LETTER TO JMG

Common apolipoprotein E polymorphisms and risk of clinical malaria in the Gambia

C Aucan, A J Walley, A V S Hill

A

polipoprotein E (apoE) is a protein involved in the transport and metabolism of plasma cholesterol and triglycerides. The apolipoprotein E gene (APOE), located at chromosome 19q13.2, has three major alleles called ε2, ε3, and ε4, defined by two single nucleotide polymorphisms (SNP) located in exon 4 at positions 3937 (T/C) and 4075 (C/T). The corresponding apoE isoforms differ at amino acid positions 112 (Cys for apoE2 and apoE3, Arg for apoE4) and 158 (Arg for apoE3 and apoE4, Cys for apoE2), and have been shown to have different functional and biochemical properties.

APOE polymorphisms have been studied in relation to several genetic diseases and disorders. The APOE ε4 allele has been associated with an increased risk of Alzheimer’s disease, coronary heart disease, and death after myocardial infarction. Conversely, the APOE ε2 allele was found to have a protective effect on the occurrence of Alzheimer’s disease. However, in other studies, APOE ε2 was associated with an increased risk of cardiovascular diseases and with some blood lipid abnormalities. It has been reported recently that APOE ε2 homozygote children from Ghana became infected with Plasmodium falciparum at an earlier age than those carrying other APOE genotypes.

In this study, performed in the Gambia, the APOE ε2, ε3, and ε4 allele distributions were analysed in children with mild (338 cases) or severe (530 cases) malaria, and in individually matched control children (560 subjects). Additionally, the APOE Th1/E47 polymorphism located in the APOE promoter region was studied in a subset of children consisting of 183 severe malaria cases and 179 controls.

MATERIALS AND METHODS

Study subjects

Between August 1989 and September 1990, 1428 children aged from 1 to 10 years were enrolled at the Royal Victoria Hospital of Banjul and at the Medical Research Council Hospital of Fajara, in the Gambia. Malaria was diagnosed if a patient with an appropriate clinical picture had parasitaemia >2500/µl, and relevant laboratory investigations did not suggest other diagnoses. Cerebral malaria was defined by a Blantyre coma score of more than 3 (persisting for more than 30 minutes after effective treatment of hypoglycaemia or convulsions) or repeated prolonged seizure (for more than 30 minutes) in a child with P falciparum parasitaemia and no other apparent cause of fits or coma. Severe malaria anaemia was defined as a haemoglobin level of less than 50 g/l on admission in a child with parasitaemia. Children with mild malaria had an uncomplicated febrile illness with P. falciparum parasitaemia and no other apparent cause of fever.

The group of severe malaria patients was matched to two control groups of children for age and area of residence. The mild controls were recruited at both hospitals and health centres in the study area. These children had mild, mostly infective, illnesses that did not require hospital admission and they did not have malarial parasites in their blood on microscopy. Severely infected controls were inpatients at the two hospitals, with a large range of other acute, mainly infective, illnesses but without evidence of current or recent malaria infection.

The ethnic composition of the population in this area is mixed: Mandinka (42%), Jola (14%), Wolof (14%), Fula (12%), and several less common ethnic groups. The children from the different groups were not matched for ethnic group; instead, analyses stratified with this variable were carried out. Details of this case control study have been described previously.

The study had the approval of the Gambian Government and of the MRC Joint Ethical Committee, and consent was obtained from the parent or guardian of each child entered.

Apolipoprotein E genotyping

Base positions mentioned in this paper refer to the APOE reference sequence GenBank AF261279. Three APOE SNP
markers, located at positions 832 (APOE-Th1/E47), 3937 (APOE-e2/e12), and 4075 (APOE-e4/e5), were studied by ligation detection reaction (LDR).\(^\text{13}\) For the APOE-Th1/E47 (G/T) SNP, PCR was performed in 15 µl of reaction mixture containing: 50 ng genomic DNA; 10 mM Tris-HCl; 50 mM KCl (pH 8.3); GeneAmp 10X Buffer II; Perkin Elmer, Beachwood, UK; 1.0 mM MgCl\(_2\); 80 µM of each dNTP; 1.0U AmpliTaq Gold DNA polymerase; and 0.33 µM each of forward (5'-TACCTTTCCTTGGGATCCAGG-3') and reverse (5'-ACTCAAGGATCCAGATCTG-3') primers.\(^\text{15}\) For the APOE 3937 (T/C) and 4075 (C/T) SNPs, a single PCR was performed in 20 µl of reaction mixture containing: 50 ng of genomic DNA; 10 mM Tris-HCl; 50 mM KCl (pH 8.3); 1.5 mM MgCl\(_2\); 50 µM of each dNTP; 1.0U AmpliTaq Gold DNA polymerase; and 0.25 µM each of forward (5'-AGATGCGGGCAGGCTTATCAGGA-3') and reverse (5'-CCTCCGAGGCCCCGGCTTGGTACAC-3') primers.\(^\text{14}\) PCR amplification reactions were performed using an MJ Research tetrad thermal cycler as follows: 94°C for 14 minutes; 39 cycles of 94°C for 60 seconds; 60°C (APOE-Th1/E47) or 67°C (APOE-Th1/E47) or in exon 4 (APOE 3937 and 4075) of the APOE gene.

RESULTS

Allele and genotype frequencies were compared between children with malaria and the control children, using the Pearson’s \(\chi^2\) test. Logistic regression analysis was then performed to take into account the effect of confounding factors such as age, gender, ethnicity, and household location.\(^\text{16}\) Statistical analyses were carried out with SPSS version 11 (SPSS Inc, USA) and EpiInfo version 1.1.2 (CDC, USA).

DISCUSSION

The results reported here demonstrate that, in this Gambian case control study, genetic polymorphisms within APOE do not significantly influence host resistance or susceptibility to severe malarial anaemia and cerebral malaria, the two most common forms of severe malaria. Surprisingly, when severe malaria cases were subdivided in clinical categories, the APOE e3/e4 genotype was found to be more common in children with both cerebral malaria and severe malarial anaemia (42.9%) than in controls (24.8%) and mild malaria cases (27.2%). However, these results must be considered with caution because they are based on a relatively small number of cases (49) and could be due simply to chance, or to a biased distribution of the APOE genotype in this particular sample. Indeed, when a correction factor is applied
Moreover, APOE receptors have been shown to bind to the sporozoites for binding to their receptor on hepatic cells, and hence influence host resistance to malaria infection. In mice models, sporozoites were shown to be less able to invade hepatic cells from LDLR knockout mice.19 Therefore, it is possible that a particular apoE isoform, such as apoE2, is less efficient than the other isoforms in competing with the sporozoites for binding to their receptor on hepatic cells, and hence influence host resistance to malaria infection. In Ghana, APOE polymorphisms were not found to influence individual blood infection levels.23 In our study, the APOE e3/e4 genotype was found to be more frequent in a small group of children (49) developing cerebral malaria and severe malarial anaemia simultaneously. This genotype was however not found to be significantly more frequent in children developing cerebral malaria only or severe malarial anaemia only, suggesting that APOE genotypes could have a role in the genetic control of this particular form of severe malaria; alternatively, this may simply be a chance result. These results suggest that APOE polymorphisms do not influence protection against cerebral malaria and severe malarial anaemia, but could have a role in protection against the early stages of the infection and possibly against a particularly severe form of severe malaria (cerebral malaria plus severe malarial anaemia). Further studies are required to assess the role of APOE polymorphisms in the risk of severe malaria in other populations.

**ACKNOWLEDGEMENTS**

We are grateful to the people of the Gambia for their cooperation. We thank C Allsopp, D Kwiatkowski, D Brewster, and N Anstey for their contributions to the design and execution of this case control study.

**Authors' affiliations**

C Aucan, A J Walley, A V S Hill, The Wellcome Trust Centre for Human Genetics, Roosevelt Drive, Oxford OX3 7BN, UK

The study was funded by the MRC and the Wellcome Trust.

A V S Hill is a Wellcome Trust Principal Research Fellow.

**Table 1** Distribution of APOE e2, e3, and e4 alleles in the Gambia

<table>
<thead>
<tr>
<th>Subjects*</th>
<th>Severe malaria</th>
<th>Cerebral malaria†</th>
<th>Severe malarial anaemia‡</th>
<th>Severe malarial anaemia + cerebral malaria‡</th>
<th>Mild malaria</th>
<th>Controls</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Alleles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1060</td>
<td>642</td>
<td>272</td>
<td>98</td>
<td>676</td>
<td>1120</td>
<td>2856</td>
</tr>
<tr>
<td>c2</td>
<td>134 (12.6)</td>
<td>80 (12.5)</td>
<td>41 (15.1)</td>
<td>7 (7.1)</td>
<td>76 (11.5)</td>
<td>155 (13.8)</td>
<td>367</td>
</tr>
<tr>
<td>c3</td>
<td>682 (64.3)</td>
<td>416 (64.8)</td>
<td>170 (62.5)</td>
<td>67 (68.4)</td>
<td>452 (66.9)</td>
<td>705 (62.9)</td>
<td>1839</td>
</tr>
<tr>
<td>c4</td>
<td>244 (23.0)</td>
<td>146 (22.7)</td>
<td>61 (22.4)</td>
<td>24 (24.5)</td>
<td>146 (21.6)</td>
<td>260 (23.2)</td>
<td>650</td>
</tr>
<tr>
<td>c2/c2</td>
<td>0.76</td>
<td>0.84</td>
<td>0.30</td>
<td>3.52</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c2/c3</td>
<td>0.68</td>
<td>0.66</td>
<td>0.17</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c2/c4</td>
<td>1.19</td>
<td>0.64</td>
<td>2.55</td>
<td>1.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c3/c3</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>c3/c4</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>c4/c4</td>
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</tbody>
</table>

*Percentages within each disease or control group are given in parentheses.
†Children (24) with severe hypoglycaemia only were excluded from this analysis.
‡Children (4) compared with the mild malaria group.

**Table 2** Distribution of APOE Th1/E47 polymorphism in the Gambia

<table>
<thead>
<tr>
<th>Subjects*</th>
<th>Severe malaria</th>
<th>Controls</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Alleles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>366</td>
<td>358</td>
<td>724</td>
</tr>
<tr>
<td>G/G</td>
<td>276 (75.4)</td>
<td>272 (76.0)</td>
<td>548</td>
</tr>
<tr>
<td>G/T</td>
<td>90 (24.6)</td>
<td>86 (24.0)</td>
<td>176</td>
</tr>
<tr>
<td>T/T</td>
<td>0.03</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>T/P</td>
<td>0.87</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

*Percentages within each disease or control group are given in parentheses.
†2×2 χ² test (df = 1) for comparison with the control group.
‡3×2 χ² test (df = 2) for comparison with the control group.

for the number of clinical groups (4) compared with controls in this study, this finding loses statistical significance. These results apparently contrast with a recent report from Ghana.20 However, different and hence complementary phenotypes were studied in the Gambia (mild and severe clinical malaria) and in Ghana, where children with the APOE e2/e2 genotype were found to be infected with P falciparum sooner than other children.20 This difference observed between children with different APOE genotypes could be explained by the fact that the different APOE isoforms have been shown to have different physiological properties and, in particular, have been shown to have different affinities for some of their receptors such as LRP and apoER2.21 Moreover, APOE receptors have been shown to bind to the circumsporozoite protein (CSP) from plasmodium sporozoites. In mice models, sporozoites were shown to be less able to invade hepatic cells from LDLR knockout mice.21 Therefore, it is possible that a particular apoE isoform, such as apoE2, is less efficient than the other isoforms in competing with the sporozoites for binding to their receptor on hepatic cells, and hence influence host resistance to malaria infection. In Ghana, APOE polymorphisms were not found to influence individual blood infection levels.22 In our study, the APOE e3/e4 genotype was found to be more frequent in a small group of children (49) developing cerebral malaria and severe malarial anaemia simultaneously. This genotype was however not found to be significantly more frequent in children developing cerebral malaria only or severe malarial anaemia only, suggesting that APOE genotypes could have a role in the genetic control of this particular form of severe malaria; alternatively, this may simply be a chance result. These results suggest that APOE polymorphisms do not influence protection against cerebral malaria and severe malarial anaemia, but could have a role in protection against the early stages of the infection and possibly against a particularly severe form of severe malaria (cerebral malaria plus severe malarial anaemia). Further studies are required to assess the role of APOE polymorphisms in the risk of severe malaria in other populations.

**ACKNOWLEDGEMENTS**

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The study was funded by the MRC and the Wellcome Trust.

A V S Hill is a Wellcome Trust Principal Research Fellow.
Correspondence to: C Aucan, The Wellcome Trust Centre for Human Genetics, Roosevelt Drive, Oxford OX3 7BN, UK; aucan@well.ox.ac.uk

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DATA ACCESS
GenBank: AF261279; OMIM: 107741

REFERENCES

ECHO

DQB1 alleles affect susceptibility to pulmonary TB in Europeans

The first study of its kind in white Europeans has suggested that the allelic frequency of histocompatibility genes is linked to susceptibility to pulmonary TB.

The frequency of DQB1 alleles in a white Polish population showed a significant positive association of DQB1*05 and pulmonary TB, with patients almost three times more likely to have DQB1*05 as controls (odds ratio (OR) 2.84; 95% confidence interval (CI) 1.57 to 5.13). This has been reported in many other ethnic populations.

On the other hand, patients were significantly less likely to have DQB1*02 (OR 0.39; 95% CI 0.21 to 0.71), which has not been noted elsewhere. Other alleles—DQB1*03, DQB1*04, and DQB1*06—had similar frequencies in patients and controls.

This preliminary study included 38 unrelated patients with newly identified active pulmonary TB in one hospital and 58 unrelated controls of similar age. Individuals in both groups were excluded, as necessary, to ensure uniform socioeconomic and ethnic background. All had had BCG immunisation. HLA typing was by low resolution PCR with sequence specific primers (PCR-SSP) of blood samples.

The study provides yet more evidence that variation in the HLA system affects response to infection in pulmonary TB. Only 1 in 10 of infected persons will develop the active disease, and genetic differences in immunological defences, and therefore the HLA system, have been implicated. The frequencies of DQB alleles have been studied in Asian and American ethnic groups, but not in Europe, despite an increasing incidence of TB there.

The frequency of DQB1 alleles influenced susceptibility to pulmonary TB in Europeans. This has been reported in many other ethnic populations.

Please visit the Journal of Medical Genetics website [www.jmg.bmj.com] for a link to the full text of this article.
Polymorphisms and malaria

Apolipoprotein E polymorphisms and risk of malaria

M A Wozniak, E M Riley, R F Itzhaki

Host genetic factors probably determine both susceptibility to infection and severity of damage by pathogens. A large number of polymorphisms have now been implicated in the onset, progression, and outcome of malaria infection, seeming to influence the ability of the host immune response to control the infection. These include:

- those associated with haemoglobinopathies;
- those within the major histocompatibility complex (HMC), including HLA class I and class II and the tumour necrosis factor promoter;
- those within genes not associated with HMC, such as ICAM-1, CD36, and possibly the gene for nitric oxide synthase;
- probably the gene for apolipoprotein E (APOE), as our recent data suggest, and upon which we comment below.

APOE has three main alleles, types 2, 3, and 4, resulting in six possible genotypes; it codes for the protein apoE, which is involved in transport of lipids in the blood and the central nervous system.

Finding that APOE-ε2 homozygous Ghanian infants were more likely to be infected with the malaria protozoon at a very young age than those with other genotypes, we predicted that severity of illness after infection might depend to some extent on APOE genotype.1 In this issue, the article by Aucan et al offers support for involvement of APOE in the development of severe malaria: people carrying an APOE-ε3/ε4 genotype may be more likely than those with the other main genotypes to suffer extremely severe malaria (cerebral malaria and severe anaemia). Our discovery that APOE-ε2 homozygotes are infected at a very early age is not inconsistent with the finding of Aucan et al that APOE-ε3/ε4 carriers are more likely to suffer extremely severe malaria. Epidemiological studies2,3 suggest that the risk of developing severe malaria is lower in children who experience their first malaria infections very early in life than in those first infected at an older age. Presumably, children infected during infancy (while still protected from clinical malaria and high parasitaemia by innate protective mechanisms and maternal antibodies) develop adaptive immune responses that protect them from severe disease in later life. On the other hand, those infected only later (after the protective mechanisms of infancy have waned) are fully susceptible and at high risk of severe or fatal disease. Thus, the earlier the infection occurs (as in ε2 homozygotes), the less the likelihood of life-threatening illness. Indeed, in the study by Aucan et al, APOE-ε2 carriers were under-represented in the extremely severe malaria (cerebral malaria with severe anaemia) group (7.1% v 11.5–13.8% in the other groups), although the difference does not reach statistical significance.

Whatever the explanation for the results of Aucan et al, our data and theirs add to the extraordinarily diverse repertoire of infectious diseases in which APOE determines outcome of, or susceptibility to, infection; and they suggest the possible use of this information for prognostic purposes.

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Authors’ affiliations
M A Wozniak, R F Itzhaki, Department of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, UK

E M Riley, Department of Infectious and Tropical Diseases, UMIST, Manchester, UK

Correspondence to: Dr M A Wozniak, Molecular Neurobiology Laboratory, Department of Optometry and Neuroscience, UMIST, Manchester M60 1QD, UK; matthew.a.wozniak@umist.ac.uk

REFERENCES

www.jmedgenet.com

CORRECTION

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This commentary should have been published alongside the article “Common apolipoprotein E polymorphisms and risk of clinical malaria in The Gambia” by CAucan, AJ Walley, and AVS Hill in the January 2004 issue (J Med Genet 2004;41:21–24). This error is much regretted and we would like to offer our sincere apologies to the authors involved.