Rapid Onset of Antidepressant Action: A New Paradigm in the Research and Treatment of Major Depression

Rodrigo Machado-Vieira, M.D, Ph.D., **Giacomo Salvadore, M.D.**, **David A. Luckenbaugh, M.A.**, **Husseini K. Manji, M.D., F.R.C.P.C.**, and **Carlos A. Zarate Jr., M.D.**
Mood and Anxiety Disorders Program, National Institute of Mental Health, Department of Health and Human Services, Bethesda, Maryland, USA

Abstract

Objective—Current therapeutics of depression are similar in their time to antidepressant action and often take weeks to months to achieve response and remission; which commonly results in considerable morbidity and disruption in personal, professional, family, and social life, as well as, risk for suicidal behavior. Thus, treatment strategies presenting a rapid improvement of depressive symptoms—within hours or even a few days—and whose effects are sustained, would have an enormous impact on public health. This article reviews the published data related to different aspects of rapid improvement of depressive symptoms.

Data Sources—Literature for this review was obtained through a search of the MEDLINE database (1966–2007) using the following keywords and phrases: rapid response, antidepressant, time to, glutamate, sleep, therapeutics, latency, and depression. The data obtained were organized according to the following topics: clinical relevance and time course of antidepressant action, interventions showing evidence of rapid response and its potential neurobiological basis, and new technologies for better understanding rapid antidepressant actions.

Data Synthesis—A limited number of prospective studies evaluating rapid antidepressant actions have been conducted. Currently, only a few interventions have been shown to produce antidepressant response in hours or a few days. The neurobiological basis of these rapid antidepressant actions is only now being deciphered.

Conclusions—Certain experimental treatments can produce antidepressant response in a much shorter period of time than existing medications. Understanding the molecular basis of these experimental interventions is likely to lead to the development of improved therapeutics rather than simply furthering our knowledge of current standard antidepressants.

Keywords

antidepressant; depression; glutamate; ketamine; rapid onset; sleep

INTRODUCTION

Major depressive disorder (depression) is a severe, recurrent, and disabling medical illness that is highly prevalent worldwide and often associated with a negative impact on medical health, quality of life, and productivity [1,2,3]. Many factors influence clinical response and outcome

Address correspondence to: Carlos A. Zarate, Jr., M.D., Chief, Mood Disorders Research Unit, Associate Clinical Director, Laboratory of Molecular Pathophysiology, National Institute of Mental Health, Mark O. Hatfield Clinical Research Center, 10 Center Dr, Unit 7SE, Rm 7-3445, Bethesda, Maryland, 20892-1282, USA.

in depression, including clinical presentation, comorbidities, past psychiatric and medical history, genetic makeup, and environmental factors [4,5,6,7].

Several classes of antidepressants are currently used in the treatment of this devastating disorder. A delayed onset of antidepressant action is one of the major limitations of all existing antidepressant therapies. For example, in the largest effectiveness study conducted to date in patients with unipolar depression, involving nearly 3,000 outpatients, only 28% of patients treated with a standard antidepressant achieved remission within 10–14 weeks [3,8]. These findings suggest that full therapeutic effects usually take many weeks to manifest and, despite long-term treatment, a considerable number of patients still do not have satisfactory improvement. Furthermore, clinical improvement that occurs during the first few weeks of treatment with antidepressants seems to be a critical factor for achieving long-term clinical stability [9]. The potential role of early onset of antidepressant action as a surrogate endpoint for long-term sustained improvement seems to be associated with long-lasting benefits by limiting harmful neurobiological effects and poor outcome secondary to repeated depressive episodes and enduring depressive symptoms[10,11,12].

Despite recent advances in the treatment of depression, reducing this delay in onset of antidepressant effects and improving the remission rates associated with existing treatments is a research goal that has not been sufficiently pursued. Thus, developing treatments with a rapid antidepressant action—especially a response or remission that occurs in a matter of hours or even a few days—could have an enormous impact on public health.

This aim of this article is to reveiw studies on: 1) time of onset of current antidepressant treatments, typically occurring within few weeks; 2) interventions leading to a significant improvement of core depressive symptoms within hours to a few days and presumed cellular mechanisms involved in the rapid onset of antidepressant actions and 3) tools for better understanding rapid antidepressant actions. It is our hope that this article will stimulate new lines of drug development research on treatments that work within hours.

Literature for this review was obtained through a search of the MEDLINE database (1966–2007) using the following keywords and phrases: rapid response, antidepressant, time to, glutamate, sleep, therapeutics, latency, and depression. The data obtained were organized according to the following topics: clinical relevance and time course of antidepressant action, interventions showing evidence of rapid response and its potential neurobiological basis, and new technologies for better understanding rapid antidepressant actions.

RATIONALE FOR THE NEED OF RAPID ANTIDEPRESSANT ACTION: HIGH MORBIDITY DURING THE PERIOD OF LATENCY IN MAJOR DEPRESSIVE DISORDER

Standard antidepressants usually require approximately one month or more for antidepressant effects to manifest, and commonly, patients remain symptomatic and functionally impaired during this initial period of treatment[13]. Jick and colleagues[14] observed an increased risk of suicide during the first month of antidepressant treatment, particularly during the first nine days; individuals showed similar rates of vulnerability regardless of the chemical class of their antidepressant. It is important to note that the higher risk of suicide and other deliberate acts of self-harm during the first month of treatment is not uncommon, and when it does occur has been postulated to be due to a mismatch in symptom improvement; that is, physical energy improves first, while resolution of depressive mood and negative thoughts (i.e., hopelessness and suicidal ideation) is more gradual. In support of this notion, Simon and colleagues[15] observed a significantly higher risk of suicide attempts during thefirst week of antidepressant treatment compared to later weeks. Another study[16] also described an increased risk for suicide

attempt in the first month after starting antidepressant treatment. Teicher and colleagues[17] observed that the risk for this outcome was decreased in those depressed patients who had an earlier antidepressant response. Therefore, an earlier and sustained improvement in depressive symptoms would be expected to lead to an earlier restoration of functional well-being and productivity, sustained long-term remission, and a lower risk for a negative outcome[18,19].

A delayed onset of antidepressant effects can also be associated with secondary psychosocial losses. It has been well documented that depression limits quality of life, thus impairing those skills necessary to work, to create and maintain relationships, to be productive, and to function in multiple other domains[20,21]. Consequently, severe depressive episodes should be characterized as an emergent condition that requires a rapidly effective intervention to limit the time spent in this state; such thinking is typically observed in many other medical disorders.

In recent years, rapid therapeutic effects have been shown to strongly modify the human and financial costs associated with many medical illnesses. For instance, triptans—which have been shown to produce maximum therapeutic effects for migraine within minutes or hours— have revolutionized the treatment of migraine. Since its release in 1991, sumatriptan has been used to treat over 200 million migranous attacks by 10 million patients [22]. Interestingly, the primary endpoint usually measured in clinical trials of triptans for acute migraine therapy has been two-hour pain relief, that is, a decrease in pain intensity from moderate/severe to mild/ none[23]. Other examples of rapid therapeutic effects in medicine include the use of corticosteroids to treat asthma, and intravenous verapamil or diltiazem to treat atrial fibrillation; both exert rapid therapeutic effects within minutes.

As a critical public health concern, these data strongly argue for the urgent need to research and develop new antidepressants that work rapidly to eliminate the early morbidity and mortality that result from depressive episodes.

TIME COURSE OF ANTIDEPRESSANT ACTION AND CLINICAL VARIABLES

Current Definitions

The timing of antidepressant response has been a well-debated topic in the psychiatric literature for the last twenty years. Although the common view is that standard antidepressants have a delayed onset of at least two weeks, this notion has been questioned by data from a number of large-scale studies and meta-analyses suggesting that some current antidepressant treatments can exert some initial beneficial effects within the first week [7,19,24,25]. However, other studies have suggested that the average time for onset of antidepressant action with standard antidepressants is around two weeks; when considering response criteria, this period goes up to 20 days [26,27,28]. Although the relevance of time course for antidepressant effects during the first days of treatment in major depressive disorder is unequivocal, a number of methodological limitations are apparent in the study of this topic. For instance, the current definitions and rating scales used for the evaluation of response/remission rates were developed to detect improvement only after 1 or more weeks based on weekly ratings and not improvement occurring within hours. Additionally, the methodological and statistical approaches for measuring this very early improvement may differ from those that have been in use. Finally, most of the findings about the early therapeutic effects of antidepressants come from post-hoc analyses and meta-analyses of trials that were not specifically designed to detect the speed of antidepressant onset, and are thus associated with several limitations[29].

Treatment response has been widely characterized as a 50% decrease in depression compared to baseline, whereas the definition of remission is usually based lower threshold[30,31]. Some authors use the term to define remission as "full or total response." Conversely, there is no such general agreement about how to define 'onset of improvement' in depression. Stassen

and colleagues[26] defined onset of improvement as the initial moment when there is decrease of more than 20% from baseline without a subsequent increase. According to this meta-analysis, the estimated rate for early improvement (20%) predicted around 70% of those who responded at four weeks. Other investigators recommend using a 30% change from baseline to define a clinically meaningful improvement[29]. Similarly, Posternak and Zimmerman[24] defined 'onset of improvement' as a sustained reduction of 20 to 33% in global symptom severity. The stringency of current criteria for evaluating rapid antidepressant effects and the lack of standard procedures for its measurement clearly demonstrate the need to test currently used depression rating scales according to different validity paradigms potentially associated with time course of improvement of depressive symptoms. Specifically, further evaluation of the optimal frequency for the application of rating scales and a clear definition of core symptoms associated with early improvement necessitate to be urgently clarified.

Overall, current hypotheses on the potential mechanisms involved in antidepressant response only weakly address the observed inter-individual variation in outcomes. Studies focusing on the onset of antidepressant effects may preferentially involve two major aspects. First, it will be critical to prospectively determine associations between the time needed for antidepressants to induce a significantly greater therapeutic effect in overall symptoms compared to placebo associated with other outcomes such as response and remission. Second, it will be key to determine the timing of improvement of individual depressive symptoms and constructs, based on findings showing that specific symptoms or groups of symptoms (clusters) may tend to remit faster than others and may generate clinically relevant predictors that may directly associate short- and long-term outcome. Variations between antidepressant classes in time to improvement of specific symptoms will be an important focus because they may point to differences in pharmacologic action.

The timing of antidepressant onset vs. placebo—Quitkin and colleagues[32,33] used a pattern analysis approach with three different trials and concluded that a real drug-placebo difference could only occur after three weeks of treatment. They emphasized that true drug responders present a delayed and sustained antidepressant onset and response, whereas placebo responders displayed early but not long-term sustained improvement. However, these conclusions have been questioned by a number of studies demonstrating early improvement (during the first two weeks) as a real antidepressant effect. Furthermore, this early therapeutic effect has the potential to predict a subsequent positive long-term outcome. A recent meta-analysis showed that patients using antidepressants had a significantly higher rate of sustained clinical response compared to placebo beginning at week one or two[25]. Similarly, Posternak and Zimmerman[24] showed a significant, persistent difference in drug-placebo effect during the first two weeks in a meta-analysis of 5,158 patients from 47 studies. Similarly, Tollefson and Holman[34] pooled the results from six trials and observed greater improvement in patients using fluoxetine compared to placebo that began in the first week. These studies provide an important impetus in furthering this line of research. Studies by Katz and colleagues[27, 35, 36], specifically designed to evaluate onset of antidepressant action are examples of this new effort to better understand the time course for achieving improvement of depressive symptoms. Thus, some antidepressants appear to exert initial therapeutic effects within the first two weeks.

Conversely, some limitations exist. First, although evidence supports this concept, the current data do not clearly define or standardize the concept of rapid antidepressant effects. Second, most of the studies pooled in the meta-analyses were not specifically designed to identify onset of improvement in terms of frequency of the assessments or statistical methods (see the section on statistical issues below). Finally, the standard depression rating scales and subscales for evaluating onset of antidepressant action may be of limited utility when measuring score changes and differences between real antidepressant- and placebo- effects when assessments are made in less than a week, as would be the case when trying to assess early improvement.

The timing for improvement of individual depressive symptoms and constructs
—Because depression is a multifaceted disorder, it has been proposed that any potentially valid outcome when evaluating rapid improvement of depressive symptoms should include the application of specific subscales that contain cognitive, vegetative, and emotional dimensions [29,35, 37]. In this context, Katz and colleagues[27,36] identified eleven depressive constructs using several rating scales during treatment with the antidepressants imipramine and amitriptyline. Some of these constructs, such as anxiety and depressed mood, were shown to significantly change during the first week of treatment in those patients who had a therapeutic response to their antidepressant after four weeks of treatment[36]. In a subsequent placebo-controlled study, Katz and colleagues[27] compared possible changes in depressive constructs using antidepressants from two different chemical classes and found that one induced significant early improvement in three days. Interestingly, placebo responders had no specific behavioral pattern. Hirschfeld and colleagues[38] observed a significant difference between duloxetine (a serotonin and noradrenergic reuptake inhibitor) and placebo after two weeks of treatment. Patients taking duloxetine showed early improvement (within the first week) in a specific group of depressive symptoms. Thus, the evaluation of early improvement in specific depressive symptoms and clusters may represent a true link between different constructs of depression and the pharmacological action of diverse classes of antidepressants. For instance, paroxetine and desipramine may induce early improvement of specific symptoms and dimensions, thus challenging the common notion that different antidepressants exert the same clinical effects[27]. Also, the use of longer, standard, weekly scales to measure depression may sometimes mask real early improvements when lack of improvement in one set of symptoms drowns out changes in others.

The relationship between early antidepressant effects and long-term outcome
—As mentioned above, several studies have demonstrated the influence of early improvement of depressive symptoms in predicting long-term outcome,[29,35,39, 40,41] Post-hoc analyses have shown that early improvement is highly predictive of response at study endpoint[42]. Montgomery [43] observed that patients showing an antidepressant onset after ten days of treatment were more likely to achieve sustained response after one month. Katz and colleagues[27,44] suggested that early behavioral changes take place during the first two weeks of treatment, and that these changes seem to predict subsequent long-term outcome. Also, Szegedi and colleagues[19] found that early improvement using mirtazapine or paroxetine during the first two weeks of treatment predicted response after six weeks of treatment. Interestingly, Parker and colleagues[45] found a consistent reduction in depressive symptoms after three days of treatment with different antidepressants, and a subsequent distinct course between responders and non-responders at this time point. In summary, these findings support the notion that early antidepressant action is associated with a better short- and long-term outcome.

STATISTICAL ISSUES IN EVALUATING RAPID ANTIDEPRESSANT ACTIONS

In examining time course of improvement of depressive symptoms, the research design should maximize the ability to find a rapid response. For example, rating patients at too few time points could yield data that cannot assess rapid response. Leon and colleagues[29] proposed a design that might lead to proper evaluation of early improvement, suggesting that patients be evaluated twice per week. Thase[46] also suggested a more frequent application of rating scales. Similarly, Kraemer and Pruyn[47] pointed out that more frequent ratings could lead to more reliable analyses, and, therefore, more powerful studies. Additionally, relatively simple measures that can be used at intervals shorter than a week could be also included in traditional trials as secondary measures to assess the speed of response to study drugs. The Life Chart Methodology (LCM)[48], developed in the Intramural NIMH program, is an example of a rating scale that could be used at many time intervals during a study. Such ratings could be used to refine assessment of change, which is valuable in its own right, but also to help guide when more

detailed rating scales should be obtained. Because of technological advances, it is feasible to perform such simple ratings at many timepoints.

Some authors have suggested that trials attempting to examine the time course for early improvement should consider the use of linear mixed models instead of repeated measures ANOVA[29,49]. Such models allow for the use the most fitting variance-covariance structure for the data, which should improve the reliability of the results. Also, linear mixed models may facilitate use of cases with some missing data. Using all available data from a trial allows the use of the full sample studied instead of completers only, or less reliable missing value estimates that occur when the last observation is carried forward.

In addition, survival analysis can be used to look at time to response or remission instead of examining response rates for various treatments[29,46,50]. Survival analysis considers the response rates in the context of the amount of time it takes to reach the specified criterion. This type of analysis provides equally valuable results with greater sensitivity to group differences given the use of timing; chi-square approaches looking at response rates across treatment groups ignore this measure. However, reporting the proportion of patients who achieve a rapid response or remission could help clinicians evaluate the potential for achieving early response with traditional and novel therapies. Identifying subgroups of patients more likely to respond early could facilitate proper examination of promising new drugs that may yield rapid antidepressant efficacy. Further, identification of these subgroups could lead to more flexible designs if dropout and adherence issues are handled appropriately for early and later responders. [51] this could lead to more flexible designs if dropout and adherence ussues are handled appropriately for early and later responders[51].

Finally, evaluating how early changes are related to long-term outcome will provide valuable information for determining when and how to use treatments. For instance, if early response does not predict later outcome, it may suggest that some important treatments might eventually need to be supplemented.

POSSIBLE NEUROBIOLOGICAL BASIS INVOLVED IN ONSET OF ANTIDEPRESSANT ACTIONS

The biological aspects of the first weeks of antidepressant treatment are still poorly understood. In the last decades, the monoaminergic hypothesis of depression has been considered a useful neurobiological model for explaining the delayed onset of antidepressant response. This hypothesis posits that a reliable and sustained antidepressant response can only occur after a minimum two-week period of treatment with standard antidepressants[32,33]. Supporting this theory, Hyman and Nestler[52] suggested that a correction of disturbances in the monoaminergic metabolism is critical to achieving antidepressant response. They proposed two periods: an initiation period before the onset of true antidepressant effects, followed by an "adaptation phase," in which enduring modulatory changes in critical circuits related to long-term antidepressant response are present. Although study of monoaminergic systems has given us some insights into the lag of onset of antidepressant action, the resulting studies and drugs used (e.g., pindolol, stimulants) have not consistently yielded treatments that work more rapidly than existing ones. It is likely that, although important in the overall mechanism of antidepressant action, these systems are considerably more upstream of ultimately more important targets. As we have noted, most standard antidepressants exert their initial effects by increasing intrasynaptic levels of serotonin and/or norepinephrine, but clinical antidepressant efficacy is observed only after chronic administration (over days to weeks). This suggests that a cascade of downstream events is ultimately responsible for their therapeutic effects. These observations have led to the idea that while dysfunction within the monoaminergic neurotransmitter systems is likely to play an important role in mediating some

facets of the pathophysiology of mood disorders, it likely represents the downstream effects of other, more primary abnormalities in signaling pathways, in special activation of plasticity pathways.

A growing body of data supports the contention that mood disorders arise from abnormalities in cellular plasticity cascades, leading to aberrant information processing in synapses and circuits mediating affective, cognitive, motoric, and neurovegetative functions[53–55]. *Neuroplasticity* is a broad term that encapsulates changes in intracellular signaling cascades and gene regulation, modifications of synaptic number and strength, variations in neurotransmitter release, modelling of axonal and dendritic architecture and, in some areas of the CNS, the generation of new neurons[56].

Animal and human studies have shown a direct regulation of neurotrophic signaling cascades by antidepressants[57]. Research on the biological underpinnings of mood disorders has therefore begun highlighting the role of neural circuits and synapses, and the plastic processes controlling their function. Information gleaned from studies of neuroplasticity in mood disorders have led to the development of new models suggesting that the presence of positive modulatory effects on diverse neuroplasticity-induced pathways are eventually associated with molecular actions that target ionic glutamatergic receptors. [54]

Several studies[58–63] have demonstrated a role for neurotrophins, cytokines, and other neurotransmitter systems in the early onset of antidepressant effects, with special focus on brain derived neurotrophic factor (BDNF). BDNF is a neurotrophin that has been implicated in antidepressant response, and that seems to increase its levels after several weeks of treatment with standard antidepressants[58]. It was demonstrated that bilateral infusion of BDNF in the hippocampus of rodents produces rapid antidepressant-like effects. Interestingly, these effects were observed less than three days after a single administration, and persisted for 10 days[59]. BDNF and other neurotrophins may be involved in the mediation of the therapeutic effects of antidepressant treatment.

It is our contention that regulation of the neurotrophic cascades by antidepressants is perhaps more pertinent to maintenance of antidepressant response than acute response. Recent data[63,64] indicates that full antidepressant response can be achieved within a few hours, but prominent neuroplastic changes or neurogenesis would not be expected to occur in this time frame; we hypothesize that increase synaptic plasticity is involved in the acute response of antidepressants. The glutamate system appears to have a crucial role in both acute antidepressant response and maintenance of response. The study of diverse glutamatergic plasticity-enhancing agents in mood disorders, including NMDA antagonists, glutamate release-reducing agents, and AMPA potentiators, is leading to ever increasing insights into the mechanism of action of effective antidepressants [60–62]. For example, preliminary investigations indicate that the rapid antidepressant effect of ketamine is the result of an enhanced synaptic plasticity caused by an increased AMPA-to-NMDA glutamate receptor throughput in critical neuronal circuits. [63] This latter concept id discussed in more detail below.

Because this article focuses on studies of systems/targets that can produce antidepressant action within hours to a few days, the agents that modulate the serotonergic, noradrenergic, and dopaminergic systems will not be reviewed here. Instead, the reader is referred to some excellent reviews of this topic[65–70].

INTERVENTIONS RESULTING IN ANTIDEPRESSANT RESPONSE IN HOURS OR A FEW DAYS

Ketamine

Accumulating evidence has revealed a common mechanism whereby dysfunction in the regulation of glutamate neurotransmission contributes to the pathophysiology of several neuropsychiatric disorders[71–73]. Glutamate receptors include α-amino-3-hydroxy-5-methyl-4-isoxazole propionic acid (AMPA), kainate, and *N*-methyl-d-aspartate (NMDA). Supporting evidence for glutamate's role in the pathophysiology of mood disorders and mechanism of comes from: 1) demonstration of glutamatergic abnormalities in patients with depression, 2) glutamatergic effects of existing antidepressant and mood stabilizing medications, 3) preclinical evidence suggesting drugs targeting various components of glutamate neurotransmission possess antidepressant and anxiolytic properties, and 4) recent studies demonstrating the effectiveness of glutamate-modulating agents in the treatment of mood disorders (reviewed in Sanacora et a al. [61]) Recently, Zarate and colleagues[64] showed that a single sub-anesthetic dose of the NMDA antagonist ketamine, when given intravenously, induces a rapid (within two hours) and sustained (1–2 weeks) antidepressant effects in patients with treatment-resistant major depression. In this study, a significant antidepressant response was found as early as 2 hours; 50% of patients met response criteria within 2 hours and 71% by 24 hours after a single dose of ketamine. Response was sustained for more than one week. This study confirmed the preliminary finding of a smaller study also showing rapid antidepressant effects with ketamine[74]. A study with ketamine in patients with treatment-resistant major depression with a similar design to the 2 previous studies has found comparable response rates and time of onset of antidepressant effect (S.J. Mathew, M.D., personal communication).

To our knowledge, there has never been a report of any other pharmacological or somatic treatment that results in such a striking quick and extended response with a single administration. This relatively sustained antidepressant effect may be due to early plasticity changes in critical local neuronal circuits involved in mood and behavior[54,64,75]. Ketamine has also been found to have antidepressant effects in animal models[76,77]. We hypothesize that the rapid onset of ketamine and its sustained effects are the result of two processes. First, the resolution of core depressive symptoms within hours resulting from ketamine is not the result of neuroplastic changes as these changes would not occur within this time frame but are the consequence of synaptic potentiation resulting from an increase in AMPA relative to NMDA glutamatergic throughput. Second, the sustained effect of ketamine is possibly the result of early neuroplastic changes.

Regarding the acute effects of ketamine, it is well known that ketamine increases the presynaptic release of glutamate[78] and that this net increase in extracellular levels of glutamate preferentially favors AMPA receptors over NMDA as the later type receptors are blocked[63]. The net effect of such interplay of NMDA and AMPA receptors resulting from ketamine is an enhanced glutamatergic throughput of AMPA relative to NMDA which leads to synaptic potentiation[79].

To support this later contention, in animal behavioral studies, we found that in the forced swim test (FST)—a test with fairly high predictive validity in identifying antidepressant compounds—ketamine significantly decreased immobility time (a greater decrease in time spent immobile indicates "antidepressant-like properties"). In the same test, NBQX, an AMPA/KA antagonist, had no effects in the FST when given alone; however when NBQX was given immediately prior to ketamine and imipramine, it prevented the decrease in immobility time with ketamine

but not imipramine. This finding suggests that, at least in animal models, the antidepressant-like properties of ketamine are mediated in part by AMPA receptor throughput[63].

Taken together, these findings suggest that modulation of the glutamatergic system in the plasticity pathways, particularly linked to the cross-talk between NMDA and AMPA, may be a critical therapeutic target for obtaining rapid antidepressant actions. Ongoing studies are underway to better understand this line of research in drug development[80].

Sleep Deprivation

Sleep deprivation (SD) has been consistently shown to induce a rapid, dramatic, and transient antidepressant effect in depressed subjects[81]. The magnitude of improvement after one night of SD seems to equal the response rate for six weeks of antidepressant treatment[82]. Its potential advantages include its rapid short-term efficacy, that it can be tested in animals and healthy controls, and that it is both relatively safe and inexpensive. Medicated patients undergoing SD seem to have significantly lower relapse rates compared to drug-free subjects[81]. Acute and chronic treatment with lithium has also been reported to significantly augment and sustain the rapid improvement seen during repeated, partial, or total SD[83–85]. Different studies have also attempted to evaluate the potential efficacy of SD augmented with strategies such as pindolol, light therapy, and sleep synchronicity[86–88]. Recently, Benedetti et al[89], treated 60 non-responders patients with repeated total SD in combination with light therapy in bipolar depression for one week and observed that 70% of these patients obtained response after this period. Limitations of these studies include the non-standardization of response criteria (reaching from a 10% improvement in a Visual Analogue Scale to the standard 50% decrease in HAM-D). Overall, further studies using more homogeneous criteria for measuring short-term and long-term outcomes are also needed to clarify its therapeutic role for achieving rapid and sustained antidepressant efficacy.

Many hypotheses have been proposed to explain the rapid antidepressant actions of SD[81, 90], through a direct regulation in neurotransmission. Regarding its effects on plasticity pathways, changes on NMDA receptor surface expression after SD have been found to occur[91], which has been associated with potential rapid antidepressant actions. Furthermore, serotonin-mediated effects have been shown to decrease sensitivity of serotonergic $_{1A}$ autoreceptors after total SD[92]. Also, messenger RNA differential display, microarray, and biochemical studies[93,94], have described that, as with antidepressant treatment, SD induces rapid up-regulation in different genes believed to be related to neuroplasticity, such as the transcription factor cAMP- Ca^{2+} response element-binding protein (CREB) and BDNF. These genes have been reported to be common final targets of existing antidepressants. Interestingly, the potential activation of plasticity-induced pathways during SD has been shown to be predominantly mediated by the activation of noradrenergic projections in the locus coeruleus. One night of SD has been demonstrated to stimulate hippocampal neurogenesis, but opposite effects have also been described[95,96]. It has thus been hypothesized that pharmacological activation of the noradrenergic system during REM could generate an antidepressant effect by a mechanism similar to SD, allowing an interaction with a sensitized postsynaptic milieu, and thereby rapidly and directly increasing the expression of neuroplasticity genes[97].

Finally, the anterior cingulate cortex (ACC) is an area that has been implicated in antidepressant response to SD using various experimental paradigms. Positron emission tomography (PET) and single photon emission computed tomography (SPECT) studies show increased baseline activity in the ACC in SD responders compared to SD non-responders; antidepressant response to SD seems to be associated with a significant decrease of activation in this area[98–100]. Clark and colleagues[101,102] used perfusion-weighted functional MRI to study the functional correlates of antidepressant response to partial sleep deprivation (pSD); they found that

responders to pSD showed increased baseline perfusion in the left ventral ACC and in the amygdala compared to non-responders, who had decreased perfusion following pSD.

Thyrotropin Releasing Hormone (TRH)

The tripeptide TRH modulates serotonergic, dopaminergic, and glutamatergic transmission in cortical and limbic areas[103–105]. The potential rapid antidepressant properties have been tested over the last several decades with mixed results[106–108]. It has been shown that intravenous administration of a single dose of TRH exerts antidepressant effects in depressed subjects within hours of treatment, and that these effects persisted for three days[109]. Interestingly, TRH expression has shown to be upregulated by BDNF[110]. In contrast, negative results were ascribed to the use of a low TRH dose or to the use of an intravenous route of administration instead of an intrathecal one; the former has been reported to undergo very rapid enzymatic degradation[111,112]. To address these methodological issues, Marangell and colleagues[106] administered intrathecal TRH to eight patients with treatment-resistant depression and measured the onset of antidepressant effect using an abbreviated version of the HAM-D. Five of eight patients showed antidepressant response in the day of TRH administration or a day later. Interestingly, TRH was also associated with a rapid decrease in suicidality. Besides the route of TRH administration, the timing of its administration also seems to be a key issue. It has been proposed that the TRH-induced rapid antidepressant effects can be only observed if administered at night, during the circadian peak of thyrotropin receptor sensitivity[113]. For instance, nocturnal intravenous TRH was shown to induce a rapid clinical response within 24 hours of its administration in patients with bipolar depression[108].

Further placebo-controlled studies with larger samples and the evaluation of TRH kinetics and bioavailability are necessary to confirm these promising findings with TRH and its role as a target for the development of improved fast-acting agents.

Somatic Treatments and Rapid Improvement of Depressive Symptoms

Electroconvulsive therapy (ECT)—ECT has been considered the most efficacious and rapidly acting long-term somatic treatment in psychiatry[114]. Some studies have found a faster onset of antidepressant response with ECT compared to imipramine and paroxetine[115,116]. Other studies also described significant improvement in depression after a single ECT application[117,118]. The potential faster antidepressant response induced by ECT was shown to be correlated with a better long-term outcome[119,120]. In a cohort of 253 depressive patients under ECT treatment (3 times a week), Husain et al[121] observed that more than 50% achieved response within the first week and 83.4% responded within 2 weeks. The same group also described a sustained response in 34.8% of patients during the first week and in 64.4% within the second week (at or before ECT #6). Regarding remission, 34% presented remission before or at the end of week two. Taken together, these findings suggest that ECT presents efficacy in achieving rapid improvement and response during depressive episodes in a large number of patients. Future controlled studies comparing its short term efficacy with different pharmacological and other somatic approaches may prove its utility in achieving rapid antidepressant efficacy. Also, maintenance therapy with ECT is not commonly used, and thus, little data show the association between early improvement and improved long-term outcome.

Other somatic interventions—Two recent studies suggested a role for rTMS as an augmentation strategy to achieve fast therapeutic actions in depression, although the antidepressant efficacy and biological mechanism of rTMS remain unclear.[122,123] Similarly, DBS (deep brain stimulation) appears to reduce elevated activity in subgenual cingulate (Cg25), hence producing rapid clinical improvement in treatment-resistant depression[124–126]. Mayberg and colleagues[125] (2005) similarly observed a sustained response in five of six

patients after two months of stimulation targeting the white matter tracts adjacent to the subgenual cingulated gyrus.

NEW TECHNOLOGIES FOR BETTER UNDERSTANDING RAPID ANTIDEPRESSANT ACTIONS: A CRITICAL ROLE FOR THE DEVELOPMENT OF IMPROVED THERAPEUTICS

Besides the potential innovative approaches in the therapeutics of depression described above, new investigational tools have been proposed to present validity for predicting rapid improvement and may represent potential endophenotypes associated with faster antidepressant response. Given our current inability to predict who will respond faster to a specific treatment, the evaluation of characteristics observed in studies using valuable technologies such as structural and functional imaging, in physiological and in genetic studies may provide a better understanding on the neurobiological basis involved in the rapid improvement and may allow the identification of surrogate outcomes and molecular targets for the next generation of faster-acting antidepressants.

PET and fMRI

Brain imaging techniques have been used to predict time course of improvement of depressive symptoms and outcome based on baseline and early changes of brain metabolism, cerebral blood flow, receptor binding occupancy, and functional patterns of activation during the execution of specific tasks. PET studies have shown that activity in the rostral anterior (pregenual) cingulate cortex in depressed subjects before treatment can subsequently differentiate drug-responders from non-responders. Specifically, hypermetabolism in this area was in fact found to be highly predictive of posterior drug response[127]. Using PET, Wu and colleagues[99] similarly showed that baseline metabolic hyperactivity in the dorsal anterior cingulate predicted SD-induced rapid antidepressant response. Parsey and colleagues[128] also observed a positive association between baseline $5HT_{1A}$ binding potential with long-term (one year) outcome after a depressive episode.

Morphological and Functional Magnetic Resonance Imaging (fMRI) studies have also been tested as predictors of antidepressant response. Greater grey matter volume changes in both anterior cingulate cortex, insula, and right temporo-parietal cortex have all been associated with faster antidepressant response to SSRI. [129] Similarly, increased activation of the anterior cingulate cortex during the face emotional task also predicted rapid improvement of depressive symptoms[129]. A recent perfusion-weighted fMRI study also showed greater baseline amygdala perfusion as a potential predictor of positive clinical response to SD[101]. In addition, differential pre-treatment brain metabolism was found in patients who responded to repetitive transcranial magnetic stimulation (TMS) using 1Hz and 20 Hz. While hypometabolism predicted positive response to 20 Hz rTMS, hypermetabolism was associated with a better outcome with 1 Hz Rtms1[130].

Electrophysiological Tools for Measuring Synaptic Plasticity Changes

The study of early plasticity associated with neuroimaging findings as a tool for detecting rapid antidepressant action is a promising area. Indirect proof of synaptic plasticity in patients with depression has been gathered through high-density EEG sleep and magnetoencephalography (MEG) studies. Studies performed by Tononi and Cirelli[131] ((University of Wisconsin) evaluating healthy subjects have shown that repetitive TMS induces a localized potentiation of TMS-evoked cortical EEG responses, which represent a long-term potentiation in human cortex, thus replicating the classic paradigm previously studied in animals[132,133]. These changes occur together with an increase in slow wave activity (SWA), which may be considered

a marker of synaptic plasticity[131]. Another promising area is the study of baseline and early changes in SWA and their correlation with antidepressant response.

Studies with MEG are underway to evaluate the early effects of antidepressant drugs that putatively exert their therapeutic effects through an increase in synaptic plasticity, such as ketamine, by measuring evoked magnetic fields related to clinical outcome. Because MEG uses source localization that allows good spatial resolution with a greater temporal resolution than the fMRI, it can also be also used to study baseline activity and early functional changes associated with antidepressant treatment during different cognitive tasks. All of the brain imaging tools mentioned above can thus effectively be used to predict the outcome of currently available treatment strategies in order to elaborate treatment algorithms that could in the future guide clinical decisions on whether to switch or continue with a specific treatment. The use of neuroimaging techniques for predicting early antidepressant response is a promising area for current and future studies on rapid antidepressant response.

Actigraphy

Actigraphy is a high resolution method for measuring circadian rhythm and sleep activity characteristics in different time series; it has recently been used to evaluate diverse treatment effects regarding regulation in the rest-activity cycle[134]. For example, a miniaturized wrist-worn device with enough capacity to record longer periods with minimal influence on patients' lifestyle has been used to identify clinical subtypes of depression related to antidepressant effects, which may provide further insight regarding the pathophysiology of depression[135]. This tool might be particularly useful for predicting short- and long-term improvement associated with specific sleep patterns.

Pharmacogenetics

The goal of studying the pharmacogenetics of antidepressants is to achieve new insights regarding potential candidate genes involved in the molecular and clinical effects of several classes of antidepressants, thus providing further insights about their mechanisms of action and relevant therapeutic targets associated with prediction of faster antidepressant response. For instance, studies have found that enzymes of the cytochrome P450 (CYP) family of genes are directly involved in diverse regulatory effects of the monoaminergic system, and polymorphisms in the CYP2D6 and 5-HT transporter promoter (HTTLPR) have been widely associated with pharmacokinetics and clinical response to diverse antidepressants[136].

CYP2D6 polymorphisms have been found to influence dose-response and serum levels of antidepressants, and may be a useful tool for agents presenting dose-response windows, such as some of the tricyclic antidepressants[137]. Many studies have evaluated the role of polymorphisms of HTTLPR in the antidepressant response of different SSRIs in Caucasians[138–140]. In these studies, clinical response was associated with a long variant (L-allele) of the HTTLPR. Durham and colleagues[139] observed that depressed elderly subjects with this polymorphism had a faster onset of response to sertraline; however, there was no association between clinical effect and this polymorphism for agents other than SSRIs[140, 141]. Serretti and colleagues[142], in a meta-analysis including 15 studies and 1435 subjects, observed a significant association between the s/s variant of the 5-HTTLPR and antidepressant response to SSRIs and SD. A significant association was found between treatment response and remission and the HTR2A gene (which encodes the 5HT2A receptor) in a large sample (n=1380) of depressive subjects treated with citalopram[4]. Recently, Tadic et al[143] found an association between MAOB A644G intron 13SNP and antidepressant response in females.

Functional polymorphisms of genes involved in HPA-axis regulation, especially glucocorticoid receptor (GR) sensitivity, have been shown to confer susceptibility for

developing depression and antidepressant response. A 3 SNP haplotype into the corticotrophin releasing hormone receptor 1 (CRHR1) was associated with antidepressant response to fluoxetine or desipramine[144]. Also, faster antidepressant response and improved cognitive function were linked to polymorphisms on the GR gene (codons 22 and 23-ER22/23EK), which is responsible for increasing GR resistance[145]. The same group also found an association between a single-nucleotide polymorphism on GR sensitivity-regulating chaperone FKBP5 with rapid response to antidepressants possibly related to the restoration of HPA axis physiological function[146,147]. Interestingly, these polymorphisms on FKBP5 are associated with its overexpression, leading to GR insensivity and elevated plasma cortisol levels[136].

Taken together, these promising pharmacogenetic findings support a central role for genes regulating these systems in the rapid response and improved outcome in depression. The greater our understanding of such individual differences, the more likely clinicians will be to identify subgroups of depressive subjects who will respond better to specific treatments, thus limiting the risks associated with lack of efficacy and treatment-resistance.

APPROACHES FOR ACHIEVING RAPID ONSET OF ANTIDEPRESSANT ACTION: WHERE DO WE GO FROM HERE?

As the evidence reviewed in this article emphasizes, it is crucial to redefine the way we understand and define the clinically relevant concepts associated with the therapeutics of depression. The model currently used has focused on weekly evaluation of available pharmacological approaches; such evaluations yield mainly small differences between agents that are known to have limited potential to induce rapid antidepressant actions.

A faster and sustained antidepressant response represents a key challenge in the development of new effective therapeutics for depression and may prevent the deleterious neurobiological and psychosocial effects secondary to recurrent or unremitting depressive episodes. Rapid onset of antidepressant action occurring within hours or days instead of weeks or months can and should be our overall goal. This new paradigm in the therapeutics of depression is expected to include not only the development of novel and improved therapeutics, but also the development of tools that enable us to evaluate antidepressant efficacy within hours or days of first administration; many other areas of medicine such as cardiology, neurology, oncology, and endocrinology currently have the tools necessary to evaluate therapeutic onset quickly and reliably. Furthermore, as our understanding of the genetics of depression expands, this knowledge can be used to inform decisions about which patients are likely to respond to which therapeutic approach. A combination of these three facets—better therapies, better evaluative tools, and better understanding of a patient's genetic profile—has the power to revolutionize current conceptions and treatments for depression.

Regarding the development of novel therapeutics, it should be pointed out that many substances are capable of inducing transitory euphoria and hyperactivity (also including psychomimetic effects) limited to the half-life of the compound being administered, but these effects cannot be characterized as a true improvement of core depressive symptoms. Thus, agents that result in rapid and sustained antidepressant effects (in core depressive symptoms and constructs) well beyond the half-life of the drug being administered may be considered a key hallmark of new pharmacological treatments potentially able to produce rapid antidepressant actions.

New interventions able to induce rapid antidepressant actions may rapidly restore disrupted neuronal circuitry, thus improving symptoms, functional well-being, and quality of life. Thus, the discovery of novel antidepressants that achieve antidepressant response and remission in a shorter period of time should be a priority in mood disorder research. Clinical and preclinical studies have been performed in this area, searching for genes, signaling pathways, and/or

neurochemical circuits that might be involved in these therapeutic effects. Potential targets for future studies in this area may include common targets related to both glutamatergic modulation, neuro-biomolecular basis for sleep, wakefulness, SD, and electrical activity in limbic-cortical circuits (e.g. stimulation of subgenual cingulate white matter with DBS).

In terms of instruments that measure early improvement, present evaluative strategies fall short. For instance, if ratings are only obtained weekly, then early response and identification of key symptoms/clusters predictive of ultimate response—perhaps occurring within hours or days of administration—will be missed. In this context, future study designs evaluating rapid improvement may only require two weeks of duration, which would have the advantage of exposing fewer patients to an experimental compound. Such pilot studies would then inform the design of future ones. These studies will also need to have both a placebo and active comparator arm.

We propose that research on rapid antidepressant actions should occur on two fronts. The first front is to identify specific symptoms or clusters that respond quickly to current antidepressant treatments, and that predict sustained improvement either for all or a subset of patients. Defining such characteristics would help personalize treatment, so that early changes (or conversely, the absence of early changes) could help physicians determine whether patients should remain in a particular trial. Patients could thus avoid trials that are not likely to result in improvement.

The second major focus should be in designing antidepressants that work rapidly within hours or a few days. There is abundant evidence from other areas of medicine that this goal is possible. For example, high blood pressure or blood glucose, pain, or a migraine attack can all be averted within a few hours. In other words, our current expectations regarding antidepressant treatments are too low; instead of assuming that patients will respond within weeks or months, we should expect and be able to measure properly antidepressant treatments that might work within hours or days. Fortunately, much of the ongoing research into antidepressant strategies holds considerable promise. It is our hope that such research will raise the bar for developing the next generation of faster-acting and more effective antidepressants to better treat this devastating illness.

Acknowledgments

References

1. Baune BT, Adrian I, et al. Medical disorders affect health outcome and general functioning depending on comorbid major depression in the general population. J Psychosom Res 2007;62(2):109–18. [PubMed: 17270568]

2. Kessler RC, Akiskal HS, et al. Prevalence and effects of mood disorders on work performance in a nationally representative sample of U.S. workers. Am J Psychiatry 2006;163(9):1561–8. [PubMed: 16946181]

3. Trivedi MH. Major depressive disorder: remission of associated symptoms. J Clin Psychiatry 2006;67 (Suppl 6):27–32. [PubMed: 16848674]

4. McMahon FJ, Buervenich S, et al. Variation in the gene encoding the serotonin 2A receptor is associated with outcome of antidepressant treatment. Am J Hum Genet 2006;78(5):804–14. [PubMed: 16642436]

5. Iosifescu DV, Nierenberg AA, et al. Comorbid medical illness and relapse of major depressive disorder in the continuation phase of treatment. Psychosomatics 2004;45(5):419–25. [PubMed: 15345787]

6. Papakostas GI, Petersen T, et al. Functioning and interpersonal relationships as predictors of response in treatment-resistant depression. Compr Psychiatry 2003;44(1):44–50. [PubMed: 12524635]

7. Taylor MJ, Freemantle N, et al. Early onset of selective serotonin reuptake inhibitor antidepressant action: systematic review and meta-analysis. Arch Gen Psychiatry 2006;63(11):1217–23. [PubMed: 17088502]

8. Fava M. New approaches to the treatment of refractory depression. J Clin Psychiatry 2000;61(Suppl 1):26–32. [PubMed: 10703760]

9. Lingam R, Scott J. Treatment non-adherence in affective disorders. Acta Psychiatr Scand 2002;105 (3):164–72. [PubMed: 11939969]

10. Sheline YI, Wang PW, et al. Hippocampal atrophy in recurrent major depression. Proc Natl Acad Sci U S A 1996;93(9):3908–13. [PubMed: 8632988]

11. Sheline YI, Sanghavi M, et al. Depression duration but not age predicts hippocampal volume loss in medically healthy women with recurrent major depression. J Neurosci 1999;19(12):5034–43. [PubMed: 10366636]

12. Sheline YI, Gado MH, et al. Untreated depression and hippocampal volume loss. Am J Psychiatry 2003;160(8):1516–8. [PubMed: 12900317]

13. Donovan S, Clayton A, et al. Deliberate self-harm and antidepressant drugs. Investigation of a possible link. Br J Psychiatry 2000;177:551–6. [PubMed: 11102331]

14. Jick H, Kaye JA, et al. Antidepressants and the risk of suicidal behaviors. Jama 2004;292(3):338–43. [PubMed: 15265848]

15. Simon GE, Savarino J, et al. Suicide risk during antidepressant treatment. Am J Psychiatry 2006;163 (1):41–7. [PubMed: 16390887]

16. Simon GE, Savarino J. Suicide attempts among patients starting depression treatment with medications or psychotherapy. Am J Psychiatry 2007;164(7):1029–34. [PubMed: 17606654]

17. Teicher MH, Glod CA, et al. Antidepressant drugs and the emergence of suicidal tendencies. Drug Saf 1993;8(3):186–212. [PubMed: 8452661]

18. Blier P, Bergeron R. Early onset of therapeutic action in depression and greater efficacy of antidepressant treatments: are they related? Int Clin Psychopharmacol 1997;12(Suppl 3):S21–8. [PubMed: 9347389]

19. Szegedi A, Muller MJ, et al. Early improvement under mirtazapine and paroxetine predicts later stable response and remission with high sensitivity in patients with major depression. J Clin Psychiatry 2003;64(4):413–20. [PubMed: 12716243]

20. Wells KB, Stewart A, et al. The functioning and well-being of depressed patients. Results from the Medical Outcomes Study. Jama 1989;262(7):914–9. [PubMed: 2754791]

21. Hirschfeld RM. The role of primary care in the treatment of depression. Am J Manag Care 2000;6(2 Suppl):S59–65. [PubMed: 10977430]

22. Tepper SJ, Donnan GA, et al. A long-term study to maximise migraine relief with zolmitriptan. Curr Med Res Opin 1999;15(4):254–71. [PubMed: 10640258]

23. Edmeads J. Defining response in migraine: which endpoints are important? Eur Neurol 2005;53(Suppl 1):22–8. [PubMed: 15920334]

24. Posternak MA, Zimmerman M. Is there a delay in the antidepressant effect? A meta-analysis. J Clin Psychiatry 2005;66(2):148–58. [PubMed: 15704999]

25. Papakostas GI, Nutt DJ, et al. Resolution of sleepiness and fatigue in major depressive disorder: A comparison of bupropion and the selective serotonin reuptake inhibitors. Biol Psychiatry 2006;60 (12):1350–5. [PubMed: 16934768]

26. Stassen HH, Delini-Stula A, et al. Time course of improvement under antidepressant treatment: a survival-analytical approach. Eur Neuropsychopharmacol 1993;3(2):127–35. [PubMed: 8364348]

27. Katz MM, Tekell JL, et al. Onset and early behavioral effects of pharmacologically different antidepressants and placebo in depression. Neuropsychopharmacology 2004;29(3):566–79. [PubMed: 14627997]

28. Stassen HH, Angst J, et al. Is there a common resilience mechanism underlying antidepressant drug response? Evidence from 2848 patients. J Clin Psychiatry 2007;68(8):1195–205. [PubMed: 17854243]

29. Leon AC, Blier P, et al. An ideal trial to test differential onset of antidepressant effect. J Clin Psychiatry 2001;62(Suppl 4):34–6. [PubMed: 11229787]discussion 37–40

30. Frank E, Kupfer DJ, et al. Three-year outcomes for maintenance therapies in recurrent depression. Arch Gen Psychiatry 1990;47(12):1093–9. [PubMed: 2244793]

31. Angst J, Ernst C. Current concepts of the classification of affective disorders. Int Clin Psychopharmacol 1993;8(4):211–5. [PubMed: 8277137]

32. Quitkin FM, Rabkin JG, et al. Identification of true drug response to antidepressants. Use of pattern analysis. Arch Gen Psychiatry 1984;41(8):782–6. [PubMed: 6378117]

33. Quitkin FM, Rabkin JD, et al. Use of pattern analysis to identify true drug response. A replication. Arch Gen Psychiatry 1987;44(3):259–64. [PubMed: 3548638]

34. Tollefson GD, Holman SL. How long to onset of antidepressant action: a meta-analysis of patients treated with fluoxetine or placebo. Int Clin Psychopharmacol 1994;9(4):245–50. [PubMed: 7868846]

35. Katz MM, Koslow SH, et al. The timing, specificity and clinical prediction of tricyclic drug effects in depression. Psychol Med 1987;17(2):297–309. [PubMed: 3299439]

36. Katz MM, Koslow SH, et al. Onset of antidepressant activity: reexamining the structure of depression and multiple actions of drugs. Depress Anxiety 1996;4(6):257–67. [PubMed: 9166653]

37. Gibbons RD, Hedeker D, et al. Some conceptual and statistical issues in analysis of longitudinal psychiatric data. Application to the NIMH treatment of Depression Collaborative Research Program dataset. Arch Gen Psychiatry 1993;50(9):739–50. [PubMed: 8357299]

38. Hirschfeld RM, Mallinckrodt C, et al. Time course of depression-symptom improvement during treatment with duloxetine. Depress Anxiety 2005;21(4):170–7. [PubMed: 16035056]

39. Coryell W, Coppen A, et al. Early improvement as a predictor of response to amitriptyline and nortriptyline: a comparison of 2 patient samples. Psychol Med 1982;12(1):135–9. [PubMed: 7079423]

40. Nagayama H, Nagano K, et al. Prediction of efficacy of antidepressant by 1-week test therapy in depression. J Affect Disord 1991;23(4):213–6. [PubMed: 1791266]

41. Feighner JP, Boyer WF. Paroxetine in the treatment of depression: a comparison with imipramine and placebo. J Clin Psychiatry 1992;53(Suppl):44–7. [PubMed: 1531824]

42. Stassen HH, Ragaz M, et al. Age-of-onset or age-cohort changes in the lifetime occurrence of depression? Psychiatr Genet 1997;7(1):27–34. [PubMed: 9264135]

43. Montgomery SA. Are 2-week trials sufficient to indicate efficacy? Psychopharmacol Bull 1995;31 (1):41–4. [PubMed: 7675988]

44. Katz MM, Bowden C, et al. Can the effects of antidepressants be observed in the first two weeks of treatment? Neuropsychopharmacology 1997;17(2):110–5. [PubMed: 9252986]

45. Parker G, Roy K, et al. How long does it take for antidepressant therapies to act? Aust N Z J Psychiatry 2000;34(1):65–70. [PubMed: 11185946]

46. Thase ME. Methodology to measure onset of action. J Clin Psychiatry 2001;62(Suppl 15):18–21.

47. Kraemer HC, Pruyn JP. The evaluation of different approaches to randomized clinical trials. Report on the 1987 MacArthur Foundation Network I Methodology Workshop. Arch Gen Psychiatry 1990;47(12):1163–9. [PubMed: 2147099]

48. Denicoff KD, Smith-Jackson EE, Disney ERl, Ali SO, Leverich GS, Post RM. Preliminary evidence of the reliability and validity of the prospective life-chart methodology (LCM-p). J Clin Psychiatry 1997;31(5):593–603.

49. Gueorguieva R, Krystal JH. Move over ANOVA: progress in analyzing repeated-measures data and its reflection in papers published in the Archives of General Psychiatry. Arch Gen Psychiatry 2004;61 (3):310–7. [PubMed: 14993119]

50. Montgomery SA, Bech P, et al. Selecting methodologies for the evaluation of differences in time to response between antidepressants. J Clin Psychiatry 2002;63(8):694–9. [PubMed: 12197449]

51. Rush AJ I, Bernstein H, et al. An evaluation of the quick inventory of depressive symptomatology and the hamilton rating scale for depression: a sequenced treatment alternatives to relieve depression trial report. Biol Psychiatry 2006;59(6):493–501. [PubMed: 16199008]

52. Hyman SE, Nestler EJ. Initiation and adaptation: a paradigm for understanding psychotropic drug action. Am J Psychiatry 1996;153(2):151–62. [PubMed: 8561194]

53. Manji HK, Lenox RH. Signaling: cellular insights into the pathophysiology of bipolar disorder. Biol Psychiatry 2000;48(6):518–30. [PubMed: 11018224]

54. Zarate CA Jr, Singh J, Manji HK. Cellular plasticity cascades: targets for the development of novel therapeutics for bipolar disorder. Biol Psychiatry 2006;59(11):1006–20. [PubMed: 16487491]

55. Post RM. Role of BDNF in bipolar and unipolar disorder: clinical and theoretical implications. J Psychiatr Res 2007;41(12):979–90. [PubMed: 17239400]

56. Duman RS. Synaptic plasticity and mood disorders. Mol Psychiatry 2002;7(Suppl 1):S29–34. [PubMed: 11986993]

57. D'Sa C, Duman RS. Antidepressants and neuroplasticity. Bipolar Disord 2002;4(3):183–94. [PubMed: 12180273]

58. Hashimoto K, Shimizu E, et al. Critical role of brain-derived neurotrophic factor in mood disorders. Brain Res Brain Res Rev 2004;45(2):104–14. [PubMed: 15145621]

59. Shirayama Y, Chen AC, et al. Brain-derived neurotrophic factor produces antidepressant effects in behavioral models of depression. J Neurosci 2002;22(8):3251–61. [PubMed: 11943826]

60. Zarate CA Jr, Du J, Quiroz J, et al. Regulation of cellular plasticity cascades in the pathophysiology and treatment of mood disorders: role of the glutamatergic system. Ann N Y Acad Sci 2003;11(1003): 273–291. [PubMed: 14684452]

61. Sanacora G, Zarate CA Jr, Krystal JH, et al. Targeting the glutamatergic system to develop novel, improved therapeutics for mood disorders. Nat Rev Drug Discov. in press

62. Zarate CA Jr, Manji HK. The role of AMPA receptor modulation in the treatment of neuropsychiatric diseases . Exp Neurol. published online ahead of print Jan 26, 2008 Doi:10.1016

63. Maeng S, Zarate CA Jr, Du J, et al. Cellular mechanisms underlying the antidepressant effects of ketamine: role of alpha-amino-3-hydroxy-5 methlisoxazole-4-propionic acid receptors. Biol Psychiatry 2008;63(4):349–52. [PubMed: 17643398]

64. Zarate CA Jr, Singh JB, Carlson PJ, et al. A randomized trial of an N-methyl-D-aspartate antagonist in treatment-resistant major depression. Arch Gen Psychiatry 2006;63(8):856–64. [PubMed: 16894061]

65. Artigas F, Adell A, et al. Pindolol augmentation of antidepressant response. Curr Drug Targets 2006;7 (2):139–47. [PubMed: 16475955]

66. Blier P, de Montigny C. Current advances and trends in the treatment of depression. Trends Pharmacol Sci 1994;15(7):220–6. [PubMed: 7940983]

67. Blier P. Possible neurobiological mechanisms underlying faster onset of antidepressant action. J Clin Psychiatry 2001;62(Suppl 4):7–11. [PubMed: 11229789]discussion 37–40

68. Ballesteros J, Callado LF. Effectiveness of pindolol plus serotonin uptake inhibitors in depression: a meta-analysis of early and late outcomes from randomised controlled trials. J Affect Disord 2004;79 (1–3):137–47. [PubMed: 15023488]

69. Sanacora G, Berman RM, et al. Addition of the alpha2-antagonist yohimbine to fluoxetine: effects on rate of antidepressant response. Neuropsychopharmacology 2004;29(6):1166. [PubMed: 15010697]

71. Belsham B. Glutamate and its role in psychiatric illness. Hum Psychpharmacol 2001;16(2):139–46.

72. Carlsson A, Waters N, Holm-Waters S, et al. Interactions between monoamines, glutamate, and GABA in schizophrenia: new evidence. Annu Rev Pharmacol Toxicol 2001;41:237–60. [PubMed: 11264457]

73. Tsai G, Coyle JT. The role of glutamatergic neurotransmission in the pathophysiology of alcoholism. Annu Rev Med 1998;49:173–84. [PubMed: 9509257]

74. Berman RM, Cappiello A, Anand A, et al. Antidepressant effects of ketamine in depressed patients. Biol Psychiatry 2000;47(4):351–54. [PubMed: 10686270]

75. Du J, Machado-Vieira R, Maeng S, et al. Enhancing AMPA to NMDA throughput as a convergent mechanism for antidepressant action. Drug Discov Today 2006;3:519–26.

76. Silvestre JS, Nadal R, et al. Acute effects of ketamine in the holeboard, the elevated-plus maze, and the social interaction test in Wistar rats. Depress Anxiety 1997;5(1):29–33. [PubMed: 9250438]

77. Mickley GA, Schaldach MA, et al. Ketamine blocks a conditioned taste aversion (CTA) in neonatal rats. Physiol Behav 1998;64(3):381–90. [PubMed: 9748108]

78. Moghaddam B, Adams B, et al. Activation of glutamatergic neurotransmission by ketamine: a novel step in the pathway from NMDA receptor blockade to dopaminergic and cognitive disruptions associated with the prefrontal cortex. J Neurosci 1997;17(8):2921–7. [PubMed: 9092613]

79. Maeng S, Zarate CA Jr, et al. Cellular Mechanisms Underlying the Antidepressant Effects of Ketamine: Role of alpha-Amino-3-Hydroxy-5-Methylisoxazole-4-Propionic Acid Receptors. Biol Psychiatry. 2007

80. Zarate CA Jr, Charney D, et al. Searching for rational anti-N-methyl-D-aspartate treatment for depression. Arch Gen Psychiatry 2007;64:1100–1101.

81. Wu JC, Bunney WE. The biological basis of an antidepressant response to sleep deprivation and relapse: review and hypothesis. Am J Psychiatry 1990;147(1):14–21. [PubMed: 2403471]

82. Gillin JC, Buchsbaum M, et al. Sleep deprivation as a model experimental antidepressant treatment: findings from functional brain imaging. Depress Anxiety 2001;14(1):37–49. [PubMed: 11568981]

83. Baxter LR Jr, Liston EH, et al. Prolongation of the antidepressant response to partial sleep deprivation by lithium. Psychiatry Res 1986;19(1):17–23. [PubMed: 3097691]

84. Szuba MP, Baxter LR Jr, et al. Lithium sustains the acute antidepressant effects of sleep deprivation: preliminary findings from a controlled study. Psychiatry Res 1994;51(3):283–95. [PubMed: 8208874]

85. Benedetti F, Colombo C, et al. Ongoing lithium treatment prevents relapse after total sleep deprivation. J Clin Psychopharmacol 1999;19(3):240–5. [PubMed: 10350030]

86. Wehr TA, Wirz-Justice A, et al. Phase advance of the circadian sleep-wake cycle as an antidepressant. Science 1979;206(4419):710–3. [PubMed: 227056]

87. Berger M, Vollmann J, et al. Sleep deprivation combined with consecutive sleep phase advance as a fast-acting therapy in depression: an open pilot trial in medicated and unmedicated patients. Am J Psychiatry 1997;154(6):870–2. [PubMed: 9167521]

88. Smeraldi E, Benedetti F, et al. Sustained antidepressant effect of sleep deprivation combined with pindolol in bipolar depression. A placebo-controlled trial. Neuropsychopharmacology 1999;20(4):380–5. [PubMed: 10088139]

89. Benedetti F, Colombo C, et al. Morning light treatment hastens the antidepressant effect of citalopram: a placebo-controlled trial. J Clin Psychiatry 2003;64(6):648–53. [PubMed: 12823078]

90. Wirz-Justice A, Van den Hoofdakker RH. Sleep deprivation in depression: what do we know, where do we go? Biol Psychiatry 1999;46(4):445–53. [PubMed: 10459393]

91. McDermott CM, Hardy MN, et al. Sleep deprivation-induced alterations in excitatory synaptic transmission in the CA1 region of the rat hippocampus. J Physiol 2006;570(Pt 3):553–65. [PubMed: 16322058]

92. Gardner JP, Fornal CA, et al. Effects of sleep deprivation on serotonergic neuronal activity in the dorsal raphe nucleus of the freely moving cat. Neuropsychopharmacology 1997;17(2):72–81. [PubMed: 9252982]

93. Cirelli C, Tononi G. Differential expression of plasticity-related genes in waking and sleep and their regulation by the noradrenergic system. J Neurosci 2000;20:9187–9194. [PubMed: 11124996]

94. Cirelli C, Tononi G. Gene expression in the brain across the sleep waking cycle. Brain Res 2000;885:303–321. [PubMed: 11102586]

95. Grassi Zucconi G, Cipriani S, et al. 'One night' sleep deprivation stimulates hippocampal neurogenesis. Brain Res Bull 2006;69(4):375–81. [PubMed: 16624668]

96. Guzman-Marin R, Suntsova N, et al. Sleep deprivation reduces proliferation of cells in the dentate gyrus of the hippocampus in rats. J Physiol 2003;549(Pt 2):563–71. [PubMed: 12679377]

97. Payne JL, Quiroz JA, et al. Timing is everything: does the robust upregulation of noradrenergically regulated plasticity genes underlie the rapid antidepressant effects of sleep deprivation? Biol Psychiatry 2002;52(10):921–6. [PubMed: 12437933]

98. Wu JC, Gillin JC, et al. Effect of sleep deprivation on brain metabolism of depressed patients. Am J Psychiatry 1992;149(4):538–43. [PubMed: 1554042]

99. Wu J, Buchsbaum MS, et al. Prediction of antidepressant effects of sleep deprivation by metabolic rates in the ventral anterior cingulate and medial prefrontal cortex. Am J Psychiatry 1999;156(8):1149–58. [PubMed: 10450253]

100. Ebert D, Feistel H, et al. Effects of sleep deprivation on the limbic system and the frontal lobes in affective disorders: a study with Tc-99m-HMPAO SPECT. Psychiatry Res 1991;40(4):247–51. [PubMed: 1811242]

101. Clark CP, Brown GG, et al. Does amygdalar perfusion correlate with antidepressant response to partial sleep deprivation in major depression? Psychiatry Res 2006;146(1):43–51. [PubMed: 16380239]

102. Clark CP, Brown GG, et al. Improved anatomic delineation of the antidepressant response to partial sleep deprivation in medial frontal cortex using perfusion-weighted functional MRI. Psychiatry Res 2006;146(3):213–22. [PubMed: 16545553]

103. Renaud LP, Blume HW, et al. Thyrotropin-releasing hormone selectively depresses glutamate excitation of cerebral cortical neurons. Science 1979;205(4412):1275–7. [PubMed: 224461]

104. Estienne MJ, Harter-Dennis JM, et al. Role of neuropeptides and amino acids in controlling secretion of hormones from the anterior pituitary gland in pigs. J Reprod Fertil 1997;(Suppl 52):3–17.

105. Crespi F, Keane PE, et al. In vivo evaluation by differential pulse voltammetry of the effect of thyrotropin-releasing hormone (TRH) on dopaminergic and serotoninergic synaptic activity in the striatum and nucleus accumbens of the rat. Exp Brain Res 1986;62(2):329–34. [PubMed: 2423357]

106. Marangell LB, George MS, et al. Effects of intrathecal thyrotropin-releasing hormone (protirelin) in refractory depressed patients. Arch Gen Psychiatry 1997;54(3):214–22. [PubMed: 9075462]

107. Sattin A. A heuristic model of mental depression derived from basic and applied research on thyrotropin-releasing hormone. Thyroid 1998;8(10):957–62. [PubMed: 9827666]

108. Szuba MP, Amsterdam JD, et al. Rapid antidepressant response after nocturnal TRH administration in patients with bipolar type I and bipolar type II major depression. J Clin Psychopharmacol 2005;25 (4):325–30. [PubMed: 16012274]

109. Prange AJ Jr, Wilson IC, et al. Thyroid-imipramine clinical and chemical interaction: evidence for a receptor deficit in depression. J Psychiatr Res 1972;9(3):187–205. [PubMed: 5083174]

110. Guerra-Crespo M, Ubieta R, et al. BDNF increases the early expression of TRH mRNA in fetal TrkB+ hypothalamic neurons in primary culture. Eur J Neurosci 2001;14(3):483–94. [PubMed: 11553298]

111. Bunevicius R, Matulevicius V. Short-lasting behavioural effects of thyrotropin-releasing hormone in depressed women: results of placebo-controlled study. Psychoneuroendocrinology 1993;18(5–6):445–9. [PubMed: 8416053]

112. Hollister LE, Berger P, et al. Protirelin (TRH) in depression. Arch Gen Psychiatry 1974;31(4):468–70. [PubMed: 4214026]

113. Gary KA, Sollars PJ, et al. Thyrotropin-releasing hormone phase shifts circadian rhythms in hamsters. Neuroreport 1996;7(10):1631–4. [PubMed: 8904771]

114. Post RM, Leverich GS, Denicoff KD, et al. Alternative approaches to refractory depression in bipolar illness. Depress Anxiety 1997;5(4):175–189. [PubMed: 9338110]

115. Gangadhar BN, Kapur RL, et al. Comparison of electroconvulsive therapy with imipramine in endogenous depression: a double blind study. Br J Psychiatry 1982;141:367–71. [PubMed: 6756530]

116. Folkerts HW, Michael N, et al. Electroconvulsive therapy vs. paroxetine in treatment-resistant depression -- a randomized study. Acta Psychiatr Scand 1997;96(5):334–42. [PubMed: 9395150]

117. Rich CL. Recovery from depression after one ECT. Am J Psychiatry 1984;141(8):334–42.

118. Segman RH, Shapira B, et al. Onset and time course of antidepressant action: psychopharmacological implications of a controlled trial of electroconvulsive therapy. Psychopharmacology (Berl) 1995;119(4):440–8. [PubMed: 7480524]

119. Kho KH, Blansjaar BA, Vothknecht S, et al. A study into predictors for the speed of response to electroconvulsive therapy. J Ect 2004;19(3):139–147. [PubMed: 12972983]

120. Kho KH, van Vreeswijk MF, et al. A meta-analysis of electroconvulsive therapy efficacy in depression. J Ect 2003;19(3):139–47. [PubMed: 12972983]

121. Husain MD, Rush AJ, Fink M, et al. Speed of response and remission in major depressive disorder with acute electroconvulsive therapy (ECT): a Consortium for Research in ECT (CORE) report. J Clin Psychiatry 2004;65(4):485–91. [PubMed: 15119910]

122. Post A, Keck ME. Transcranial magnetic stimulation as a therapeutic tool in psychiatry: what do we know about the neurobiological mechanisms? J Psychiatr Res 2001;35(4):193–215. [PubMed: 11578638]

123. Loo CK, Mitchell PB. A review of the efficacy of transcranial magnetic stimulation (TMS) treatment for depression, and current and future strategies to optimize efficacy. J Affect Disord 2005;88(3): 255–67. [PubMed: 16139895]

124. Carlson PJ, Singh JB, et al. Neural circuitry and neuroplasticity in mood disorders: insights for novel therapeutic targets. NeuroRx 2006;3(1):22–41. [PubMed: 16490411]

125. Mayberg HS, Lozano AM, et al. Deep brain stimulation for treatment-resistant depression. Neuron 2005;45(5):651–60. [PubMed: 15748841]

126. Greenberg BD, Malone DA, et al. Three-year outcomes in deep brain stimulation for highly resistant obsessive-compulsive disorder. Neuropsychopharmacology 2006;31(11):2384–93. [PubMed: 16855529]

127. Mayberg HS, Brannan SK, et al. Cingulate function in depression: a potential predictor of treatment response. Neuroreport 1997;8(4):1057–61. [PubMed: 9141092]

128. Parsey RV, Olvet DM, et al. Higher 5-HT1A receptor binding potential during a major depressive episode predicts poor treatment response: preliminary data from a naturalistic study. Neuropsychopharmacology 2006;31(8):1745–9. [PubMed: 16395308]

129. Chen CH, Ridler K, et al. Brain imaging correlates of depressive symptom severity and predictors of symptom improvement after antidepressant treatment. Biol Psychiatry 2007;62(5):407–14. [PubMed: 17217921]

130. Kimbrell TA, Little JT, et al. Frequency dependence of antidepressant response to left prefrontal repetitive transcranial magnetic stimulation (rTMS) as a function of baseline cerebral glucose metabolism. Biol Psychiatry 1999;46(12):1603–13. [PubMed: 10624541]

131. Tononi G, Cirelli C. Sleep function and synaptic homeostasis. Sleep Med Rev 2006;10(1):49–62. [PubMed: 16376591]

132. Bliss TV, Lomo T. Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit following stimulation of the perforant path. J Physiol 1973;232(2):331–56. [PubMed: 4727084]

133. Esser SK, Huber R, et al. A direct demonstration of cortical LTP in humans: A combined TMS/EEG study. Brain Res Bull 2006;69(1):86–94. [PubMed: 16464689]

134. Winkler D, Pjrek E, et al. Relationship between power spectra of the awake EEG and psychomotor activity patterns measured by short-term actigraphy. Neuropsychobiology 2003;48(4):176–81. [PubMed: 14673214]

135. Winkler D, Pjrek E, Praschak-Rieder N, et al. Actigraphy in patients with seasonal affective disorder and healthy control subjects treated with light therapy. Biol Psychiatry 2005;58(4):331–36. [PubMed: 16102546]

136. Binder EB, Holsboer F. Pharmacogenomics and antidepressant drugs. Ann Med 2006;38(2):82–94. [PubMed: 16581694]

137. Burke MJ, Preskorn SH. Therapeutic drug monitoring of antidepressants: cost implications and relevance to clinical practice. Clin Pharmacokinet 1999;37(2):147–65. [PubMed: 10496302]

138. Arias B, Catalan R, et al. 5-HTTLPR polymorphism of the serotonin transporter gene predicts non-remission in major depression patients treated with citalopram in a 12-weeks follow up study. J Clin Psychopharmacol 2003;23(6):563–7. [PubMed: 14624186]

139. Durham LK, Webb SM, et al. The serotonin transporter polymorphism, 5HTTLPR, is associated with a faster response time to sertraline in an elderly population with major depressive disorder. Psychopharmacology (Berl) 2004;174(4):525–9. [PubMed: 12955294]

140. Murphy GM Jr, Hollander SB, et al. Effects of the serotonin transporter gene promoter polymorphism on mirtazapine and paroxetine efficacy and adverse events in geriatric major depression. Arch Gen Psychiatry 2004;61(11):1163–9. [PubMed: 15520364]

141. Minov C, Baghai TC, et al. Serotonin-2A-receptor and -transporter polymorphisms: lack of association in patients with major depression. Neurosci Lett 2001;303(2):119–22. [PubMed: 11311507]

142. Serretti A, Kato M, et al. Meta-analysis of serotonin transporter gene promoter polymorphism (5-HTTLPR) association with selective serotonin reuptake inhibitor efficacy in depressed patients. Mol Psychiatry 2007;12(3):247–57. [PubMed: 17146470]

143. Tadic A, Rujescu D, et al. A monoamine oxidase B gene variant and short-term antidepressant treatment response. Prog Neuropsychopharmacol Biol Psychiatry 2007;31(7):1370–7. [PubMed: 17640790]

144. Licinio J, O'Kirwan F, et al. Association of a corticotropin-releasing hormone receptor 1 haplotype and antidepressant treatment response in Mexican-Americans. Mol Psychiatry 2004;9(12):1075–82. [PubMed: 15365580]

145. van Rossum EF, Binder EB, et al. Polymorphisms of the glucocorticoid receptor gene and major depression. Biol Psychiatry 2006;59(8):681–8. [PubMed: 16580345]

146. Binder EB, Salyakina D, et al. Polymorphisms in FKBP5 are associated with increased recurrence of depressive episodes and rapid response to antidepressant treatment. Nat Genet 2004;36(12):1319–25. [PubMed: 15565110]

147. Vermeer H, Hendriks-Stegeman BI, et al. Glucocorticoid-induced increase in lymphocytic FKBP51 messenger ribonucleic acid expression: a potential marker for glucocorticoid sensitivity, potency, and bioavailability. J Clin Endocrinol Metab 2003;88(1):277–84. [PubMed: 12519866]