ORIGINAL ARTICLE

Modulation of Cortical-Limbic Pathways in Major Depression

Treatment-Specific Effects of Cognitive Behavior Therapy

Kimberly Goldapple, MSc; Zindel Segal, PhD; Carol Garson, MA; Mark Lau, PhD; Peter Bieling, PhD; Sidney Kennedy, MD; Helen Mayberg, MD

Background: Functional imaging studies of major depressive disorder demonstrate response-specific regional changes following various modes of antidepressant treatment.

Objective: To examine changes associated with cognitive behavior therapy (CBT).

Methods: Brain changes underlying response to CBT were examined using resting-state fluorine-18–labeled deoxyglucose positron emission tomography. Seventeen unmedicated, unipolar depressed outpatients (mean ± SD age, 41 ± 9 years; mean ± SD initial 17-item Hamilton Depression Rating Scale score, 20 ± 3) were scanned before and after a 15- to 20-session course of outpatient CBT. Whole-brain, voxel-based methods were used to assess response-specific CBT effects. A post hoc comparison to an independent group of 13 paroxetine-treated responders was also performed to interpret the specificity of identified CBT effects.

Results: A full course of CBT resulted in significant clinical improvement in the 14 study completers (mean ± SD posttreatment Hamilton Depression Rating Scale score of 6.7 ± 4). Treatment response was associated with significant metabolic changes: increases in hippocampus and dorsal cingulate (Brodmann area [BA] 24) and decreases in dorsal (BA 9/46), ventral (BA 47/11), and medial (BA 9/10/11) frontal cortex. This pattern is distinct from that seen with paroxetine-facilitated clinical recovery where prefrontal increases and hippocampal and subgenual cingulate decreases were seen.

Conclusions: Like other antidepressant treatments, CBT seems to affect clinical recovery by modulating the functioning of specific sites in limbic and cortical regions. Unique directional changes in frontal cortex, cingulate, and hippocampus with CBT relative to paroxetine may reflect modality-specific effects with implications for understanding mechanisms underlying different treatment strategies.

Arch Gen Psychiatry. 2004;61:34-41

From the Rotman Research Institute at Baycrest Centre (Ms Goldapple and Dr Mayberg) and Department of Psychiatry, Centre for Addiction and Mental Health (Drs Segal, Lau, Bieling, Kennedy, and Mayberg and Ms Garson), University of Toronto, Toronto, Ontario.

RANDOMIZED CLINICAL TRIALS in patients with both mild and severe major depression consistently demonstrate similar rates of response to cognitive behavior therapy (CBT) and antidepressant pharmacotherapy.[1,2] Although it is generally assumed that these disparate treatments have different primary *targets* of action, with cortical "top-down" vs subcortical or "bottom-up" mechanisms theorized,[3-5] definitive neural mechanisms that mediate antidepressant *response* are not yet characterized for either treatment modality.

Preclinical studies[6-10] of antidepressant medications emphasize a bottom-up chain of events, including aminergic reuptake inhibition and associated presynaptic autoregulatory desensitization, up- and down-regulation of multiple postsynaptic receptor sites, and receptor-mediated second messenger and neurotrophic intracellular signaling effects. Requisite brain regions that mediate these events are unknown, although putative primary sites of action in the dorsal raphe, locus ceruleus, hippocampus, and hypothalamus are well described, with documented secondary changes in frontal cortex also reported.[11-16] Neuroimaging studies[17] of medication effects show a similar time course of differential acute and chronic subcortical and cortical changes. Across studies[17-21] of antidepressant *response*, frontal cortex changes are the most consistently reported, with normalization of frontal overactivity and underactivity described. Additionally, changes have been seen in limbic and subcortical regions, including the subgenual cingulate, hippocampus, posterior cingulate, and insula, with decreased activity the most commonly observed effect.[17,19-23]

In contrast, little is known about brain mechanisms that mediate clinical re-

sponse to CBT for depression. The literature[24-26] characterizing brain changes associated with CBT response is sparse and based largely on the treatment of obsessive-compulsive and anxiety disorders. Theoretical models of CBT action in the treatment of depression generally implicate top-down mechanisms, because the intervention focuses on modifying attention and memory functions involved in the mediation of depression-relevant cognitions, affective bias, and maladaptive information processing.[27-32] The time course of symptom changes with CBT further supports an initial cortical site of action, as improvement in hopelessness and views of self and mood generally precede changes in vegetative and motivational symptoms—a timeline not seen in patients treated with pharmacotherapy.[3,33] Brain correlates of this chronology are, however, untested. Recent functional imaging studies[34,35] examining brain changes following interpersonal psychotherapy report a variety of regional effects, but there is no consistent pattern across the few published studies.

A critical question is whether disparate antidepressant treatments result in common or modality-specific neural effects. As a first step in addressing this issue, this study examined changes in regional glucose metabolism measured with positron emission tomography (PET) associated with depression remission following 15 to 20 sessions of CBT. Metabolic change patterns with CBT response were contrasted post hoc with those of a previous study[21] of paroxetine treatment to further test the hypothesis that modulation of distinct neural targets by different interventions within a putative limbic-cortical depression "network" occurs with clinical remission, regardless of the specific treatment modality.[36,37]

METHODS

PATIENT SELECTION

Seventeen unmedicated, depressed patients (6 men, 11 women; mean ± SD age, 41 ± 9 years; mean ± SD 17-item Hamilton Depression Rating Scale [HDRS] score, 20 ± 3) with symptoms that required treatment were recruited to the Mood and Anxiety Disorders Program at the Centre for Addiction and Mental Health in Toronto, Canada, through newspaper advertisement. The clinical diagnosis of a major depressive episode, unipolar type, was confirmed using the Structured Clinical Interview for *DSM-III-R* and *DSM-IV* criteria.[38,39] By history, none of the enrolled patients were considered treatment refractory. Mean ± SD education was 16 ± 2 years, and 10 of 14 were unmarried. Exclusion criteria included history of neurological disease, head trauma, or other Axis I psychiatric diagnoses, as well as current psychotic symptoms, substance abuse, antidepressant treatment within the preceding month, and pregnancy. Six patients were completely drug naive, and none had been treated with CBT for depression in the past. One patient required antidepressant washout for 4 weeks. Written informed consent was obtained from all participants, and the study was conducted as approved by the Centre for Addiction and Mental Health Ethics Committee.

TREATMENT PROTOCOL

All patients received 15 to 20 individualized outpatient sessions of CBT. Treatment was conducted by 1 of 2 trained CBT therapists (M.L. and P.B.) with 10 and 8 years of experience, respectively, according to the treatment manual described by Beck et al.[27] All CBT sessions were audiotaped to enable ratings of treatment fidelity, which were confirmed by the supervising psychologist (Z.S.). Patients undergoing CBT used a number of therapeutic strategies intended to reduce automatic reactivity to negative thoughts or attitudes and to combat dysphoric mood. Behavioral activation was used to address the disruption of routine often brought on by depression and focused on increasing the frequency of pleasant and masterful events in patients' lives, especially in those areas where marked avoidance and withdrawal were noted. Cognitive monitoring taught patients how to dismantle seemingly complex chains of thinking and feeling into separate components that could then be evaluated for evidence of biased information processing. Between sessions, patients were asked to test their interpretations and beliefs through the use of behavioral experiments and to record their thinking using thought records. During the sessions, the therapists used collaborative inquiry to guide the patient to a more evidence-based and less reactive construal of their experience.

Clinical response was monitored weekly using the Beck Depression Inventory.[40] The HDRS scores (17-item)[41] were assessed at study onset, at study completion, and once midway through therapy (eighth session). Patients were classified as responders based on the criteria of at least a 50% reduction in HDRS or nonresponders for those with a decrease in HDRS score of less than 20%.[42]

IMAGING STUDIES

Positron emission tomography measurements of regional cerebral glucose metabolism were obtained at baseline and again at the end of treatment using standard imaging methods[43] and a previously published protocol.[17,44] Both scans were acquired within 1 week of the first and last therapeutic session. For each scan, a 5-mCi (185-Mbq) dose of fluorine-18–labeled deoxyglucose (FDG) was injected intravenously, with image acquisition beginning after 40 minutes (PC 2048b; GEMS-Scanditronix, Uppsala, Sweden). All scans were acquired with patients supine, awake, and in the resting state, with eyes closed and ears uncovered. Patients were asked to refrain from food, coffee, and alcohol intake for a minimum of 6 hours before each scan session. None of the participants were smokers. Patients were taking no medications at the time of either scan with the exception of 1 woman who was taking long-standing estrogen and thyroid therapy. Patients were given no explicit cognitive instructions but were asked to avoid ruminating on any one topic during the FDG uptake period. Wakefulness was additionally monitored every 10 minutes by a study investigator. A debriefing session took place following the uptake period to document compliance. Presence of active random thoughts was not quantitatively assessed. Emission data was acquired during a 35-minute period (approximately 1 million counts per slice; 10-cm field of view). A customized, thermoplastic face mask was used to minimize head movement for the initial scan and for accurate repositioning at the second session. Raw images (15 parallel slices; 6.5-mm center-to-center interslice distance) were corrected for attentuation, reconstructed, and smoothed to a final in-plane resolution of 7.0 mm at full width at half maximum.

DATA ANALYSIS

Statistical analyses were performed using SPM99 statistical software (Wellcome Department of Cognitive Neurology, London, England) implemented in Matlab (version 5.3; Mathworks Inc, Sherborn, Mass). The data were first screened for

Locations of Regional Metabolic Changes With Cognitive Behavior Therapy and Paroxetine

Region	BA	CBT Treated (n = 14)				Paroxetine Treated (n = 13)			
		Increase/ Decrease	Coordinates, x/y/z*	Voxels in Cluster, No.	*z* Score†	Increase/ Decrease	Coordinates, x/y/z*	Voxels in Cluster, No.	*z* Score†
Same Regions, Same Direction									
Ventral lateral frontal	47	↓	–40/52/–2	2697	3.78‡	↓	44/38/–8	967	3.30
Same Regions, Different Direction									
Dorsolateral prefrontal	9	↓	48/24/26	5739	3.39	↑	–34/14/42	305	2.82
			50/8/22	2490	3.51		–22/26/40	305	2.71
			–52/18/24	154	3.56				
Inferior parietal	40	↓	46/–56/42	66	2.95‡	↑	–48/–38/30	2072	3.63
			54/–58/44	66	2.41				
Inferior temporal	20	↓	–58/–22/–28	566	3.88	↑	–52/–18/–22	188	3.01
Hippocampus/parahippocampal gyrus		↑	–26/–36/–8	10 271	3.83‡	↓	32/–24/–22	307	3.40
			38/–10/–14	555	2.97				
Unique to Each Treatment									
Dorsal cingulate	24b	↑	–8/2/30	3153	4.28				
	24c		14/–18/34	3153	4.62‡				
Medial prefrontal	10	↓	14/56/16	363	3.71‡				
Orbital frontal	11	↓	20/52/–22	760	4.09‡				
			–14/34/–28	106	2.72				
Ventrolateral prefrontal	45/46	↓	–48/44/10	2697	3.59				
			30/52/16	2904	4.36				
Posterior cingulate	23/31	↓	8/–38/26	3977	3.64‡				
Ventral subgenual cingulate	24/25					↓	8/42/0	179	3.68‡
Insula						↓	54/–4/12	967	3.33‡
Brainstem						↑	–12/–40/–30	137	3.27
Cerebellum						↑	–40/–62/–22	1721	4.24

Abbreviations: BA, Brodmann area; CBT, cognitive behavior therapy; ↓ decrease; ↑, increase.
*Coordinates in millimeters relative to anterior commissure. x Indicates right (+)/left (–); y, anterior (+)/posterior (–); and z, superior (+)/inferior (–).
†*z* Scores greater than 2.6 correspond to $P<.01$; *z* scores greater than 3.09 correspond to $P<.001$ (2-tailed).
‡Significant in conjunction analysis: CBT changes vs paroxetine changes, $P<.005$.

distributional properties, outliers, and missing values. This process rejected no scans. All scans were then normalized to the Montreal Neurological Institute's ICBM 152 stereotactic template within SPM99, which references brain locations in 3-dimensional space relative to the anterior commissure.[45,46] The images were then corrected for differences in the whole-brain global mean and smoothed using a gaussian kernel to a final in-plane resolution of 10 mm at full width at half maximum. Absolute glucose metabolic rates were not calculated.

Response-specific CBT effects were the primary focus of this study, reflected by the following series of statistical analyses. Significant regional changes before and after treatment were first assessed using SPM and a pairwise random-effects design.[47,48] Based on previous results of antidepressant medication effects,[17] peak voxel value significance thresholds were set at $P<.01$ (uncorrected) for 5 targeted regions (ventral subgenual cingulate Brodmann area [BA] 25, dorsal anterior cingulate BA 24, dorsolateral prefrontal cortex BA 9/46, hippocampus, and posterior cingulate BA 23/31) and at $P<.001$ (uncorrected) for all other regions. Cluster significance thresholds were set at 50 contiguous voxels (voxel=8 mm^3) to further reduce type I errors introduced by potential noise. Resulting *t* values were converted to *z* scores, with brain locations reported as x, y, and z coordinates in Montreal Neurological Institute space with approximate BAs identified by mathematical transformation of SPM99 coordinates into Talairach space[49] (additional information available at http://www.mrc-cbu.cam.ac.uk/Imaging/) (**Table**).

To assist in interpreting any identified metabolic changes with CBT, several additional post hoc analyses were performed. Metabolic changes with response to CBT were statistically contrasted to those seen in a previously published data set of comparably recruited depressed men (n=13; mean±SD age, 36±10 years; mean±SD education, 15±2 years; 7 unmarried; mean±SD HDRS score, 22.4±3.6) who had been similarly scanned following clinical response to 6 weeks of paroxetine treatment.[21] A conjunctional analysis using statistical criteria identical to those described herein was performed to directly compare the change pattern of CBT responders to that of paroxetine responders ([CBT scan 2-1]–[paroxetine scan 2-1]). The specific paroxetine change pattern was also examined separately to determine if significant differences in the conjunctional analysis were due to differences in magnitude of the same change or distinct treatment-specific effects of each intervention. Scans from the paroxetine treatment group were acquired with the same PET camera and an identical scanning protocol to that used for the CBT study. Furthermore, the paroxetine raw data were reprocessed and reanalyzed in SPM99 to match all variables used for the primary CBT analyses. In the absence of a controlled randomized trial of CBT and medication, this set of post hoc analyses provided a critical perspective toward interpreting the main CBT response findings. Baseline scans for the 2 groups were also compared.

RESULTS

CLINICAL EFFECTS

Fourteen of the 17 patients completed the full treatment course (mean±SD number of sessions, 17.7±2 for 26±7 weeks). Three participants withdrew within the first

2 weeks due to worsening of symptoms (2 patients) or inability to comply with CBT instructions (1 patient); no second scan was acquired for these patients. For the 14 completers, the mean±SD HDRS scores were 20±3 before treatment and 6.7±4 after treatment, with a decrease of 66%±22% (t=9.66, P<.001). Of these 14 completers, 9 patients met the 50% decrease criteria for full response (final mean±SD HDRS score, 4.7±3.5; decrease of 78±17). The remaining 5 patients had no less than a 35% decrease in their HDRS scores (final mean±SD HDRS score, 10.4±0.7). Because of the small overall sample size and lack of a pure CBT nonresponder group, all patients were included in the pretreatment-to-posttreatment analysis. Patients in the paroxetine-treated comparison group had a similar severity of symptoms at baseline (mean±SD HDRS score, 22.8±3.6) and showed a comparable clinical response (posttreatment mean±SD HDRS score, 6.0±4.1; mean±SD decrease of 75%±14%; t=17.2, P<.001).

REGIONAL METABOLIC CHANGE EFFECTS

Treatment with CBT was associated with significant regional metabolic changes (Table, left; **Figure 1**, top). Areas of increased metabolism before to after treatment included the hippocampus and dorsal midcingulate (BA 24b/c). In addition, widespread decreases were observed in dorsolateral prefrontal (BA 9/46), ventrolateral prefrontal (BA 11/47), and superior and inferior medial frontal regions (BA 9/10/11), as well as posterior cingulate (BA 31), inferior parietal (BA 40), and inferior temporal cortex (BA 20). The same significant metabolic change pattern was seen when the 5 patients who showed less than the 50% response rate were excluded from the analysis. The findings seem specific for clinical response rather than solely the passage of time, because covarying for the HDRS score nullified the between-occasion effects.

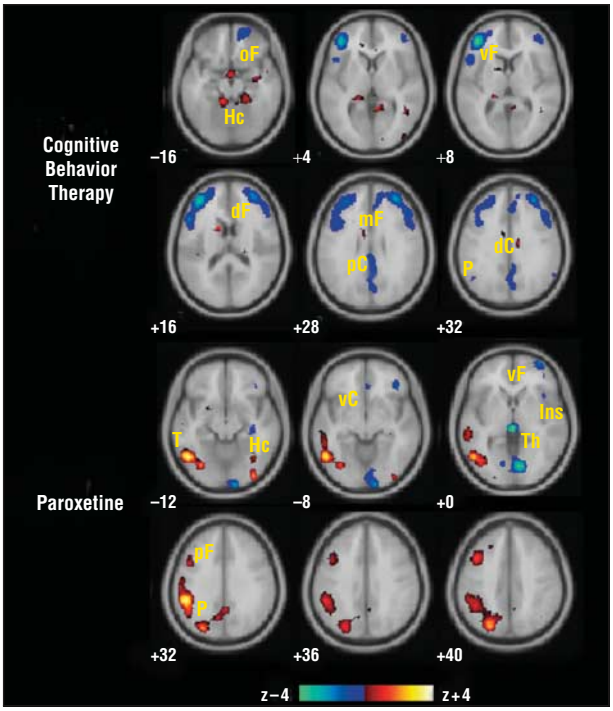

Figure 1. Changes in regional glucose metabolism (fluorine-18–labeled deoxyglucose positron emission tomography) in cognitive behavior therapy (CBT) responders (top) and paroxetine responders (bottom) following treatment. Metabolic increases are shown in orange and decreases in blue. Frontal and parietal decreases and hippocampal increases are seen with CBT response. The reverse pattern is seen with paroxetine. Common to both treatments are decreases in ventral lateral prefrontal cortex. Additional unique changes are seen with each: increases in anterior cingulate and decreases in medial frontal, orbital frontal, and posterior cingulate with CBT and increases in brainstem and cerebellum and decreases in ventral subgenual cingulate, anterior insula, and thalamus with paroxetine. oF Indicates orbital frontal Brodmann area (BA) 11; vF, ventral prefrontal BA 47; Hc, hippocampus; dF, dorsolateral prefrontal BA 9/46; mF, medial frontal BA 10; pC, posterior cingulate BA 23/31; P, inferior parietal BA 40; T, inferior temporal BA 20; vC, subgenual cingulate BA 25; ins, anterior insula; and Th, thalamus. Slice location is in millimeters relative to anterior commissure. Numbers are BA designations.

POST HOC ANALYSES

The conjunctional analysis contrasting CBT response change to paroxetine response change identified significant differences between the 2 treatments in numerous cortical and limbic regions (Table): dorsolateral prefrontal (BA 9), ventromedial frontal (BA 10/11), and inferior parietal (BA 40) cortices, as well as insula, hippocampus, ventral subgenual cingulate (BA 25), anterior and dorsal midcingulate (BA 24), posterior cingulate (BA 31), insula, brainstem, and cerebellum. The separate analyses of the 2 change patterns were in fact necessary to determine which group drove these differences and in what direction (Table).

The dorsolateral prefrontal, inferior parietal, and hippocampal differences identified in this conjunctional analysis represented an inverse pattern for CBT and paroxetine. The between-treatment differences in dorsal midcingulate, ventromedial frontal, and posterior cingulate were related to unique changes with CBT treatment and were not seen with paroxetine at any statistical threshold (Table). Differences involving subgenual cingulate (BA 25), insula, brainstem, and cerebellum likewise were due to unique paroxetine treatment effects (Table). Similar for the 2 treatments were decreases in ventral prefrontal cortex (BA 47).

Direct comparison of baseline scans for the CBT and paroxetine groups demonstrated no significant differences. There were also no significant correlations between metabolism and weeks of treatment across groups. Finally, covarying the pretreatment and posttreatment changes with the HDRS score nullified the changes in both groups, providing additional evidence that the divergent change patterns reflect treatment-specific response effects.

COMMENT

Reciprocal limbic increases (hippocampus, dorsal midcingulate) and cortical decreases (dorsolateral, ventrolateral, and medial orbital frontal; inferior temporal and parietal) were identified following successful treatment with CBT. These regional changes involve sites similar, and in some cases identical, to those seen previously with paroxetine and other pharmacotherapies,[21,37] but the changes were in the opposite direction.

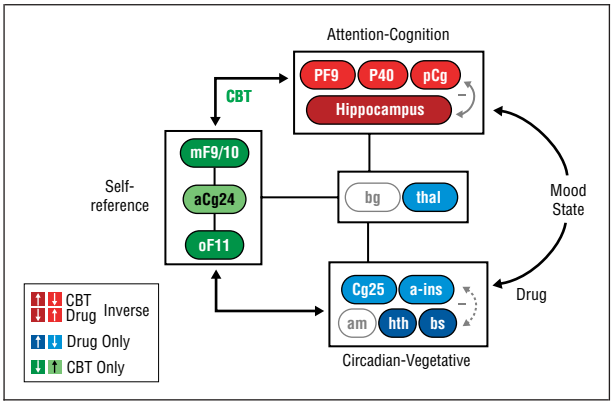

Figure 2. Schematic model illustrating relationships among regions mediating cognitive behavior therapy (CBT) and drug response. Regions with known anatomical and functional connections that also show significant metabolic changes following successful treatment are grouped into 3 compartments—cognitive, autonomic, and self-reference. Red regions designate areas of change seen with both treatments. Green regions designate changes unique to CBT. Blue regions designate changes unique to paroxetine. Solid black lines and arrows identify known corticolimbic, limbic-paralimbic, and cingulate-cingulate connections. Gray arrows indicate reciprocal changes with treatment. The model proposes that illness remission occurs when there is modulation of critical common targets (red regions), an effect facilitated by top-down (medial frontal, anterior cingulate) effects of CBT (green) or bottom-up (brainstem, striatal, subgenual cingulate) actions of paroxetine (blue). PF9 indicates dorsolateral prefrontal; p40, inferior parietal; pCg, posterior cingulate; mF9/10, medial frontal; aCg24, anterior cingulate; oF11, orbital frontal; bg, basal ganglia; thal, thalamus; Cg25, ventral subgenual cingulate; a-ins, anterior insula; am, amygdala; hth, hypothalamus; and bs, brainstem. Numbers are Brodmann area designations.

Interpreted in the context of an extensive PET and functional magnetic resonance imaging behavior mapping literature, the metabolic change pattern seen with resolution of depressive symptoms following CBT provides tentative neural correlates of the long-theorized psychological or top-down mechanisms that mediate CBT response[33,50] (**Figure 2**). Examples of such parallels include localization of tasks involving directed attention, reward-based decision making, and monitoring of emotional salience to the anterior cingulate and orbital frontal cortex[51-58]; memory encoding, retrieval, and consolidation to the hippocampus[59-61]; and working memory, self-referential processing, and cognitive ruminations to dorsolateral, medial frontal, and ventral prefrontal cortex, respectively.[62-65] Components of these behaviors have been implicated in the initiation and maintenance of the depressive state[31,32,57,66] and seem to be specifically targeted in CBT.[27,31,32] Although speculative, hippocampal and mid and anterior cingulate increases coupled with decreases in medial frontal, dorsolateral, and ventrolateral prefrontal activity with CBT treatment might be nonetheless interpreted as correlates of CBT-conditioned increases in attention to personally relevant emotional and environmental stimuli associated with a learned ability to reduce online cortical processes at the level of encoding and retrieval of maladaptive associative memories, as well as a reduction in both ruminations and the overprocessing of irrelevant information.

In further support of a critical role for medial frontal modulation with CBT response compared with medication are the unique changes in anterior and dorsal midcingulate (BA 24), medial frontal (BA 10), and orbital frontal (BA 11) with treatment response. Although both groups demonstrated hyperactivity in medial frontal regions before treatment, only CBT was associated with widespread changes. Activation of these regions has been previously associated with emotional processing tasks in nondepressed control participants, including the active rethinking and reappraisal of emotional feelings.[58,63-65,67] Exaggerated activity in this region has been similarly reported in depressed patients in response to sad words, supporting the previously recognized negative emotional bias in this patient population.[66] These observations are consistent with nonimaging studies that demonstrate increased relapse risk in those remitted depressed patients with persistent mood-linked reactivity to negative emotional stimuli[31] and increased sustained remission for patients in whom this reactivity is reduced.[32,68] Referable to the patients in this study, selective changes with CBT in these regions may reflect a reduced bias toward the processing of negative information in the recovered state, with implications for future relapse risk.

The frontal decreases seen with CBT response are strikingly similar to those reported in a recent FDG-PET study[34] of interpersonal psychotherapy for major depression. Regional changes with CBT treatment for other disorders also describe areas of overlap with those reported herein for depression. For instance, changes in the hippocampus are reported with CBT treatment for social phobia, although the changes are in the reverse direction.[26] A third distinct pattern of caudate and posterior orbital cortex decreases has been shown with CBT treatment for obsessive-compulsive disorder.[24,25] Together, these findings suggest that brain change pattern variations with CBT for various disorders likely reflect both fundamental differences in the underlying psychopathology (depression, obsessive-compulsive disorder, social phobia) and procedural differences inherent in the cognitive method used to treat each condition.[69] *Method* in this context not only refers to the subtleties of the CBT procedures themselves but also includes patient expectation and conditioned learning facilitated by both the specific intervention and the individual physician-patient interaction.

These various elements, inherent in any specified therapy, likely also explain the differences between the pattern of response to CBT and that reported for placebo medication,[70] a response considered by some to be an uncontrolled psychological form of treatment. In the case of fluoxetine treatment for depression, the change pattern for placebo fluoxetine overlapped that seen with response to the active medication to which it was experimentally linked (frontal, parietal increases, subgenual cingulate decreases) rather than the *psychological* intervention pattern seen here with CBT (frontal decreases, hippocampal increases). Brain changes with placebo response, in fact, directly shadowed the true drug-response pattern, similar to that shown with both an acute dose of a dopamine-agonist in patients with Parkinson disease (striatal dopamine changes)[71] and an acute dose of an opiate analgesic (cingulate and brainstem blood flow changes),[72] suggesting a complex interaction of the specific treatment and expected behavioral effects. Obvi-

ously, a placebo-controlled CBT trial will be necessary to fully test the hypothesis that placebo-response changes mirror the specific intervention to which they are paired, meaning that placebo CBT would be expected to overlap true CBT changes, not those seen with placebo medication. A wait-list control group will also be needed to address effects potentially attributable to spontaneous remission with either treatment.

There are other potential explanations for reported change-pattern differences across various psychological treatment studies for depression, including the type of cognitive intervention (CBT vs interpersonal psychotherapy), the imaging modality (PET vs single-photon emission computed tomography; glucose metabolism vs blood flow), and the point of the second scan within the treatment course (6-8 vs >15 weeks). Although it is possible that brain changes with an incomplete course of a nonpharmacologic treatment may be similar to those seen with full clinical response, this is clearly not the case with antidepressant medication, where analyses of time course (1 vs 6 weeks) and response effects (responder vs nonresponder at 6 weeks) show significantly different metabolic change patterns.[17] This may also explain differences in the nonpharmacotherapy treatment change patterns reported across other published reports.[34,35] Explicit studies of the time course of brain changes with various cognitive interventions, including a parallel assessment of both responders and nonresponders, are needed to further test these hypotheses. Examination of the time course of change in HDRS scores in this CBT responder group (without corresponding PET scans) would suggest that metabolic change effects might be reasonably seen after 8 sessions (eighth session mean ± SD HDRS score, 11.5 ± 6), perhaps providing an early indication of who is most likely to respond to a full treatment course.[50]

Despite the absence of a prospective, randomized study design and obvious differences in treatment duration, the post hoc paroxetine comparison performed herein provided several critical clues for further interpreting the identified CBT change effects. Most notably, the conjunctional analyses demonstrated a complex set of change pattern differences between CBT and paroxetine responders. Most significantly, in contrast to the CBT increases in hippocampus and decreases in frontal cortex, the independent paroxetine analyses demonstrated the reverse pattern—frontal increases and hippocampal decreases. The localization and pattern of changes seen in the paroxetine group, including the unique changes in subgenual cingulate (BA 25), insula, and brainstem, replicate previous human and animal metabolic studies of various pharmacotherapies, including other selective serotonin reuptake inhibitors and tricyclics.[16-19,21,37]

This divergent pattern of frontal decreases and hippocampal increases with CBT relative to paroxetine is not explained by pretreatment metabolic abnormalities, because the 2 groups show no significant differences when directly compared. The differential change patterns also appear not to be simply the result of differences in the mean duration of treatment between the 2 groups, because there were no significant correlations between brain metabolism and weeks of treatment. Interestingly, in both groups, there is considerable overlap between the regions of metabolic change and areas of reported glial cell loss in postmortem studies, notably, dorsolateral, ventrolateral, and medial frontal cortices.[73] That said, neither group showed significant baseline hypometabolism in either frontal cortex or hippocampus, suggesting a more complex relationship among glial abnormalities, brain atrophy, and metabolic change patterns than previously suggested.[74-76] Quantitative magnetic resonance imaging volumetric analyses, however, were not performed.

Taken together, the treatment-specific change patterns in CBT and paroxetine responders support our initial hypothesis that each treatment targets different primary sites with differential top-down and bottom-up effects—medial frontal and cingulate cortices with cognitive therapy (Figure 2, green) and limbic and subcortical regions with pharmacotherapy (brainstem, insula, subgenual cingulate; Figure 2, blue), both resulting in a net change in critical prefrontal-hippocampal pathways (Figure 2, red). The overall modulation of this complex system rather than any one focal regional change may be most critical for disease remission. As previously stated, definitive conclusions regarding treatment-specific effects will require a randomized design of depressed patients seeking either treatment.

It has been previously suggested that variations in scan patterns both at baseline and following treatment reflect such clinical factors as illness severity, cognitive impairment, anxiety, psychomotor retardation, and depressive subtypes.[77-81] In this study, there were no significant differences in illness severity, demographics, HDRS factor scores, or any other depression-related variable that might alternatively explain the differential metabolic change patterns across the 2 treatment groups. Detailed neuropsychological testing, however, was not performed. Although the paroxetine comparison group was exclusively composed of men, no significant sex differences were seen in either the baseline scans or change patterns of the CBT group, although statistical power was inadequate to definitely exclude sex effects.

Another potential confounder is the ongoing behavior of each patient at the time of each scan, particularly since patients were studied in a relatively uncontrolled state (eyes-closed rest). Previous studies[82,83] during a variety of cognitive tasks demonstrate that medial frontal regions show decreases relative to rest, suggesting an ongoing activation of these regions in the resting state. The medial frontal increases, seen at baseline in both the CBT and paroxetine patients relative to healthy controls, although possibly interpretable as a pretreatment marker of increased attention to self, do not appreciably change with treatment, despite clinical improvement. Furthermore, the localization of these reported self-directed resting state markers is considerably more caudal to those demonstrated herein either at baseline or with CBT response, suggesting that these baseline and change effects reflect disease rather than a confounding of the short-term behavioral state.

Similarly, in test-retest studies[84-86] that examined effects of test environment, novelty, and levels of anxiety, published reports demonstrate a pattern of hyperactivity in lateral frontal cortices associated with the first test condition. Again, neither group in this study showed this dor-

solateral prefrontal pattern at rest, although both groups showed significant changes in these regions following clinical recovery. Although neither group was tested explicitly for state anxiety at the time of the scan, anxiety subscales of the HDRS performed just before each scan session showed no differences between the groups at baseline. In addition, comorbid anxiety disorders were among protocol exclusion criteria. It is possible that the absence of prefrontal findings at baseline reflect a first-test effect in both groups, in essence, counteracting the expected frontal hypometabolism typical of many published studies of major depression.[79] This, however, would not explain the differential changes in frontal cortex seen following treatment where again both groups showed comparable anxiety subscale scores. In the absence of more subtle behavioral measures, there is no evidence to support the conclusion that the disparate changes in frontal activity for one group relative to the other are a function of state anxiety. The potential contributions of other uncontrolled individual variables, such as family history, specific gene polymorphisms, temperament, early life abuse, or previous depressive episodes, were not examined.[87-89]

Finally, although the 2 groups were studied as independent cohorts, met identical inclusion criteria, and were recruited through the same media outlets, the possibility of a selection bias still exists. A trial with random assignment of patients to 1 of the 2 treatments of comparable duration is needed to fully address this concern and is the focus of an ongoing study. That said, it is worth noting that the self-selection by patients of a specific antidepressant intervention may reflect their probabilistic calculation of benefit, taking past treatment into account. Anecdotally, many of those in the CBT group who had previously been treated with medication expressed strong disinterest in repeating pharmacotherapy. In fact, many demonstrated considerable insight, believing that their negative thoughts and beliefs were causing and maintaining their depressive state. In addition, those who had taken antidepressant medications in the past tended to minimize their effectiveness due to associated adverse effects. These subjective reports may provide important targets for future investigations of the predictive value of patient treatment preferences and their neural correlates.[90]

Submitted for publication September 11, 2002; final revision received June 17, 2003; accepted June 24, 2003.

This study was supported in part by the Sandra Rotman Chair in Neuropsychiatry, Rotman Research Institute (Toronto), the Canadian Institute for Health Research, and a University of Toronto Institute of Medical Science Open Fellowship Award (Ms Goldapple).

This study was presented in part at the 2002 Annual Meeting of the Society of Biological Psychiatry; May 17, 2002; Philadelphia, Pa.

We thank Doug Hussey, BSc, RTNM, and Kevin Cheung, RTNM, for their expert technical assistance with PET scan acquisition and data reconstruction.

Corresponding author: Helen Mayberg, MD, Rotman Research Institute, Baycrest Centre, 3560 Bathurst St, Toronto, Ontario, Canada M6A 2E1 (e-mail: hmayberg @rotman-baycrest.on.ca).

REFERENCES

1. Hollon SD, DeRubeis RJ, Evans MD, Wiemer MJ, Garvey MJ, Grove WM, Tuason VB. Cognitive therapy and pharmacotherapy for depression: singly and in combination. *Arch Gen Psychiatry.* 1992;49:774-781.
2. DeRubeis RJ, Gelfand LA, Tang TZ, Simons AD. Medications versus cognitive behavior therapy for severely depressed outpatients: mega-analysis of four randomized comparisons. *Am J Psychiatry.* 1999;156:1007-1013.
3. Rush AJ, Kovacs M, Beck AT, Weissenburger J, Hollon SD. Differential effects of cognitive therapy and pharmacotherapy on depressive symptoms. *J Affect Disord.* 1981;3:221-229.
4. Derryberry D, Tucker DM. Neural mechanisms of emotion. *J Consult Clin Psychol.* 1992;60:329-338.
5. Tucker DM, Luu P, Pribram KH. Social and emotional self-regulation. *Ann N Y Acad Sci.* 1995;769:213-239.
6. Frazer A, Hensler JG. 5-HT1A receptors and 5-HT1A-mediated responses: effect of treatments that modify serotonergic neurotransmission. *Ann N Y Acad Sci.* 1990;600:460-474; discussion 474-275.
7. Chaput Y, de Montigny C, Blier P. Presynaptic and postsynaptic modifications of the serotonin system by long-term administration of antidepressant treatments: an in vivo electrophysiologic study in the rat. *Neuropsychopharmacology.* 1991;5:219-229.
8. Haddjeri N, Blier P, de Montigny C. Long-term antidepressant treatments result in a tonic activation of forebrain 5HT1A receptors. *J Neurosci.* 1998;18:10150-10156.
9. Hyman SE, Nestler EJ. Initiation and adaptation: a paradigm for understanding psychotropic drug action. *Am J Psychiatry.* 1996;153:151-162.
10. Duman RS, Malberg J, Thome J. Neural plasticity to stress and antidepressant treatment. *Biol Psychiatry.* 1999;46:1181-1191.
11. Arango V, Underwood MD, Mann JJ. Postmortem findings in suicide victims: implications for in vivo imaging studies. *Ann N Y Acad Sci.* 1997;836:269-287.
12. Vaidya VA, Marek GJ, Aghajanian GK, Duman RS. 5-HT2A receptor-mediated regulation of brain-derived neurotrophic factor mRNA in the hippocampus and the neocortex. *J Neurosci.* 1997;17:2785-2795.
13. Frechilla D, Otano A, Del Rio J. Effect of chronic antidepressant treatment on transcription factor binding activity in rat hippocampus and frontal cortex. *Prog Neuropsychopharmacol Biol Psychiatry.* 1998;22:787-802.
14. Chen B, Dowlatshahi D, MacQueen GM, Wang JF, Young LT. Increased hippocampal BDNF immunoreactivity in subjects treated with antidepressant medication. *Biol Psychiatry.* 2001;50:260-265.
15. Blier P, de Montigny C. Serotonin and drug-induced therapeutic responses in major depression, obsessive compulsive and panic disorders. *Neuropsychopharmacology.* 1999;21(2 suppl):91S-98S.
16. Freo U, Ori C, Dam M, Merico A, Pizzolato G. Effects of acute and chronic treatment with fluoxetine on regional glucose cerebral metabolism in rats: implications for clinical therapies. *Brain Res.* 2000;854:35-41.
17. Mayberg HS, Brannan SK, Tekell JL, Silva JA, Mahurin RK, McGinnis S, Jerabek PA. Regional metabolic effects of fluoxetine in major depression: serial changes and relationship to clinical response. *Biol Psychiatry.* 2000;48:830-43.
18. Passero S, Nardini M, Battistini N. Regional cerebral blood flow changes following chronic administration of antidepressant drugs. *Prog Neuropsychopharmacol Biol Psychiatry.* 1995;19:627-636.
19. Buchsbaum MS, Wu J, Siegel BV, Hackett E, Trenary M, Abel L, Reynolds C. Effect of sertraline on regional metabolic rate in patients with affective disorder. *Biol Psychiatry.* 1997;41:15-22.
20. Brody AL, Saxena S, Silverman DHS, Alborzian S, Fairbanks LA, Phelps ME, Huang S, Wu H, Maidment K, Baxter LR. Brain metabolic changes in major depressive disorder from pre- to post-treatment with paroxetine. *Psychiatry Res.* 1999;91:127-139.
21. Kennedy SH, Evans KR, Kruger S, Mayberg HS, Meyer JH, McCann S, Arifuzzman AI, Houle S, Vaccarino FJ. Changes in regional brain glucose metabolism measured with positron emission tomography after paroxetine treatment of major depression. *Am J Psychiatry.* 2001;158:899-905.
22. Goodwin GM, Austin MP, Dougall N, Ross M, Murray C, O'Carroll RE, Moffoot A, Prentice N, Ebmeier KP. State changes in brain activity shown by the uptake of 99mTc-exametazime with single photon emission tomography in major depression before and after treatment. *J Affect Disord.* 1993;29:243-253.
23. Bench CJ, Frackowiak RSJ, Dolan RJ. Changes in regional cerebral blood flow on recovery from depression. *Psychol Med.* 1995;25:247-262.
24. Baxter LR Jr, Schwartz JM, Bergman KS, Szuba MP, Guze BH, Mazziotta JC, Alazraki A, Selin CE, Ferng HK, Munford P. Caudate glucose metabolic rate changes with both drug and behavior therapy for obsessive-compulsive disorder. *Arch Gen Psychiatry.* 1992;49:681-689.
25. Schwartz JM. Neuroanatomical aspects of cognitive-behavioural therapy response in obsessive-compulsive disorder: an evolving perspective on brain and behaviour. *Br J Psychiatry Suppl.* 1998;35:38-44.
26. Furmark T, Tillfors M, Marteinsdottir I, Fischer H, Pissiota A, Langstrom B, Fredrikson M. Common changes in cerebral blood flow in patients with social phobia treated with citalopram or cognitive-behavioral therapy. *Arch Gen Psychiatry.* 2002;59:425-433.
27. Beck AT, Rush AJ, Shaw BF. *Cognitive Therapy of Depression.* New York, NY: Guilford Press; 1979.
28. Simons AD, Garfield SL, Murphy GE. The process of change in cognitive therapy

and pharmacotherapy for depression: changes in mood and cognition. *Arch Gen Psychiatry.* 1984;41:45-51.
29. DeRubeis RJ, Evans MD, Hollon SD, Garvey MJ, Grove WM, Tuason VB. How does cognitive therapy work? cognitive change and symptom change in cognitive therapy and pharmacotherapy for depression. *J Consult Clin Psychol.* 1990; 58:862-869.
30. Clark D, Beck AT, Alford B. *Scientific Foundations of Cognitive Theory and Therapy of Depression.* New York, NY: John Wiley; 1999.
31. Segal ZV, Gemar M, Williams S. Differential cognitive response to a mood challenge following successful cognitive therapy or pharmacotherapy for unipolar depression. *J Abnorm Psychol.* 1999;108:3-10.
32. Teasdale JD, Moore RG, Hayhurst H, Pope M, Williams S, Segal ZV. Metacognitive awareness and prevention of relapse in depression: empirical evidence. *J Consult Clin Psychol.* 2002;70:275-287.
33. Rush AJ, Beck AT, Kovacs M, Weissenburger J, Hollon SD. Comparison of the effects of cognitive therapy and pharmacotherapy on hopelessness and self-concept. *Am J Psychiatry.* 1982;139:862-866.
34. Brody AL, Saxena S, Stoessel P, Gillies LA, Fairbanks LA, Alborzian S, Phelps ME, Huang SC, Wu HM, Ho ML, Ho MK, Au SC, Maidment K, Baxter LR Jr. Regional brain metabolic changes in patients with major depression treated with either paroxetine or interpersonal therapy: preliminary findings. *Arch Gen Psychiatry.* 2001;58:631-640.
35. Martin SD, Martin E, Rai SS, Richardson MA, Royall R. Brain blood flow changes in depressed patients treated with interpersonal psychotherapy or venlafaxine hydrochloride: preliminary findings. *Arch Gen Psychiatry.* 2001;58:641-648.
36. Mayberg HS. Limbic-cortical dysregulation: a proposed model of depression. *J Neuropsychiatry Clin Neurosci.* 1997;9:471-481.
37. Mayberg HS. Modulating limbic-cortical circuits in depression: targets of antidepressant treatments. *Semin Clin Neuropsychiatry.* 2002;7:255-268.
38. Frank E, Prien RF, Jarrett RB, Keller MB, Kupfer DJ, Lavori PW, Rush AJ, Weissman MM. Conceptualization and rationale for consensus definitions of terms in major depressive disorder: remission, recovery, relapse, and recurrence. *Arch Gen Psychiatry.* 1991;48:851-855.
39. Spitzer RL, Williams JB, Gibbon M, First MB. Structured Clinical Interview for *DSM-III-R* (SCID), I: history, rationale, and description. *Arch Gen Psychiatry.* 1992; 49:624-629.
40. Beck AT, Steer R, Brown G. *Beck Depression Inventory B: Second Edition Manual.* San Antonio, Tex: The Psychological Corp; 1996.
41. Hamilton M. A rating scale for depression. *J Neurol Neurosurg Psychiatry.* 1960; 23:56-62.
42. Stassen HH, Delini-Stula A, Angst J. Time course of improvement under antidepressant treatment: a survival-analytical approach. *Eur Neuropsychopharmacol.* 1993;3:127-135.
43. Phelps ME, Huang SC, Hoffman EJ, Selin C, Sokoloff L, Kuhl DE. Tomographic measurement of local cerebral glucose metabolic rate in humans with (F-18)2-fluoro-2-deoxy-D-glucose: validation of method. *Ann Neurol.* 1979;6:371-388.
44. Mayberg H, Brannan S, Mahurin R, et al. Cingulate function in depression: a potential predictor of treatment response. *Neuroreport.* 1997;8:1057-1061.
45. Collins DL, Neelin P, Peters TM, Evans AC. Automatic 3D intersubject registration of MR volumetric data in standardized Talairach space. *J Comput Assist Tomogr.* 1994;18:192-205.
46. Brett M, Johnsrude IS, Owen AM. The problem of functional localization in the human brain. *Nat Rev Neurosci.* 2002;3:243-249.
47. Friston KJ, Holmes AP, Worsley KJ, Poline JB, Frith CD, Frackowiak RSJ. SPMs in functional imaging: A general linear approach. *Hum Brain Mapp.* 1995;2:189-210.
48. Friston KJ, Worsley KJ, Frackowak JS, Mazziotta JC, Evans C. Assessing the significance of focal activations using their spatial extent. *Hum Brain Mapp.* 1994; 1:214-220.
49. Talairach J, Tournoux P. *Co-planar Stereotaxic Atlas of the Human Brain.* Stuttgart, Germany: Georg Thieme Verlag; 1988.
50. Tang TZ, Derubeis RJ. Sudden gains and critical sessions in cognitive-behavioral therapy for depression. *J Consult Clin Psychol.* 1999;67:894-904.
51. Bush G, Luu P, Posner MI. Cognitive and emotional influences in anterior cingulate cortex. *Trends Cogn Sci.* 2000;4:215-222.
52. Bush G, Vogt BA, Holmes J, Dale AM, Greve D, Jenike MA, Rosen BR. Dorsal anterior cingulate cortex: a role in reward-based decision making. *Proc Natl Acad Sci U S A.* 2002;99:523-528.
53. Koski L, Petrides M. Distractibility after unilateral resections from the frontal and anterior cingulate cortex in humans. *Neuropsychologia.* 2002;40:1059-1072.
54. Whalen PJ, Bush G, McNally RJ, Wilhelm S, McInerney SC, Jenike MA, Rauch SL. The emotional counting Stroop paradigm: a functional magnetic resonance imaging probe of the anterior cingulate affective division. *Biol Psychiatry.* 1998; 44:1219-1228.
55. Rolls ET. The orbitofrontal cortex. *Philos Trans R Soc Lond B Biol Sci.* 1996; 351:1433-1444.
56. Tremblay L, Schultz W. Relative reward preference in primate orbitofrontal cortex. *Nature.* 1999;398:704-708.
57. Murphy FC, Sahakina BJ, Rubinsztein JS, Michael A, Rogers RD, Robbins TW, Paykel ES. Emotional bias and inhibitory control processes in mania and depression. *Psychol Med.* 1999;29:1307-1321.
58. Elliott R, Rubinsztein JS, Sahakian BJ, Dolan RJ. Selective attention to emotional stimuli in a verbal go/no-go task: an fMRI study. *Neuroreport.* 2000;11: 1739-1744.
59. McIntosh AR. Mapping cognition to the brain through neural interactions. *Memory.* 1999;7:523-548.
60. Strange BA, Fletcher PC, Henson RN, Friston KJ, Dolan RJ. Segregating the functions of human hippocampus. *Proc Natl Acad Sci U S A.* 1999;96:4034-4039.
61. Gron G, Bittner D, Schmitz B, Wunderlich AP, Tomczak R, Riepe MW. Hippocampal activations during repetitive learning and recall of geometric patterns. *Learn Mem.* 2001;8:336-345.
62. Grady C. Neuroimaging & activation of the frontal lobes. In: Miller BL, Cummings JL, eds. *The Human Frontal Lobes, Functions and Disorders.* Baltimore, Md: Guilford; 1999:196-230.
63. Craik FIM, Moroz TM, Moscovitch M, Stuss DT, Winocur G, Tulving E, Kapur S. In search of the self: a PET investigation. *Psychol Sci.* 1999;10:26-34.
64. Kelley WM, Macrae CN, Wyland CL, Caglar S, Inati S, Heatherton TF. Finding the self? an event-related fMRI study. *J Cogn Neurosci.* 2002;14:785-794.
65. Fossati P, Hevonor SJ, Grahma SJ, Grady C, Keightley ML, Craik F, Mayberg HS. In search of the emotional self: a fMRI study using positive and negative emotional words. *Am J Psychiatry.* 2003;160:1938-1945.
66. Elliott R, Rubinsztein JS, Sahakian BJ, Dolan RJ. The neural basis of mood congruent processing biases in depression. *Arch Gen Psychiatry.* 2002;59:597-604.
67. Ochsner KN, Bunge SA, Gross JJ, Gabrieli JD. Rethinking feelings: an FMRI study of the cognitive regulation of emotion. *J Cogn Neurosci.* 2002;14:1215-1229.
68. Teasdale JD, Scott J, Moore RG, Hayhurst H, Pope M, Paykel ES. How does cognitive therapy prevent relapse in residual depression? evidence from a controlled trial. *J Consult Clin Psychol.* 2001;69:347-357.
69. Heimberg RG. Cognitive-behavioral therapy for social anxiety disorder: current status and future directions. *Biol Psychiatry.* 2002;51:101-108.
70. Mayberg, HS, Silva JA, Brannan SK, Tekell JL, McGinnis S, Mahurin RK, Jerabek PA. The functional neuroanatomy of the placebo effect. *Am J Psychiatry.* 2002; 159:728-737.
71. de la Fuente-Fernandez R, Ruth TJ, Sossi V, Schulzer M, Calne DB, Stoessl AJ. Expectation and dopamine release: mechanism of the placebo effect in Parkinson's disease. *Science.* 2001;293:1164-1166.
72. Petrovic P, Kalso E, Petersson KM, Ingvar M. Placebo and opioid analgesia–imaging a shared neuronal network. *Science.* 2002;295:1737-1740.
73. Rajkowska G. Cell pathology in mood disorders. *Semin Clin Neuropsychiatry.* 2002;7:281-292.
74. Ongur D, Drevet WC, Price JL. Glial reduction in the subgenual prefrontal cortex in mood disorders. *Proc Natl Acad Sci U S A.* 1998;95:13290-13295.
75. Sheline YI, Wang PW, Gado MH, Csernansky JG, Vannier MW. Hippocampal atrophy in recurrent major depression. *Proc Natl Acad Sci U S A.* 1996;93:3908-3913.
76. Drevets WC, Price JL, Simpson JR Jr, Todd RD, Reich T, Vannier M, Raichle ME. Subgenual prefrontal cortex abnormalities in mood disorders. *Nature.* 1997; 386:824-827.
77. Bench CJ, Friston KJ, Brown RG, Frackowiak RS, Dolan RJ. Regional cerebral blood flow in depression measured by positron emission tomography: the relationship with clinical dimensions. *Psychol Med.* 1993;23:579-590.
78. Mayberg HS, Lewis PJ, Regenold W, Wagner HN. Paralimbic hypoperfusion in unipolar depression. *J Nucl Med.* 1994;35:929-934.
79. Ketter TA, George MS, Kimbrell TA, Benson BE, Post RM. Functional brain imaging, limbic function, and affective disorders. *Neuroscientist.* 1996;2:55-65.
80. Dunn RT, Kimbrell TA, Ketter TA, Frye MA, Willis MW, Luckenbaugh DA, Post RM. Principal components of the Beck Depression Inventory and regional cerebral metabolism in unipolar and bipolar depression. *Biol Psychiatry.* 2002;51: 387-399.
81. Brody AL, Saxena S, Mandelkern MA, Fairbanks LA, Ho ML, Baxter LR. Brain metabolic changes associated with symptom factor improvement in major depressive disorder. *Biol Psychiatry.* 2001;50:171-178.
82. Gusnard DA, Raichle ME, Raichle ME. Searching for a baseline: functional imaging and the resting human brain. *Nat Rev Neurosci.* 2001;2:685-694.
83. Andreasen NC, O'Leary DS, Cizadlo T, Arndt S, Rezai K, Watkins GL, Ponto LL, Hichwa RD. Remembering the past: two facets of episodic memory explored with positron emission tomography. *Am J Psychiatry.* 1995;152:1576-1585.
84. Gur RC, Gur RE, Resnick SM, Skolnick BE, Alavi A, Reivich M. The effect of anxiety on cortical cerebral blood flow and metabolism. *J Cereb Blood Flow Metab.* 1987;7:173-177.
85. Stapleton JM, Morgan MJ, Liu X, Yung BC, Phillips RL, Wong DF, Shaya EK, Dannals RF, London ED. Cerebral glucose utilization is reduced in second test sessions. *J Cereb Blood Flow Metab.* 1997;17:704-712.
86. Schmidt ME, Ernst M, Matochik JA, Maisog JM, Pan BS, Zametkin AJ, Potter WZ. Cerebral glucose metabolism during pharmacologic studies: test-retest under placebo conditions. *J Nucl Med.* 1996;37:1142-1149.
87. Kendler KS, Thornton LM, Gardner CO. Genetic risk, number of previous depressive episodes, and stressful life events in predicting onset of major depression. *Am J Psychiatry.* 2001;158:582-586.
88. Neumeister A, Konstantinidis A, Stastny J, Schwarz MJ, Vitouch O, Willeit M, Praschak-Rieder N, Zach J, de Zwaan M, Bondy B, Ackenheil M, Kasper S. Association between serotonin transporter gene promoter polymorphism (5HTTLPR) and behavioral responses to tryptophan depletion in healthy women with and without family history of depression. *Arch Gen Psychiatry.* 2002;59:613-620.
89. Heim C, Newport DJ, Heit S, Graham YP, Wilcox M, Bonsall R, Miller AH, Nemeroff CB. Pituitary-adrenal and autonomic responses to stress in women after sexual and physical abuse in childhood. *JAMA.* 2000;284:592-597.
90. Mayberg HS. Modulating dysfunctional limbic-cortical circuits in depression: towards development of brain-based algorithms for diagnosis and optimized treatment. *Br Med Bull.* 2003;65:193-207.