Brain serotonin-2 receptors in acute mania

Lakshmi N. Yatham, Peter F. Liddle, Jonathan Erez, Marcia Kauer-Sant’Anna, Raymond W. Lam, Miguel Imperial, Vesna Sossi and Thomas J. Ruth

Background
Although 5-hydroxytryptamine (5-HT) has been implicated in mania, the precise alterations in the 5-HT system remain elusive.

Aims
To assess brain 5-HT2 receptors in drug-free individuals experiencing a manic episode in comparison with healthy volunteers using positron emission tomography (PET).

Method
Participants \( (n=10) \) with DSM–IV bipolar I disorder – manic episode and healthy controls \( (n=10) \) underwent \([^{18}F]\)-setoperone scans. The differences in 5-HT2 receptor binding potential between the two groups were determined using statistical parametric mapping (SPM) analysis.

Results
Age was a significant correlate with 5-HT2 receptor binding potential with a similar magnitude of correlation in both groups. The SPM analysis with age as a covariate showed that the individuals with current mania had significantly lower 5-HT2 receptor binding potential in frontal, temporal, parietal and occipital cortical regions, with changes more prominent in the right cortical regions compared with controls.

Conclusions
This study suggests that brain 5-HT2 receptors are decreased in people with acute mania.

Declaration of interest
None.
Data analysis

Demographic and clinical variables

Student’s t-tests were used to examine the differences in age between individuals with mania and controls. Relationships between 5-HT2 receptor binding potential and YMRS scores were assessed using Pearson’s correlation coefficient. All tests were two-tailed, with significance set at \( P < 0.05 \).

5-HT2 receptor binding potential

The rationale and methods for determining 5-HT2 receptor binding potential have been described previously in detail elsewhere. Briefly, cerebellum was used as a reference region and the region/cerebellum ratios from scans during the pseudo-equilibrium period (70 to 110 min post-injection) were used to compute 5-HT2 receptor binding potential images for each participant. Previous studies have shown that the binding potential estimated using the ratio method correlates well with the other invasive and non-invasive methods, and this approach has been used in a number of other studies to estimate 5-HT2 receptor binding potential. Statistical parametric mapping (SPM5; Wellcome Department of Cognitive Neurology, Institute of Neurology, London; www.fil.ion.ucl.ac.uk/spm/software) software run on Matlab 7 (Mathworks Inc, Natick, MA, USA) was used for aligning frames from 70 to 110 min to create a mean image for each participant. The mean image was then coregistered to each participant’s magnetic resonance (MR) image. Each participant’s PET and MR images were normalised to the standard coordinate frame (Montreal Neurological Institute (MNI) template) used in SPM5. Then a 5-HT2 receptor binding potential image was created for each participant by dividing each pixel in the normalised mean image with that image’s average cerebellar value. A mean activity value from two large regions of interest (one on the right and one on the left) drawn on three contiguous cerebellar slices was used as that image’s average cerebellar value.

In order to assess the relationship between 5-HT2 receptor binding potential and age, we extracted the 5-HT2 receptor binding potential values for frontal, temporal and parietal grey matter regions. The Pick_Atlas program (Wake Forest University School of Medicine, Winston-Salem, NC, USA; www.ansir.wfubmc.edu) run on Matlab 7 was used to create a grey matter mask for frontal, temporal, and parietal cortical regions. The mask for each cortical region was applied to the 5-HT2 receptor binding potential images of each participant and the mean for each cortical grey matter region was extracted.

SPM analysis

Since 5-HT2 receptor binding potential significantly declined with age in both individuals with mania and controls, the differences in 5-HT2 receptor binding potential between participants with mania and healthy individuals was computed using age as a covariate with the SPM5. A 12 mm Gaussian filter was used to smooth the binding images before SPM analysis was performed. The grey matter threshold was set at 130% of the mean intensity as this threshold eliminated most white matter voxels and included most grey matter voxels. In addition to examining the significance of difference in 5-HT2 receptor binding potential for each voxel between the two groups, we also computed the significance of clusters of contiguous voxels in which the difference in 5-HT2 receptor binding potential exceeded a threshold of \( z = 2.57 \) corresponding to \( P = 0.01 \). The method implemented in SPM5 calculates the significance of clusters using cluster criteria that takes into account the number of contiguous voxels. The corrected cluster significance was set at \( P < 0.05 \).

Results

Ten people with mania (three males and seven females) and ten controls (three males and seven females) participated in the study. The details of clinical characteristics and demographics for the ten people with mania are presented in Table 1.

Of the ten people with mania, seven were drug naive and the other three were drug free (one for more than 3 years, one for more than 2 weeks, and one had sertraline discontinued about 2 weeks prior to the baseline PET scan). Seven participants were in their first manic episode and the other three had one to ten previous manic episodes. Eight of the ten had no previous depressive episodes but one had one episode and the other had about ten previous depressive episodes. The duration of the current manic episode for individuals ranged from 1 to 8 weeks. The mean YMRS was 27.1 (s.d. = 8.3). There was no significant difference in age between people with mania (mean 34, s.d. = 12.4) and controls (mean 32.5, s.d. = 13.71) \( (P = 0.8) \).

As expected, there was a significant negative correlation between age and the 5-HT2 receptor binding potential (frontal \( r = -0.81 \); temporal \( r = -0.85 \); parietal \( r = -0.71 \); \( P < 0.001 \) for all regions examined) and this correlation was similar in both groups.

Table 1. Sociodemographic and clinical characteristics of the ten participants with acute mania

<table>
<thead>
<tr>
<th>Participant number</th>
<th>Age, years</th>
<th>Young Mania Rating Scale score on scan day</th>
<th>Drug status</th>
<th>Duration of current episode, weeks</th>
<th>Previous depressive episodes, n</th>
<th>Previous manic episodes, n</th>
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<tbody>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>2</td>
<td>25</td>
<td>24</td>
<td>2 weeks free</td>
<td>3</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>25</td>
<td>&gt; 3 years free</td>
<td>4</td>
<td>1</td>
<td></td>
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<tr>
<td>4</td>
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<td>25</td>
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<td>2</td>
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<tr>
<td>6</td>
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<td>25</td>
<td>Naive</td>
<td>1.5</td>
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<tr>
<td>7</td>
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<td>25</td>
<td>Naive</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>Naive</td>
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<td>0</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>25</td>
<td>&gt; 2 weeks free</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
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<tr>
<td>4</td>
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<td>25</td>
<td>Naive</td>
<td>2</td>
<td>1</td>
<td>0</td>
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</tbody>
</table>

Mean 34 (s.d. = 12.4) Mean 27.1 (s.d. = 8.3)
and the 5-HT2 receptor binding potential. A significant correlation between the duration of manic episode and YMRS scores in participants with mania. There was no significant correlation between 5-HT2 receptor binding potential and YMRS scores in participants with mania.

Further, to exclude the possibility that reductions in binding potential were observed in an extensive cluster of voxels (corrected $P = 0.016$ bilaterally in cortical regions but changes were more prominent in the right frontal, temporal, parietal and occipital cortical regions (Fig. 1). This cluster had 23,974 grey matter voxels. The mean decrease in binding potential for the entire cluster was 19.9%. There were a number of individual voxels in which the reductions in binding potential met significance criteria for false discovery rate ($P < 0.025$ after correction for multiple comparisons). The voxels that showed the most significant decrease ($z \geq 3.1$) in binding potential were located in the right fusiform gyrus, right insula, right inferior temporal gyrus, right middle occipital gyrus, right medial frontal gyrus and right middle frontal gyrus. The 5-HT2 receptor binding potential remained significantly lower in individuals with mania when the analysis was repeated without controlling for age as a covariate. Further, to exclude the possibility that reductions in brain 5-HT2 receptor binding potential in our study participants are a result of reductions in brain grey matter volumes, we compared brain volumes and total grey matter volumes between participants with mania and controls in this study. The results showed no differences in either measure between the two groups.

We found no increase in 5-HT2 receptor binding potential in people with mania in any of the brain areas. There was no significant correlation between 5-HT2 receptor binding potential and YMRS scores in participants with mania. There was no significant correlation between the duration of manic episode and the 5-HT2 receptor binding potential.

**Discussion**

Given the difficulty recruiting drug-naive or drug-free people with mania, it is not surprising that this is the first study to examine brain 5-HT2 receptors in this population. It took over 4 years to recruit 10 people with acute mania who were drug naive or free and able to provide informed consent. The results showed that 5-HT2 receptor binding potential is decreased in frontal, temporal, parietal and occipital cortical regions, suggesting a reduction in brain 5-HT2 receptor density in these regions in individuals with mania. Furthermore, consistent with previous studies, the results of this study indicate that 5-HT2 receptor density decreases with age.

**5-HT2 receptors in platelets and brain**

Previous studies in mood disorders have used platelets as models for brain 5-HT neurons to assess various aspects of 5-HT function. Two previous studies that assessed 5-HT2 receptors in mania in platelets reported conflicting findings, with one reporting no change whereas the other reported an increase in 5-HT2 receptor density in drug-free people with mania compared with healthy controls. However, it must be remembered that although platelet 5-HT2 receptor protein is very similar to brain 5-HT2 receptor protein, the platelets’ 5-HT2 receptors are not subjected to the same sort of regulatory mechanisms as brain 5-HT2 receptors, which are extensively modulated because of inter-neuronal connections. The present study and several previous studies have shown that brain 5-HT2 receptor density decreases with age but no such correlation was found between platelet 5-HT2 receptors and age. Furthermore, PET studies by our group and other groups have shown that the 5-HT2 receptor density in platelets does not correlate with brain 5-HT2 receptors, thus raising questions about the utility of gleaning information on brain 5-HT status by studying 5-HT binding in platelets.

**Limitations**

Some limitations of this study must be considered. First, the number of individuals with mania studied was small. However, we have applied a statistical test that provides a strict control against type I error and hence it is unlikely that the reduction in 5-HT2 receptors observed in the participants with mania in this study arose purely by chance.

Second, the study sample was somewhat unusual in that only two of the ten individuals in the mania sample had previous depressive episodes and that two had their first manic episode after age 50. However, it must be remembered that mania is uncommon after age 50 and that all medical causes of manic symptoms, including substance misuse, were excluded in our participants. Nonetheless, given the smaller sample size and the nature of our study sample, a high degree of caution is warranted in the interpretation of findings as they might not be generalisable to the entire population with mania.

Third, the 5-HT2 binding potential in our study was estimated using cortex/cerebellum ratios and not by measuring maximum binding potential ($B_{\text{max}}$) and the dissociation constant ($K_d$) using arterial input function. Given this, we cannot exclude the possibility that reduced 5-HT2 binding potential was a result of changes in $K_d$ and not a result of changes in $B_{\text{max}}$. This, however, is unlikely because previous studies of alteration in receptor binding in other psychiatric conditions have shown changes in $B_{\text{max}}$ and not $K_d$ and thus the reduction in 5-HT2 binding potential in our study likely indicates reduced 5-HT2 receptors in people with mania. Furthermore, although the two previous platelet studies in mania yielded conflicting findings with regard to changes in 5-HT2 receptor density, both studies reported no alteration in $K_d$ for 5-HT2 receptors.

Fourth, it is possible that the reduction in 5-HT2 binding potential is because of an increase in 5-HT in the synaptic space.
in people with acute mania that might be expected to occupy 5-HT_{2} receptors, thus leaving a fewer receptors for the setopone to bind. This, however, is unlikely as most studies of 5-HT metabolite 5-HIAA levels in people with mania have not reported any consistent increases but rather lower levels compared with healthy controls. Further, PET studies have shown that increases in 5-HT levels in synaptic space with fenfluramine do not result in any changes in 5-HT_{2} or 5-HT_{1A} receptor binding suggesting that endogenous 5-HT levels do not affect estimates of 5-HT_{2} receptor density with PET.

Fifth, no studies to date assessed the effects of lorazepam on brain 5-HT_{2} receptors and hence it is not possible to exclude the effects of lorazepam on 5-HT_{2} receptors as some of our sample with acute mania but not controls received lorazepam prior to scanning.

Reduction in brain 5-HT_{2} receptor density: a state or trait marker?

Since some previous studies that examined brain 5-HT_{2} receptors in people with major depression have reported a reduction in these receptors compared with controls, and given the fact that we found reduced 5-HT_{2} receptors in people with mania, one could argue that a reduction in brain 5-HT_{2} receptors predisposes individuals to both depression as well as mania. However, decreased brain 5-HT_{2} receptor density is unlikely to predispose individuals to depression because several effective antidepressant treatments also down-regulate brain 5-HT_{2} receptors in people with depression, including the tricyclic antidepressant desipramine, the selective serotonin reuptake inhibitor (SSRI) paroxetine, and the SSRI and 5-HT_{2} antagonist nefazodone, as well as the somatic treatment electroconvulsive therapy (ECT) (details available from author on request). Given this, we have previously argued that a reduction in brain 5-HT_{2} receptors observed in people with depression is not a cause of depression but rather a compensatory mechanism of the brain to cope with the state of depression. Such down-regulation of 5-HT_{2} receptors is expected to lead to spontaneous remission of depressive symptoms in some individuals but those people that are not able to mount effective compensatory down-regulation of brain 5-HT_{2} receptors may require treatment with anti-depressants or ECT to further down-regulate these receptors to improve from depression. In contrast, antidepressant treatments either induce or worsen manic symptoms in people with bipolar disorder. Given that antidepressant treatments down-regulate brain 5-HT_{2} receptors, the propensity of antidepressants to worsen/induce mania is consistent with the hypothesis that a reduction in brain 5-HT_{2} receptors either predisposes individuals to mania or is a cause of mania. The fact that YMRS scores did not correlate with 5-HT_{2} binding and that treatment of acute mania with valproate does not alter brain 5-HT_{2} receptors lends support to the hypothesis that decreased 5-HT_{2} receptor density is a trait marker for bipolar disorder. However, studies that assessed the association between 5-HT_{2} receptor polymorphisms and bipolar disorder have yielded no consistent findings.

Reduction in brain 5-HT_{2} receptors and increased dopamine in mania

Regardless of whether a reduction in brain 5-HT_{2} receptors is a state or a trait marker for mania, it is important to reconcile this observation with the fact that drugs that reduce dopamine transmission are effective anti-manic agents whereas drugs that increase dopamine transmission induce or worsen mania. Interestingly, there is evidence that 5-HT_{2} receptors are located on dopaminergic neurons. Within the 5-HT_{2} receptor family, 5-HT_{2A} receptors facilitate stimulated but not basal dopamine release in the nucleus accumbens and striatum whereas 5-HT_{2C} receptors inhibit both basal and stimulated-impulse flow-dependent mesocortical dopamine function. Since the ligand in this study binds to both 5-HT_{2A} and 5-HT_{2C} receptors (although it has higher affinity for 5-HT_{2A} receptors), it is likely that reduced binding observed in people with mania represents a reduction in both these receptor subtypes. Accordingly, a reduction in 5-HT_{2A} receptors will have no effect on basal dopamine release whereas a reduction in 5-HT_{2C} receptors would be expected to be associated with enhanced dopamine release and transmission. This may explain the efficacy of antidi dopaminergic drugs for mania.

Brain 5-HT_{2} receptors and grey matter volume

Previous studies of people experiencing a first manic episode have not shown any consistent reductions in grey matter volumes compared with age- and gender-matched controls. Further, a preliminary analysis of our study sample has indicated no changes in either total brain volume or grey matter volume compared with matched controls. Thus, the reduction in 5-HT_{2} receptor density observed in our sample cannot be attributable to changes in grey matter volume. Interestingly, the reduction in 5-HT_{2} receptors observed in our sample was diffuse and included frontal, temporal, parietal and occipital cortical regions although the changes were more prominent in the right limbic regions. A reduction in 5-HT_{2C} receptors in these regions is expected to be associated with enhanced dopamine release. Further studies should assess both 5-HT_{2C} receptors and the magnitude of dopamine release in acute mania to verify this hypothesis.

References


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