Glial fibrillary acidic protein in late life major depressive disorder: an immunocytochemical study

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Depression is a common disorder with a prevalence in late life of 2%–3% for major depressive disorder (MDD) and 12%–15% for all depressive syndromes. It is associated with considerable morbidity and significantly increased mortality, but its aetiology remains unclear. Magnetic resonance imaging studies have shown an increase in white matter lesions (WMLs) or signal hyperintensities in MDD. These results provide some support for the vascular depression hypothesis and further imply that DLPFC abnormalities in depression.

Methods: Postmortem tissue was obtained from 20 elderly patients with a history of major depressive disorder (MDD) and 20 control subjects. Sections were stained for GFAP using standard immunocytochemistry. Sets of images were obtained from all cortical layers in the DLPFC and ACC with the exception of layer IV in the ACC, and from gyral and deep white matter in both regions. The percentage of the area of each image occupied by GFAP was calculated using true colour image analysis, and mean values obtained for each region examined.

Results: Immunoreactivity for GFAP was low in grey matter (for example, Mean (SEM) 0.76 (0.2)% in DLPFC layer V in depressed subjects), but higher in white matter (for example, 12.02 (2.2)% in DLPFC deep white matter in depressed subjects). Pronounced gliosis was observed within grey matter in a few cases only. GFAP immunoreactivity was significantly higher in layer I of the DLPFC in depressed subjects 15.8 (2.6)% than in controls 9.7 (1.3)% (t=2.2; df=27.5, p=0.04). No difference was detected in any other region.

Conclusions: The data suggest an increase in GFAP in elderly MDD patients is limited to layer 1 of the DLPFC. These results provide some support for the vascular depression hypothesis and further imply that DLPFC abnormalities in depression.

Abbreviations: ICAM-1; intercellular adhesion molecule 1; DLPFC, dorsolateral prefrontal cortex; GFAP, glial fibrillary acidic protein; ACC, anterior cingulate cortex; MDD, major depressive disorder; WML, white matter lesion
subjects (23–45 years), but was not significantly different from control values in an older subgroup (46–86 years). A significant increase in GFAP immunoreactivity with age in MDD subjects was also detected.28

The aim of this study was to examine GFAP immunoreactivity in grey and white matter in the DLPFC and in the ACC in postmortem tissue obtained from 20 elderly depressed subjects age 60 years or over at death, and 20 age matched controls. Our hypothesis was that expression of GFAP as revealed by GFAP immunoreactivity, and reflecting astroglialosis, would be higher in elderly depressed subjects than in control subjects.

METHODS
Subjects
Brain tissue from 40 elderly subjects (20 depressed and 20 controls) was obtained from our Neuropathology Department Brain Tissue Bank. Postmortem permission for research had been given and ethical approval granted for the study. Cases consisted of 20 subjects with major depression and 20 controls. All subjects were 60 years or over at death. Full details of the clinical and neuropathological assessment of subjects and of exclusion criteria have been published elsewhere.26 Briefly, depressed subjects had suffered at least one documented episode of DSM-IV major depression,27 but had never had DSM-IV criteria for dementia or other major psychiatric disorder. Control subjects met the same criteria but had never suffered a DSM-IV depressive episode. All subjects received a full postmortem examination and were excluded if they met neuropathological criteria for Alzheimer’s disease or any neurological disorder. The control and depressed groups were comparable in vascular risk factors.28

Tissue
Full face coronal blocks were taken from the right, formalin fixed, hemisphere in the DLPFC (Brodmann areas (BA) 9 and 46), and the ACC (BA 24). Sections of ACC contained tissue obtained either from the region located immediately rostral to the genu of the corpus callosum, or from the region immediately caudal to this—that is, these last sections contained corpus callosum, flanked by upper and lower cingulate cortex. After embedding in paraffin wax 10 µm sections were prepared on 3x2 slides.

GFAP immunocytochemistry
Tissue sections were stained for GFAP using standard immunocytochemistry. After dewaxing in xylene and rehydration through graded alcohols, sections were microwaved at 450 W for two five minute bursts in 0.01 M citrate buffer (pH 6) to optimise antigen retrieval.26 Endogenous peroxidase activity in the tissue was neutralised in 0.05 M TRIS buffered saline (TBS, pH 7.6) containing 3% H2O2 for 15 minutes. After block with an appropriate serum, sections were incubated with a rabbit polyclonal anti-GFAP antibody (Dako, catalogue no Z0334, used at 1:4000) for one hour. Sections were then incubated for 30 minutes with an appropriate secondary antibody, then for 30 minutes with avidin-biotinylated horseradish peroxidase complex (serum, secondary antibody and ABC complex, “Elite” Vectastain ABC kit, PK-6101, Vector Laboratories). GFAP was then visualised by incubating sections in TBS containing 0.025% diaminobenzidine (DAB) and 0.066% H2O2 for five minutes. Sections were given three washes in TBS between all incubation steps except between application of serum and application of primary antibody. Finally, all sections were lightly counterstained in haematoxylin and mounted in DPX.

Image capturing
Analysis was performed on one section for each case. Standard cytoarchitectural maps were used to identify the DLPFC and the ACC,19 29 and the limits of these cortical regions were marked on each slide with a permanent marker pen. Images were captured using a ×10 objective lens on a Zeiss Axioplan 2 light microscope coupled to a 3-chip CCD true colour video camera (JVC KY F55B). Images were taken from deep white matter (10 images per section), cortical grey matter (five images per section), and gyral white matter (five images per section). Gyral white matter was that area of white matter immediately adjacent to, or contained within the gyral fold of the grey matter of the DLPFC and the ACC. Images were obtained from layers I, II, III, V, VI in the ACC, and layers I, II, III+IV, V, VI, in the DLPFC. Cortical layers were identified by standard morphological criteria for neurons within granular cortex (DLPFC) and agranular cortex (ACC). In both brain regions, the image obtained in layer I was taken immediately inside the edge of the section. We and others have observed differential intensity of stain for GFAP in layer I,29 and therefore it was necessary to obtain the image from a standard position in all sections. The very edge of the section was excluded from the image to exclude artefactual staining. In all other layers, images were located randomly within the layer in question.

Image analysis
The area of staining for GFAP in each image, expressed as a percentage, was calculated using a commercially available software program that permitted true colour analysis (Image Pro Plus, version 4.0; Media Cybernetics). A macro was set by taking the average of RGB values in 50 separate images measured manually, and images were then rated automatically. Analysis was carried out blind to diagnosis.

Statistics
The Kolgomorov-Smirnov test was first applied to data to determine whether the distribution within each dataset was normal or skewed. Subsequently, data were tested for significance using an independent samples t test or a Mann-Whitney test as appropriate. The Pearson correlation test was also applied to investigate whether data correlated to age of subjects, postmortem interval, and duration of fixation.

RESULTS
White matter could usually be distinguished from grey matter by the greater intensity of staining for GFAP in the former. Cell profiles immunoreactive for GFAP displayed classic astrocytic morphology, with GFAP+ve cell bodies and processes (fig 1). Although the intensity of staining for GFAP was generally higher in the ACC as compared with the DLPFC, the comments that follow apply equally to both brain regions. Within the cortex, the highest level of staining was observed in layer I, which invariably contained numerous distinct GFAP+ve cell profiles (fig 1A, B). GFAP+ve processes extended from layer I of the cortex as far as layer III. The degree of staining for GFAP in cortical layers other than layer I was in most cases low (fig 1C). In around one quarter of DLPFC cases, virtually no GFAP+ve cell profiles were detectable in cortical layers II-VI. However, a few cases showed more intense GFAP immunoreactivity in grey matter (fig 1D). Some positive staining of processes within layer VI was evident. GFAP+ve profiles appeared more frequently within white matter, both in the white matter contained within the gyral folds (fig 1E), and within the deep white matter (fig 1F). Substantial variability in the areal fraction for GFAP immunoreactivity was noted both between and within individual cases in both groups. While mean values for the areal fraction of GFAP staining were almost always slightly higher in the depressed group, a significant difference was found between the groups of controls and depressed subjects only in layer I of the grey matter of the DLPFC (t=2.2; df=27.5, p=0.04). No
significantly difference was observed in any other region examined (fig 2); DLPFC white matter $p > 0.4$; DLPFC grey matter other than layer I, $p > 0.1$; ACC white matter, $p > 0.7$; ACC grey matter, $p > 0.4$. There was no correlation between GFAP immunoreactivity and age, postmortem interval, or length of time in fixative, with the exception of GFAP immunoreactivity in the gyral white matter of the DLPFC, which correlated positively with duration of fixation ($n=40$, $r = -0.48$, $p=0.002$).

**DISCUSSION**

This study has investigated the distribution of GFAP immunoreactivity in the grey and white matter of the DLPFC and the ACC of elderly MDD patients and age matched controls. Increased GFAP immunoreactivity in depressed subjects was found only in layer I of the DLPFC, and therefore this study has provided only limited support for the vascular depression hypothesis. Nevertheless we consider this finding important, as representing the first evidence for gliosis in elderly MDD patients in excess of that which accompanies normal aging.

We are unable to directly compare our GFAP grey matter data with those reported previously relating to the distribution of ICAM-1 in MDD, as these data were not layer specific. However, our observation of increased ICAM-1 in DLPFC white matter in MDD in our earlier study, when taken with the absence of increased GFAP in DLPFC white matter in this study, suggests that ICAM-1 may be upregulated in white matter in elderly MDD patients in the absence of gliosis. Data from this study show both similarities with and differences from other relevant publications. The general pattern of GFAP immunoreactivity we observed, with lower levels of staining in grey matter than in white matter, conforms to a previous description of the distribution of GFAP in normal human brain. Our finding that GFAP immunoreactivity in cortical layers III+IV and V of the DLPFC was not different from controls agrees with those of another study in depressed subjects aged 46–86 year. However, the absence of a correlation between age and GFAP immunoreactivity in both groups in our study may be considered surprising given that both GFAP mRNA and GFAP protein have been reported to increase with age in brain tissue of normal human subjects, while GFAP immunoreactivity increases with age in MDD patients. This difference may have been attributable to the age range of subjects, which was considerably narrower in our study than in those just mentioned. Finally, we obtained markedly lower values for the areal fraction of GFAP immunoreactivity in DLPFC grey matter than did another study that also

![Figure 1](http://jnnp.bmj.com/)

**Figure 1** GFAP immunoreactivity in DLPFC and ACC grey and white matter. (A), (B) Layer I of DLPFC cortex (A, control, B, depressed); (C) DLPFC grey matter, (D) ACC grey matter, (E) ACC gyral white matter, (F) ACC deep white matter. GFAP immunoreactivity is clearly more pronounced in (B) (depressed) than in (A) (control). (C), (E), and (F) show typical levels of GFAP immunoreactivity in grey matter, gyral white matter, and deep white matter respectively, while (D) shows unusually high GFAP immunoreactivity in ACC grey matter. Sections are 10 µm paraffin wax, stained for GFAP as described in Methods, and counterstained with haematoxylin. Scale bar applicable to all images =50 µm.
quantified GFAP immunoreactivity in MDD, that of Miguel-Hidalgo and coworker. The reason for this difference is unclear. Our data for DLPFC grey matter were not influenced by postmortem delay or duration of fixation. We used a different embedding material (wax compared with celloidin) and a different primary antibody than Miguel-Hidalgo and coworkers and such technical differences may have contributed to the differences in data obtained in the two studies. Alternatively, these differences may reflect the variability that has been observed in the GFAP content of human cerebral cortex between different people. It is clear that the degree of gliosis in grey matter was relatively mild in most of our sample, and absent from some cases. It has been suggested that age related increases in GFAP protein are secondary to degenerative processes such as synaptic loss, and do not occur in aging in the absence of neurodegeneration, so that age related gliosis may not be inevitable. Our data do not necessarily indicate that the characteristics of astrocytes do not change in elderly MDD patients in regions other than layer I of the DLPFC. It is possible for instance that the DLPFC and the ACC of MDD patients might contain a lowered density of enlarged GFAP +ve astrocytes. In addition as lower than control levels of GFAP immunoreactivity have been observed in young MDD subjects, it is possible that our findings in the depressed group represent a greater increase in GFAP with age than in normal subjects, although given the generally low levels of GFAP immunoreactivity observed in this study the relevance of this is unclear. The vascular depression hypothesis suggests that the roots of depression in a subset of elderly patients are different from those that cause depression with early onset. It is clearly relevant to inquire whether our findings and those of other published studies suggest that these two classes of depression are characterised by differing neuropathology. While no study has specifically answered this question, existing reports suggest that the nature of glial alterations may vary between elderly and younger MDD subjects. Our observation of equal or increased immunoreactivity for GFAP in the DLPFC and ACC of control and depressed subjects contrasts with reduced GFAP immunoreactivity in the DLPFC of depressed subjects under 46 years old. The observation of this last study that the packing density of GFAP +ve cell bodies was lower than controls in young MDD subjects, but showed a non-significant tendency towards greater than control values in MDD subjects over 46 years, suggests that astrocytic loss may be a feature of...
depression with early onset but not of depression in older subjects. This suggestion is supported by reports that glia are lost from various regions of frontal cortex in MDD subjects aged less than 66 years, although to our knowledge this parameter has not been quantified in subjects older than this. It is clear that the picture of glial alterations in MDD is incomplete, and is complicated both by the use of different cut off ages in different studies, and by a lack of distinction between subjects suffering from depression with early onset and depression with late onset in elderly MDD groups.

In conclusion, our study has provided partial support for the hypothesis of vascular depression. More research is necessary to further clarify neuropathological differences between elderly and younger MDD subjects, and in particular between early onset and late onset depressives.

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