, Cardiff CF4 4XN, UK
M Liddell
M Owen

Department of Geriatric Medicine, University of Wales College of Medicine, West Wing, Cardiff Royal Infirmary, Newport Road, Cardiff CF2 1SZ, UK
A Bayer

Correspondence to Dr Liddell.
Received 9 July 1993
Revised version accepted for publication 6 October 1993
maximum likelihood procedure. The significance of linkage disequilibrium (D) was tested by a likelihood ratio test.

Results

APO CII ASSOCIATION STUDY

Results were obtained for 78 controls (38 males) and 89 patients (43 males) and are shown in table 1. The frequency of the smaller 3.5 kb allele in the control group was 0.52 and in the patient group 0.53. Forty seven of the patient group were known to have affected first degree relatives and, considering this subgroup, the frequency of the A2 allele was 0.57. This difference was not statistically significant ($\chi^2 = 1.31$, df = 1, p = 0.25). The observed distributions of genotypes were close to the values expected on the basis of Hardy-Weinberg equilibrium in both the patients ($\chi^2 = 0.2$, df = 1, p = 0.65) and controls ($\chi^2 = 3.16$, df = 1, p = 0.08).

APO E ASSOCIATION STUDY

Apo E genotyping was successful in 77 controls (38 males) and 86 patients (43 males) and the results are shown in table 2. The figure illustrates the appearance of the six possible Apo E genotypes after digestion of Apo E PCR products with CfoI and electrophoresis through 10% polyacrylamide. In the control group the frequencies of e2 (0.11), e3 (0.77), and e4 (0.12) alleles did not differ markedly from those found previously in population surveys. In contrast, the prevalence of the e4 allele was markedly increased in the patients (0.33) as compared to the control group (0.12) and this was highly significant ($\chi^2 = 18.4$, df = 1, p = 0.0002; OR = 3.5; 95% confidence interval 2.6–3.4). The risk of AD in e4 homozygotes (OR = 10.67, 95% confidence interval 2.3–48.8) was greater than in the absence of the e4 allele (OR = 2.22, 95% confidence interval 1.1–4.7) when compared with those without the e4 allele. However, the difference between e4 homozygotes and heterozygotes did not achieve statistical significance ($\chi^2 = 3.7$, df = 1, p = 0.055; OR = 4.8; 95% confidence interval 1–23.9). Genotype frequencies in the control group were close to those expected on the basis of HWE ($\chi^2 = 0.51$, df = 1, p = 0.5). Significant departure from HWE was observed in the patients ($\chi^2 = 9.97$, df = 1, p = 0.002), reflecting the relative excess of e4 homozygotes in this group.

A one way analysis of variance comparing age of onset in patients with no, one, or two copies of the e4 allele found no significant effect (F ratio = 1.95, df = 2, p = 0.15). On the other hand, there appeared to be some effect of family history on the prevalence of the e4 allele, the frequency of the e4 allele being 0.4 in the presence and 0.26 in the absence of a family history of AD, although this trend was not statistically significant ($\chi^2 = 2.3$, df = 1, p = 0.13).

LINKAGE EQUILIBRIUM BETWEEN THE APO CII AND APO E LOCI

Using the data in table 3 it is possible to ascertain unambiguously 134 patient and 122 control Apo E-Apo CII haplotypes. In the patient group, there appears to be a slight excess of the e4 A2 haplotype, but the distribution skew was not significant at the 5% level ($\chi^2 = 4.55$, df = 2, p = 0.1). There was no suggestion of linkage disequilibrium occurring in the control group ($\chi^2 = 1.83$, df = 2, p = 0.4).

Discussion

We have replicated the original observation of Strittmatter et al. of an association between

<table>
<thead>
<tr>
<th>Genotypes of Apo CII</th>
<th>Genotypes of Apo E</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1A_1$</td>
<td>$A_1A_2$</td>
</tr>
<tr>
<td>$A_2A_2$</td>
<td>$A_2A_3$</td>
</tr>
<tr>
<td>$A_3A_3$</td>
<td></td>
</tr>
</tbody>
</table>

The appearance of the six possible Apo E genotypes after digestion of PCR amplified Apo E DNA with CfoI and electrophoresis through 10% polyacrylamide (after Wenham et al.). The tracks are identified as follows: Track M, DNA size markers; track 1, Apo E 3/4 genotype; track 2, Apo E 2/4 genotype; track 3, 2/3 genotype; track 4, Apo E 4/4 genotype; track 5, Apo E 3/3 genotype; track 6, Apo E 2/2 genotype; track 7, undigested PCR amplified DNA.

The signiﬁcance of linkage disequilibrium (D) was tested by a likelihood ratio test.

The results are shown in table 2. The figure illustrates the appearance of the six possible Apo E genotypes after digestion of Apo E PCR products with CfoI and electrophoresis through 10% polyacrylamide. In the control group the frequencies of e2 (0.11), e3 (0.77), and e4 (0.12) alleles did not differ markedly from those found previously in population surveys. In contrast, the prevalence of the e4 allele was markedly increased in the patients (0.33) as compared to the control group (0.12) and this was highly significant ($\chi^2 = 18.4$, df = 1, p = 0.0002; OR = 3.5; 95% confidence interval 2.6–3.4). The risk of AD in e4 homozygotes (OR = 10.67, 95% confidence interval 2.3–48.8) was greater than in the absence of the e4 allele (OR = 2.22, 95% confidence interval 1.1–4.7) when compared with those without the e4 allele. However, the difference between e4 homozygotes and heterozygotes did not achieve statistical significance ($\chi^2 = 3.7$, df = 1, p = 0.055; OR = 4.8; 95% confidence interval 1–23.9). Genotype frequencies in the control group were close to those expected on the basis of HWE ($\chi^2 = 0.51$, df = 1, p = 0.5). Significant departure from HWE was observed in the patients ($\chi^2 = 9.97$, df = 1, p = 0.002), reflecting the relative excess of e4 homozygotes in this group.

A one way analysis of variance comparing age of onset in patients with no, one, or two copies of the e4 allele found no significant effect (F ratio = 1.95, df = 2, p = 0.15). On the other hand, there appeared to be some effect of family history on the prevalence of the e4 allele, the frequency of the e4 allele being 0.4 in the presence and 0.26 in the absence of a family history of AD, although this trend was not statistically significant ($\chi^2 = 2.3$, df = 1, p = 0.13).

LINKAGE EQUILIBRIUM BETWEEN THE APO CII AND APO E LOCI

Using the data in table 3 it is possible to ascertain unambiguously 134 patient and 122 control Apo E-Apo CII haplotypes. In the patient group, there appears to be a slight excess of the e4 A2 haplotype, but the distribution skew was not significant at the 5% level ($\chi^2 = 4.55$, df = 2, p = 0.1). There was no suggestion of linkage disequilibrium occurring in the control group ($\chi^2 = 1.83$, df = 2, p = 0.4).

Discussion

We have replicated the original observation of Strittmatter et al. of an association between
the e4 allele of apolipoprotein E and AD. Our data also suggest that the risk of AD may be greater in e4 homozygotes than in heterozygotes. The frequency of the e4 allele in our patients is not as strong as in the first study (0.33 ± 0.50). A plausible explanation for this difference is that the cases studied by Strittmatter et al.13 were all from multiply affected families. In contrast, our patient group, although enriched for a positive family history, contained almost 50% of apparently sporadically occurring AD. In fact, Saunders et al.4 have found that the frequency of the e4 allele in probable sporadic AD was 0.36, a figure which is closer to our own. Interestingly, these workers also found that the e4 frequency in 176 cases of necropsy proven AD was, at 0.4, higher than the rate for clinically diagnosed probable AD. This raises the possibility that diagnostic inaccuracy may have reduced the e4 frequency in our clinically diagnosed series. However, the trend in our data suggests that the e4 allele frequency is higher in the family history positive cases and this would be in keeping with the presumptive increase in genetic loading expected in AD kindreds.

Our inability to show an association between AD and the single allele of the Apo CII TaqI RFLP is in odds with the work of Schellenberg et al.11 It is possible that the increased familial loading in their sample may, in part, account for this difference. Another possibility is that there is an age effect on the allele frequency of this RFLP such that bearers of the small TaqI RFLP are more likely to reach advanced age. Thus, the fact that our control group was age matched, whereas that of Schellenberg et al was not, may explain why the frequency of the smaller allele was larger in our controls (0.53) than in the earlier study (0.39). Inadequate digestion of the DNA by TaqI in our study would seem to be an unlikely explanation for the differences in Apo CII TaqI RFLP allele frequencies between the two studies, since we obtain an excess of the smaller, therefore digested, restriction fragment.

The fact that we were unable to show linkage disequilibrium between alleles of the Apo CII and Apo E genes, in keeping with the later work of Houlton et al., although in view of the data trend in the patient group, it may well be that a larger patient series would show linkage disequilibrium between the two loci in AD patients.

The contribution made by apolipoprotein E to the pathogenesis of AD is unclear. Of course, it is logically possible that the Apo E gene merely acts as a neutral marker for some other gene with which it is in linkage disequilibrium and which predisposes to AD. However, a number of lines of evidence point to the direct involvement of apolipoprotein E in the pathogenesis of AD. Like APP, it is known to be a neuronal stress protein, because its synthesis is greatly increased following injury to the nervous system.25-28 Apolipoprotein E has also been shown to bind to amyloid deposits in AD and Creutzfeldt-Jakob disease, as well as to intracellular neurofibrillary tangles.29 Recent work suggests that it may facilitate the deposition of A4 peptide as amyloid. Strittmatter et al.13 have convincingly shown that apolipoprotein E binds avidly to synthetic A4 peptide and have gone on to show that the apolipoprotein e4 allele, at physiological pH, binds more rapidly to b amyloid peptide than the e3 form.13,30 In another study Schmechel et al.11 have shown that AD brains from patients with one or two e4 alleles have increased amyloid deposition as compared to brains from those who do not possess this allele. These findings suggest that apolipoprotein e4 might increase the rate at which amyloid deposits accumulate. If this is correct, then it is perhaps surprising that our data, and that of Saunders et al.,6 do not show a relationship between e4 genotype and age of onset of AD. However, this may have occurred as a result of ascertainment biases. Indeed, a more recent study of 42 families with late onset AD32 found that mean age of onset decreased from 84 to 68 years with increasing number of e4 alleles.

Whatever the role apolipoprotein E plays in the pathogenesis of AD, it seems that there is an increased prevalence of the e4 allele in patients with AD. The prevalence may be even further in family history positive AD cases. We estimate that considering the patient group as a whole, possession of the e4 allele increases the risk of AD by some 3-5-fold, and the relative risk in e4 homozygotes may be as high as 10.

This work was generously supported by a grant from the Mental Health Foundation. Additional funds were provided by the Swansea and Liue Valley branch of the Alzheimer’s Disease Society. We also thank Dr M E Robinson and M A L Jones Barlow, and Drs Daniels of the Health Centre, Dinas Powys for their help in the collection of the control group; Professor G Wilcock, Department of the Care of the Elderly, Frenchay Hospital, Bristol, for clinical material; and Dr Allen Roses for access to data before publication.