

Ketamine for Rapid Reduction of Suicidal Thoughts in Major Depression: A Midazolam-Controlled Randomized Clinical Trial

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Objective: Pharmacotherapy to rapidly relieve suicidal ideation in depression may reduce suicide risk. Rapid reduction in suicidal thoughts after ketamine treatment has mostly been studied in patients with low levels of suicidal ideation. The authors tested the acute effect of adjunctive subanesthetic intravenous ketamine on clinically significant suicidal ideation in patients with major depressive disorder.

Method: In a randomized clinical trial, adults (N=80) with current major depressive disorder and a score ≥ 4 on the Scale for Suicidal Ideation (SSI), of whom 54% (N=43) were taking antidepressant medication, were randomly assigned to receive ketamine or midazolam infusion. The primary outcome measure was SSI score 24 hours after infusion (at day 1).

Results: The reduction in SSI score at day 1 was 4.96 points greater for the ketamine group compared with the midazolam group (95% CI=2.33, 7.59; Cohen's $d=0.75$). The proportion of

responders (defined as having a reduction $\geq 50\%$ in SSI score) at day 1 was 55% for the ketamine group and 30% for the midazolam group (odds ratio=2.85, 95% CI=1.14, 7.15; number needed to treat=4.0). Improvement in the Profile of Mood States depression subscale was greater at day 1 for the ketamine group compared with the midazolam group (estimate=7.65, 95% CI=1.36, 13.94), and this effect mediated 33.6% of ketamine's effect on SSI score. Side effects were short-lived, and clinical improvement was maintained for up to 6 weeks with additional optimized standard pharmacotherapy in an uncontrolled follow-up.

Conclusions: Adjunctive ketamine demonstrated a greater reduction in clinically significant suicidal ideation in depressed patients within 24 hours compared with midazolam, partially independently of antidepressant effect.

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There is a lack of evidence-based pharmacotherapy for suicidal patients with major depressive disorder. The 26.5% increase in U.S. suicide rates from 1999 to 2015 (1) underscores this treatment need. The American Psychiatric Association's practice guideline on management of patients with suicidal behavior states that "evidence for a lowering of suicide rates with antidepressant treatment is inconclusive" (2, p. 14). Standard antidepressants may reduce suicidal ideation and behavior in depressed adults, mediated by improvement in depressive symptoms, but this effect takes weeks (3). Other somatic treatments with some evidence for antisuicidal effects include clozapine in schizophrenia (4) and ECT (5) and lithium (6) in mood disorders.

Suicidal depressed patients need rapid relief of suicidal ideation. Depression remits in one-third or fewer patients, and fewer than half achieve even 50% relief with typical first-line medications (7). Although suicidal behavior is usually

associated with depression (8), most antidepressant trials have excluded suicidal patients and did not assess suicidal ideation and behavior systematically, which has resulted in limited data on this topic (9). Depression predicts suicide attempts via its effect on suicidal ideation (10).

Ketamine, a drug with dissociative and glutamate receptor-blocking properties that was approved by the U.S. Food and Drug Administration in 1970 for anesthetic use, has recently become a target of research for its antidepressant effects, which occur within hours at subanesthetic doses (11). Reports of reduction in suicidal ideation after ketamine infusion are promising, but the conclusiveness of results for major depression has been limited by measurement of suicidal ideation with a single item from a depression inventory (12–16), lack of a control group (15–17), use of a saline control (12, 13), and use of samples with low levels of suicidal ideation (16, 18) or mixed diagnoses (19).

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We conducted a randomized clinical trial of an adjunctive infusion of ketamine compared with the short-acting benzodiazepine anesthetic midazolam in patients with major depressive disorder who had clinically significant suicidal ideation, as assessed by score on the Scale for Suicidal Ideation (SSI) (20). The primary outcome measure was SSI score 24 hours after infusion. Other outcome measures included global depression ratings, clinical ratings during 6-week open follow-up treatment, and safety measures. Given ketamine's dissociative effects, there is no ideal comparator, so, as in the trial by Murrugh et al. (21), we used midazolam because it is a psychoactive anesthetic agent with a similar half-life and no established antidepressant or antisuicidal effects. We hypothesized that ketamine would produce a greater reduction in suicidal ideation at 24 hours compared with midazolam.

METHOD

Participants

Eligible patients were 18–65 years old and had a DSM-IV diagnosis of major depressive disorder, a score ≥ 16 on the 17-item Hamilton Depression Rating Scale (HAM-D) (22), and a score ≥ 4 on the SSI, which is considered a clinically significant cutoff for suicidal ideation (18, 23, 24). A prospective study of 6,891 psychiatric outpatients (23) found that a baseline SSI score > 2 predicted suicide during up to 20 years of follow-up, adjusting for other risk factors.

Eligible patients had a voluntary admission to an inpatient research unit at New York State Psychiatric Institute, and patients were discharged when assessed as stable and not an imminent safety risk. Exclusion criteria included unstable medical or neurological illness, significant electrocardiographic abnormality, pregnancy or lactation, current psychosis, history of ketamine abuse or dependence, other drug or alcohol dependence within the past 6 months, suicidal ideation due to binge substance use or withdrawal, prior ineffective trial of or adverse reaction to ketamine or midazolam, daily opioid use greater than 20 mg of oxycodone or equivalent during the 3 days before infusion, a score < 25 on the Mini-Mental State Examination (25) for persons > 60 years old, lack of capacity to consent, and inadequate understanding of English. There was no exclusion for body mass index or weight. Participants were allowed to continue on stable dosages of current psychiatric medications, except that benzodiazepines could not be taken within 24 hours before the infusion. Recruitment was conducted via Internet and local media advertisements and clinician referral. The protocol was approved by the Institutional Review Board of the New York State Psychiatric Institute, and written informed consent was obtained from all participants.

Intervention

Participants were randomly assigned to receive intravenous racemic ketamine hydrochloride at 0.5 mg/kg or midazolam at 0.02 mg/kg, in 100 mL normal saline infused over 40 minutes. To minimize additive sedation, we used a lower midazolam dose than the 0.045 mg/kg dose used in studies where participants

underwent a washout of concomitant psychotropic medications (21). In addition to safety concerns, excessive sedation could compromise blinding, since subanesthetic ketamine does not tend to induce sleep and can be stimulating. Blood pressure, blood oxygen saturation, heart rate, and respiratory rate were monitored every 5 minutes during the infusion. A psychiatrist certified in advanced cardiac life support administered the infusion, and an anesthesiologist was available for consultation by telephone. After assessments at 24 hours, participants received optimized standard clinical pharmacological treatment for 6 months, with weekly research ratings for the first 6 weeks in an uncontrolled follow-up observation.

Outcome and Measures

Raters were doctoral- or master's-level psychologists. Diagnoses, including substance abuse or dependence, were made using the Structured Clinical Interviews for DSM-IV axis I and II disorders (SCID I and II) (26, 27) in a weekly consensus conference of research psychologists and psychiatrists. Suicidal ideation due to binge substance abuse was assessed by clinical history, and past antidepressant trials and current medications were inventoried with our baseline clinical-demographic form, which surveys a range of variables not captured by other instruments. Videotaped assessments were used for weekly reliability monitoring. Intraclass correlation coefficients for key clinical ratings were 0.94 for the SCID I, 0.96 for the HAM-D, and 0.98 for the SSI.

The clinician-rated SSI assessed current severity of suicidal ideation with 19 items scaled from 0 (least severe) to 2 (most severe) (20). Items probe wish to die, passive and active suicide attempt thoughts, duration and frequency of ideation, sense of control, deterrents, and preparatory behavior for an attempt (23). The SSI has moderately high internal consistency and good concurrent and discriminant validity (28). It was administered at screening, at baseline within 24 hours before infusion, at 230 minutes after infusion, at 24 hours after infusion, and at weeks 1–6 of follow-up. For brevity we use "day 1" to refer to the 24-hour postinfusion assessment. Depressive symptoms were assessed with the 17- and 24-item HAM-D (22), the Beck Depression Inventory (BDI) (29), and the Profile of Mood States (POMS) (30). Anxiety was measured with a 5-point Likert scale asking patients to self-rate from 0 (not at all) to 4 (extremely anxious).

Adverse effects were measured with the Systematic Assessment for Treatment Emergent Events–General Inquiry (31), the Clinician-Administered Dissociative States Scale (CADSS; score range, 0–92) (32), and the positive symptom subscale of the Brief Psychiatric Rating Scale (BPRS), which includes conceptual disorganization, grandiosity, hallucination, and delusions (subscale score range, 0–24) (33). Efficacy ratings and the CADSS and BPRS positive symptom subscale (at baseline, at 230 minutes, and at day 1) were collected by psychologist raters who were not present during the infusion. Administration of the immediate postinfusion CADSS and BPRS positive symptom subscale and all adverse effect ratings were done by the physician who supervised the infusion.

Participants were asked at 3 and 6 months about poststudy ketamine use.

Randomization and Blinding

A permuted, blocked design was used, with 1:1 assignment between treatments and block size randomized between 4 and 6 with equal probability. Randomization was stratified on two baseline factors: whether the patient was taking psychiatric medication (yes/no), and whether the patient's baseline SSI score was <8 or ≥ 8 . The latter stratification factor, based on median baseline SSI score in our previous clinical trial in suicidal depressed patients (34), was to increase the likelihood that the treatment groups would be similar in baseline SSI severity.

Patients and study personnel were blind to treatment. To assess the adequacy of the blind, patients and raters were asked in the day 1 ratings whether they thought the infusion was midazolam or ketamine or if they had "no idea." Treatment response was defined as a day 1 SSI score $\geq 50\%$ below baseline. We defined remission more stringently as a day 1 SSI score $\geq 50\%$ below baseline and less than the eligibility threshold of 4. A remission level of improvement was defined to ensure that the midazolam group would have every opportunity to receive ketamine. Nonremitters were unblinded, and those who had received midazolam were offered an open ketamine infusion, usually the following day. Pre-existing medications were held constant from preinfusion baseline until completion of day 1 ratings after the final infusion. Remitters remained blind and received a letter from the pharmacy after completing follow-up treatment informing them of their randomized drug.

Statistical Analysis

The study was powered assuming a two-sided test of the group effect at an alpha level of 0.05. Effect size estimates, standard deviations, and correlations were based on previous reports (15, 34). A planned sample size of 70, assigned 1:1 to each treatment, provided $\geq 80\%$ power to detect a 25% reduction in SSI score over 24 hours in the ketamine group and none in the midazolam group. The actual sample size is 80.

Histograms and residual plots of outcomes were inspected for normality. Group comparisons on baseline characteristics were made using the chi-square test or Fisher's exact test as appropriate for categorical variables and the two-sample t test for continuous variables. The modified intent-to-treat analysis included all randomized participants who were assessed for the primary outcome measure, SSI score at day 1 ($N=80$). The primary hypothesis was tested using an analysis of covariance (ANCOVA) model of the change in SSI score from baseline to day 1, with treatment group and baseline SSI score as the predictors. Randomization stratum (taking or not taking psychiatric medication), by definition not associated with treatment group, was not associated with the primary outcome measure ($p=0.84$) and so was not included in the model. Effect size calculations used Cohen's d and number needed to treat. Cohen's d was calculated as the difference in

mean group change divided by the standard deviation of baseline values for the whole sample.

Secondary analyses used ANCOVA models to test for differential change between groups in SSI score and depressive symptom ratings (the 17- and 24-item HAM-D, the BDI, and the POMS) from baseline to 230 minutes and in depressive symptom ratings from baseline to day 1. Response was compared by drug using logistic regression. Linear regression was used in an exploratory analysis of treatment effects on the suicidal desire/ideation and planning subscales of the SSI (35). Mediation analyses were performed using a structural equation modeling framework in Mplus, version 7 (36). Paired t tests were used to determine whether the participants assigned to midazolam who received an open ketamine treatment after day 1 ($N=35$) experienced significant subsequent change in SSI or HAM-D scores. For the longitudinal data analysis, mixed-effects linear regression of SSI and 17-item HAM-D scores over the 6-week follow-up period was used to test for significant change from baseline across the entire sample, regardless of treatment group, since 35 of 40 patients in the midazolam group were nonremitters and received a subsequent open ketamine infusion. Safety analyses included univariate tests comparing infusion-related cardiorespiratory effects, adverse events, and postinfusion severity of positive, dissociative, and anxiety symptom ratings between groups. SAS, version 9.4 (SAS Institute, Cary, N.C.), and SPSS, version 23 (IBM, Armonk, N.Y.), were used for the analyses.

RESULTS

Participants

Enrollment was conducted from November 2012 to December 2016, and data collection was completed in February 2017. (A CONSORT chart is available in the data supplement that accompanies the online edition of this article; see Figure S1.) Of the 82 participants who underwent randomized assignment to treatment, two (one in each group) withdrew before the day 1 assessment and were excluded from the analysis. The groups did not differ significantly in baseline characteristics except for frequency of borderline personality disorder (Table 1). No participant met SCID criteria for current substance abuse; two participants had substance abuse in partial remission (alcohol abuse in one case, cannabis abuse in the other). At baseline, participants reported a lifetime medication history of, on average, four ($SD=2.4$) antidepressants and two ($SD=1.2$) antidepressant classes; 45 participants (56%) had previously taken a mood stabilizer, 49 (61%) a second-generation antipsychotic, 32 (40%) a stimulant, 51 (64%) a benzodiazepine, 25 (31%) other anxiolytics, and 27 (34%) sleep medications. These frequencies did not differ significantly between groups. Three participants had never taken any psychiatric medications, including any antidepressants, and 22 participants had received ECT. Frequencies of current medication classes at baseline were as follows: antidepressants, $N=43$; anticonvulsants, $N=21$;

TABLE 1. Baseline Characteristics of Patients With Major Depressive Disorder and Clinically Significant Suicidal Ideation Treated With a Subanesthetic Infusion of Ketamine or Midazolam^a

Variable ^b	Midazolam Group (N=40)		Ketamine Group (N=40)	
	N	%	N	%
Female	26	65.0	22	55.0
White race	39	97.5	35	87.5
Hispanic ethnicity	1	2.5	0	0.0
Married	7	18.0	7	18.0
Currently employed	15	37.5	10	25.0
Prior psychiatric hospitalization	29	73.0	27	68.0
Prior suicide attempt ^c	22	55.0	17	42.5
Personality disorder ^d	13	36.0	16	41.0
Borderline personality disorder ^{d,e}	3	8.0	11	28.0
History of substance use disorder	9	22.5	11	27.5
Mood disorder in first-degree relative	23	57.5	24	60.0
Suicide or attempt in first-degree relative	3	7.5	2	5.0
	Mean	SD	Mean	SD
Age (years)	40.7	13.1	38.4	13.2
Scale for Suicidal Ideation score	15.7	6.9	14.3	6.3
Hamilton Depression Rating Scale (17-item) score	22.6	3.9	22.2	4.6
Beck Depression Inventory score	33.9	8.1	31.8	8.1
Years of education	15.9	2.4	15.9	2.8
	Median	Range	Median	Range
Duration of current episode (weeks)	50	2–2,860	60	8–572
Age at onset of first major depressive episode (years)	14	5–45	16	6–51
Lifetime number of major depressive episodes	3	1 to “too many to count”	4.5	1 to “too many to count”
Body mass index	27.8	17.2–51.5	25.3	19.9–46.7

^a The data are based on the modified intent-to-treat sample. Ns for the measures reported as means or medians range from 35 to 40 for each group. There were no significant differences between groups except as otherwise noted.

^b Assessed with the study’s research Baseline Clinical-Demographic form unless otherwise noted.

^c Assessed with the Columbia Suicide History Interview (48).

^d Assessed with the Structured Clinical Interview for DSM-IV Axis II Personality Disorders (27).

^e Significant difference between groups (p=0.03).

antipsychotics, N=14; benzodiazepines, N=27; and lithium, N=2 (see Table S1 in the data supplement). These frequencies did not differ significantly between groups.

Primary Outcome Measure: Day 1 Suicidal Ideation

The average SSI score at day 1 was 4.96 points lower in the ketamine group compared with the midazolam group (estimate=4.96, 95% CI=2.33, 7.59; t=3.75, df=77, p<0.001) (Figure 1). Cohen’s d for the difference in mean group change was 0.75, a medium effect size. Including baseline borderline personality disorder diagnosis as a covariate had little effect on the results (estimate=4.76, 95% CI=1.89, 7.63; t=3.30, df=71, p=0.002).

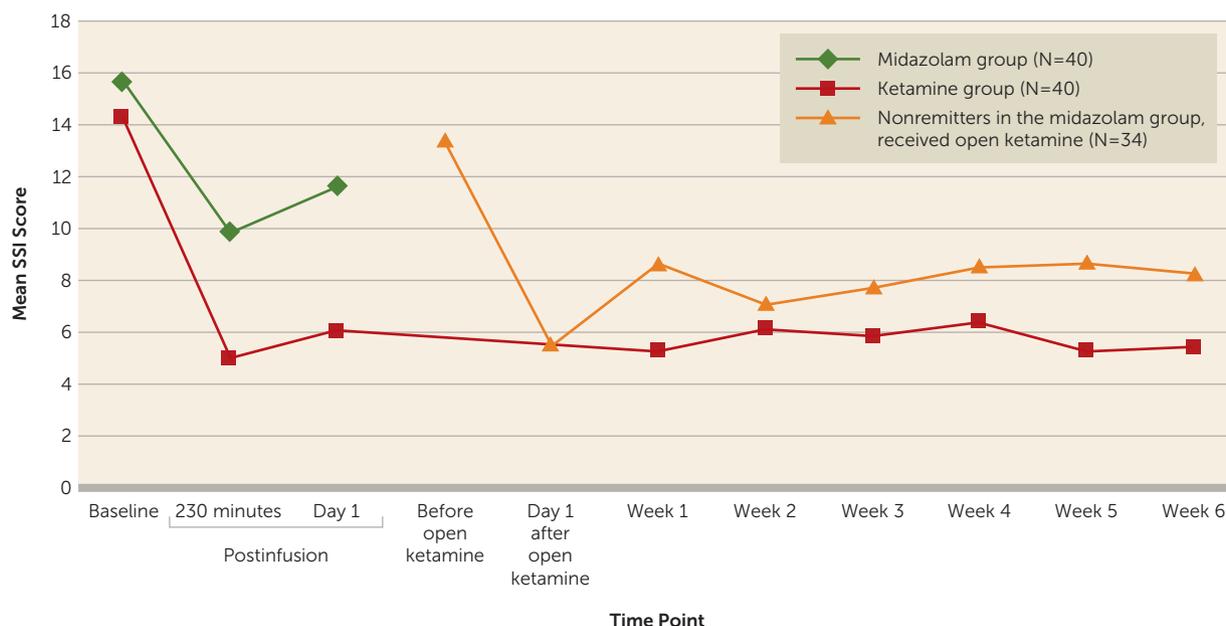
Secondary Outcome Measures

Suicidal ideation. The proportion of responders on the SSI at day 1 was 55% in the ketamine group and 30% in the midazolam group (odds ratio=2.85, 95% CI=1.14, 7.15; p=0.024; number needed to treat=4.00). The decrease in suicidal ideation at 230 minutes after the infusion was greater in the ketamine group compared with the midazolam group (mean reduction, 9.69 points and 5.41 points, respectively; differential drug effect estimate=4.29 points, 95% CI=1.73, 6.84;

t=3.34, df=77, p=0.001). Exploratory analysis showed that the odds of an SSI score of 0 at day 1 were 2.8-fold greater for the ketamine group, although the difference fell short of statistical significance (p=0.088). Among those who continued to have suicidal ideation on day 1, we found no differential drug effect on the SSI planning subscale but greater improvement in the ketamine group in the suicidal desire and ideation subscale (35) (estimate=1.37, df=58, t=2.02, p=0.049).

Postinfusion worsening of SSI ratings at 230 minutes was observed in four patients in the midazolam group, and at day 1 in nine patients in the midazolam group and two in the ketamine group.

Depressive symptoms. The day 1 POMS total mood disturbance score showed greater improvement in the ketamine group compared with the midazolam group (estimate=21.19, 95% CI=2.95, 39.43; df=75, t=2.31, p=0.023), as did scores on the depression subscale (estimate=7.65, 95% CI=1.36, 13.94; df=75, t=2.42, p=0.018) and the fatigue subscale (estimate=4.12, 95% CI=0.73, 7.50; df=75, t=2.42, p=0.018). There was partial mediation (33.6%) of ketamine’s effect on day 1 SSI score through its effect on POMS depression rating

FIGURE 1. Change in Suicidal Ideation Over Time in Suicidal Patients With Major Depression Treated With a Subanesthetic Infusion of Ketamine or Midazolam^a

^aThe data are based on the modified intent-to-treat sample (N=40 per group). The primary outcome measure was score on the Scale for Suicidal Ideation (SSI) 24 hours after infusion (day 1); the reduction was greater for the ketamine group than for the midazolam group ($p < 0.001$). SSI scores range from 0 to 38, with higher scores indicating greater severity. Remission was defined as an SSI score $\geq 50\%$ below baseline at day 1 and less than the study eligibility threshold of 4. For nonremitters, the blind was broken and patients who were allocated to midazolam were offered an open ketamine infusion, usually the following day. Thirty-five midazolam nonremitters received an open ketamine infusion, and one withdrew from the study before the day 1 assessment.

(indirect path estimate = -1.62 , $SE = 0.81$, $p < 0.050$; direct path estimate = -3.20 , $SE = 1.12$, $p = 0.005$).

Ketamine showed advantages that fell short of statistical significance on the day 1 clinician-rated 17-item HAM-D (estimate = 2.83 points, 95% CI = -0.12 , 5.77; $t = 1.91$, $df = 77$, $p = 0.06$), the 24-item HAM-D (estimate = 3.54 points, 95% CI = -0.29 , 7.36; $t = 1.84$, $df = 77$, $p = 0.07$), and the self-rated BDI (estimate = 4.66 points, 95% CI = -0.04 , 9.36; $t = 1.98$, $df = 69$, $p = 0.05$). The proportions of responders in the ketamine and midazolam groups, respectively, were as follows: on the 17-item HAM-D, 30% and 15% (odds ratio = 2.43, 95% CI = 0.81, 7.30; number needed to treat = 6.67; $p = 0.11$); on the 24-item HAM-D, 25% and 15% (odds ratio = 1.89, 95% CI = 0.61, 5.82; number needed to treat = 10.00; $p = 0.26$); on the BDI, 36% and 17% (odds ratio = 2.83, 95% CI = 0.93, 8.57; number needed to treat = 5.14; $p = 0.06$).

Open ketamine infusion. In the midazolam group, 35 participants did not meet the SSI remission criteria and received an open ketamine infusion (Figure 1). Day 1 ratings showed improvement from postmidazolam scores as follows: on the SSI, estimate = -7.85 ($SD = 6.58$; $df = 33$, $t = -6.96$, $p < 0.001$); on the 17-item HAM-D, estimate = -7.26 ($SD = 6.93$; $df = 33$, $t = -6.11$, $p < 0.001$); and on the 24-item HAM-D, estimate = -9.85 ($SD = 9.43$; $df = 33$, $t = -6.09$, $p < 0.001$).

Follow-up ratings for weeks 1–6. Longitudinal analysis of the uncontrolled 6-week follow-up showed that clinical

improvement after randomized and open ketamine treatment was generally maintained through 6 weeks of open, optimized clinical follow-up treatment with respect to SSI score and depression ratings (Figures 1 and 2; see also Tables S2 and S3 in the online data supplement).

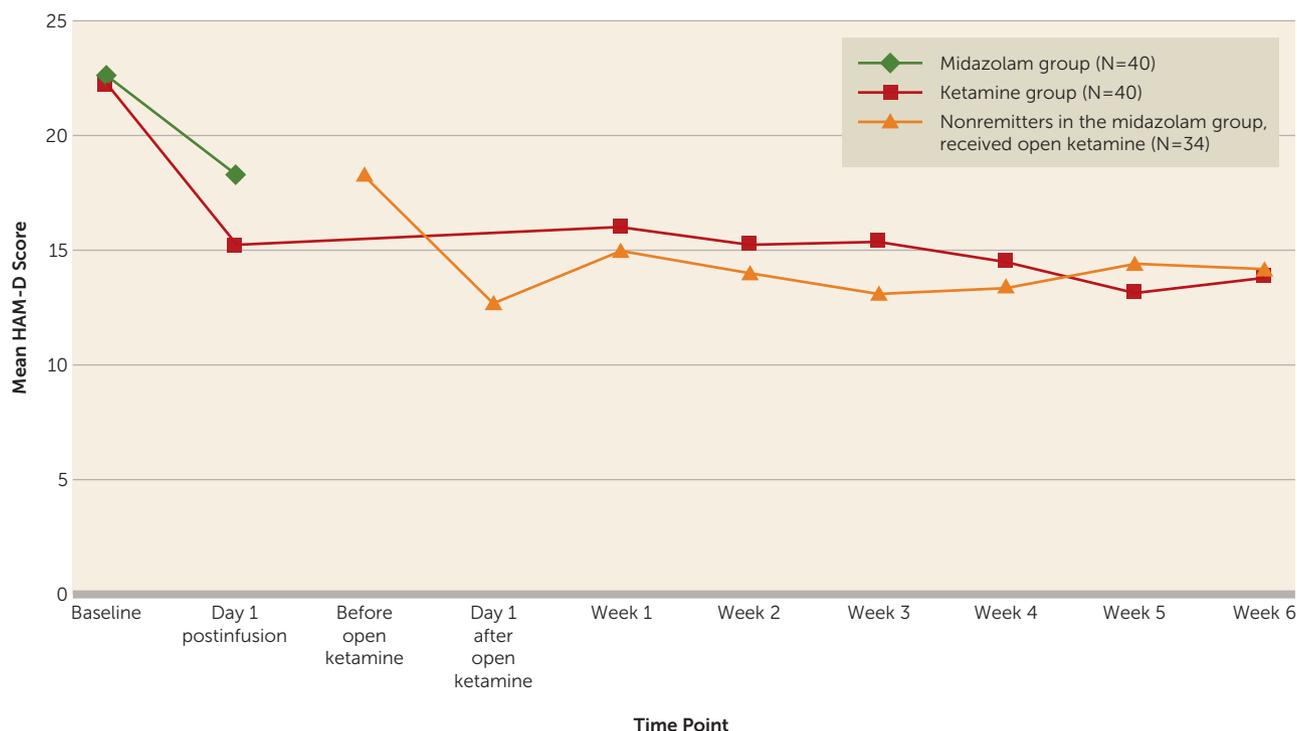
Blinding. On day 1, raters correctly guessed the blinded drug in 42% of midazolam and 44% of ketamine cases ($\chi^2 = 0.02$, $df = 1$, $p = 0.895$). Patients guessed correctly 55% of the time with both drugs ($\chi^2 = 0.00$, $df = 1$, $p = 1.000$).

Safety Outcomes

Cardiorespiratory effects. Ketamine was associated with a mean transient increase in systolic blood pressure of 15.28 mmHg ($SD = 9.79$), compared with 3.75 mmHg ($SD = 6.46$) for midazolam ($t = -6.22$, $df = 78$, $p < 0.001$). A mean increase in diastolic blood pressure of 13.38 mmHg ($SD = 8.48$) was observed with ketamine, compared with 4.03 mmHg ($SD = 5.50$) with midazolam ($t = -5.85$, $df = 78$, $p < 0.001$). It took a mean of 5.28 minutes for blood pressure to return to baseline after ketamine, and 0 minutes after midazolam. Cardiorespiratory effects are summarized in Table S4 in the data supplement.

Psychiatric and other adverse effects. Baseline dissociative symptom scores and BPRS positive symptom subscale scores did not differ significantly between groups ($p > 0.7$). CADSS scores were higher immediately after ketamine (mean = 17.63, $SD = 13.55$) than after midazolam (mean = 0.88, $SD = 1.42$)

FIGURE 2. Change in Depressive Symptoms Over Time in Suicidal Patients With Major Depression Treated With a Subanesthetic Infusion of Ketamine or Midazolam^a



^a The data are based on the modified intent-to-treat sample (N=40 per group). Score on the 17-Item Hamilton Depression Rating Scale (HAM-D) 24 hours after infusion (day 1) was a secondary outcome measure. Remission was defined as a Scale for Suicidal Ideation score $\geq 50\%$ below baseline at day 1 and less than the study eligibility threshold of 4. For nonremitters, the blind was broken and patients who were allocated to midazolam were offered an open ketamine infusion, usually the following day. The reduction in HAM-D score was greater in the ketamine group compared with the midazolam group, but the difference fell short of statistical significance ($p=0.06$).

($U=1475.50$, $p<0.001$), but the groups did not differ significantly in CADSS score at 230 minutes ($p=0.82$) or at day 1 ($p=0.83$) (see Figure S2 in the data supplement). BPRS positive symptom subscale scores were higher immediately after ketamine treatment (mean=0.68, SD=1.80), whereas no patient had a score >0 after midazolam treatment ($U=980.00$, $p=0.002$); there were no significant group differences at 230 minutes ($p=0.32$) or at day 1 ($p=0.63$).

Participants in the midazolam group reported higher anxiety 230 minutes after infusion (mean=2.10, SD=1.34) than did those in the ketamine group (mean=1.40, SD=1.13) (estimate=2.68, 95% CI=1.15, 6.23; $p=0.023$), but there was no significant difference between groups at day 1 ($p=0.497$). Adverse effects, mostly physical, assessed with the Systematic Assessment for Treatment Emergent Events, are summarized in Table S5 in the online data supplement.

At the follow-up assessments for ketamine abuse, 68 (85%) participants were reached at 3 months and 62 (78%) at 6 months. None showed evidence of abuse, five (6%) reported receiving ketamine off-label in private clinics, and one had contemplated using some provided by a friend.

Serious adverse events. There were 10 serious adverse events requiring institutional review board report: two were for unrelated medical illness, one for sedative misuse without suicidal intent, four for suicide attempts (three after and one

before study procedures), and three for inpatient admissions for increased suicidal ideation. No serious adverse event resulted in serious medical sequelae or institutional review board–required protocol modification. (Details are provided in Table S6 in the online data supplement.) No suicides occurred during the protocol. Two suicides occurred after the study, at 6 and 26 months, during treatment in the community, both by patients in the ketamine group, one of whom had been a remitter and the other a nonresponder.

DISCUSSION

In major depression with clinically significant suicidal ideation, a single subanesthetic ketamine infusion, adjunctive to ongoing pharmacotherapy, was associated with a greater reduction in suicidal thoughts at day 1, the primary outcome measure, compared with midazolam control infusion. The adjusted mean difference of 4.96 points on the clinician-rated SSL, a Cohen’s d of 0.75, and a number needed to treat of 4 for response represent a medium-sized effect. Adverse effects—mainly blood pressure increase and dissociative symptoms—were similar to those reported in other ketamine studies (37) and were mostly mild to moderate, and transient, typically resolving within minutes to hours after infusion. Improvement in suicidal ideation largely persisted during the

6-week period of uncontrolled observation, during which standard pharmacological treatments were also optimized.

To our knowledge, there is no established definition of a clinically meaningful reduction in score on a standard suicidal ideation scale. A prospective study (N=6,891) of patients with depressive disorders (23) found that a baseline SSI score >2 predicted suicide during up to 20 years of follow-up. In a prospective study of 562 inpatients (64% with a mood disorder) who endorsed suicidal thoughts (38), those who experienced a 50% reduction within 24 hours from a severe level (suicidal ideation “most of the time”) had one-third the risk of subsequent self-harm events during a mean length of stay of 24 days, compared with those whose suicidal thoughts remained elevated. Trials during recent decades show that the average advantage for antidepressant drug compared with placebo was 2 to 4 points on measures such as the 17-item HAM-D (39). The United Kingdom’s National Institute for Health and Care Excellence considers a standardized mean difference such as a Cohen’s *d* value ≥ 0.5 , or a between-group difference of ≥ 3 points on the HAM-D or the BDI, to be clinically significant (40). Together these data suggest that the advantage found in this study for reduction of suicidal ideation 24 hours after ketamine, compared with midazolam, is clinically meaningful.

Given concerns about ketamine’s 1- to 2-week antidepressant effect in previous studies (11), it is notable that the improvement in suicidal ideation in this trial was largely maintained through the 6-week follow-up ratings. This may be partly explained by the fact that patients continued prior psychotropic medication, which was optimized after completion of day 1 postinfusion ratings. Our result is consistent with the Hu et al. trial (41), in which patients with major depression who were randomly assigned to receive a single ketamine infusion on day 1 of escitalopram therapy experienced a faster response compared with patients who received a saline control infusion, and the benefits were maintained for 4 weeks.

We found greater reductions in overall mood disturbance, depression, and fatigue, assessed with the POMS, on day 1 after ketamine compared with midazolam. The response rates we found for depression using the HAM-D and the BDI were surprisingly low compared with other randomized controlled ketamine trials (42). Contributing factors may include concurrent antidepressant and other psychiatric medications, the effect of hopelessness as a feature of suicidal states, and the possibility that our sample was not treatment resistant and may have been more prone to midazolam placebo response.

The fact that the differential drug effect on global mood and depression was strongest for the POMS and the BDI may be related partly to their emphasis on subjective experience of core depressive symptoms, which correlate more strongly with suicidal ideation than do other symptom types (43). A secondary analysis of adjunctive ketamine (N=14) found a reduction in suicidal ideation even when depression did not remit (17). Ketamine is mechanistically distinct from currently approved antidepressants, its therapeutic effects possibly involving rapid synapse formation (44). Our mediation

model results suggest that its effects on depression and suicidal thoughts are at least partially independent.

The only other midazolam-controlled trial of adjunctive ketamine infusion using SSI score at day 1 as the primary outcome measure was a study of patients with mood and anxiety disorders (N=24) and a score ≥ 4 on the suicide item of the Montgomery-Åsberg Depression Rating Scale (MADRS) (19). Differences from our trial included mixed diagnoses, inpatient and outpatient settings, a higher midazolam dose (0.045 mg/kg), and use of the self-report SSI, which correlates >0.90 with the clinician-rated version that we used, although patients report higher scores than clinicians (45). The results did not show a differential treatment effect on the primary outcome measure, but a difference favoring ketamine was found at 24 hours on the MADRS suicide item and at 48 hours on the SSI, which was no longer significant at 72 hours. The study did not find a differential effect on global depression ratings or correlations between changes in SSI and total MADRS scores.

A midazolam-controlled ketamine trial (21) in treatment-resistant depression (N=73) found an 8-point advantage for ketamine on the primary outcome measure, MADRS score at day 1 (Cohen’s *d*=0.81; odds ratio for response=2.2). A subsequent analysis reported an advantage at day 1 for ketamine in reduction of a suicidal ideation index comprising the self-report SSI (mean baseline score=6) and suicide items from two depression scales, which was fully mediated by reduction in MADRS score minus the suicide item (18).

We found stronger effects on suicidal ideation than on global depression compared with the latter trial (21), although both studies involved patients with moderate to severe baseline depression severity according to MADRS and HAM-D guidelines (46). Reasons for the difference may include our study design, in which we allowed patients to stay on their current, stable dosage of antidepressant medication instead of employing a medication washout during the week before the trial began. Fifty-four percent of our sample was taking antidepressant medication at baseline. Residual antidepressant effects from the concomitant medication in both treatment groups in our study may have diminished the antidepressant effect of ketamine. Another study difference was in the samples; the earlier study included patients with treatment-resistant depression, and our study included patients with clinically significant suicidal ideation.

Limitations of our study include the primary outcome measure of suicidal ideation as opposed to behavior. Suicide or attempts are more significant, but their low base rates, even in at-risk populations, mean that very large samples and long follow-up periods are required. Suicidal ideation is feasible and significant as an outcome measure, as clinicians assess it when evaluating need for hospitalization because it predicts suicide attempts (47) and suicide (23). Among patients in our study who had suicidal ideation at day 1, there was no differential drug effect on the SSI planning subscale, but greater improvement in the ketamine group on the suicidal desire and ideation subscale, which correlated with depression,

hopelessness, and past suicide attempt in a study by Witte et al. (35).

In our sample, there were more patients with borderline personality disorder in the ketamine group than in the midazolam group (28% compared with 8%). While there is no reason to think this would affect study infusion response in a particular direction, when it was included as a covariate it had little effect on the primary outcome measure. The higher rate of dissociative side effects with ketamine, found in other studies, makes midazolam an imperfect control (21), but differences in rates of correct guesses on the blinded infusion drug were not statistically significant, among raters or participants. Other limitations include open-label treatment during the week 1–6 follow-up ratings, during which standard pharmacological treatments were optimized, and the small percentages of Hispanic and nonwhite participants.

In summary, in this randomized trial in suicidal depressed patients, a single adjunctive subanesthetic ketamine infusion was associated with a clinically significant reduction in suicidal ideation at day 1 that was greater than with the midazolam control infusion. In the context of standard, optimized treatment after the ketamine infusion, this improvement appeared to persist for at least 6 weeks. The clinical applicability of our findings was improved with infusion administration by a psychiatrist and without a medication washout, as has been done in some studies (12, 13, 21). Research is needed to understand ketamine's mechanism of action and to investigate strategies and safety of longer-term treatment.

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FIGURE S1. CONSORT Flow Chart

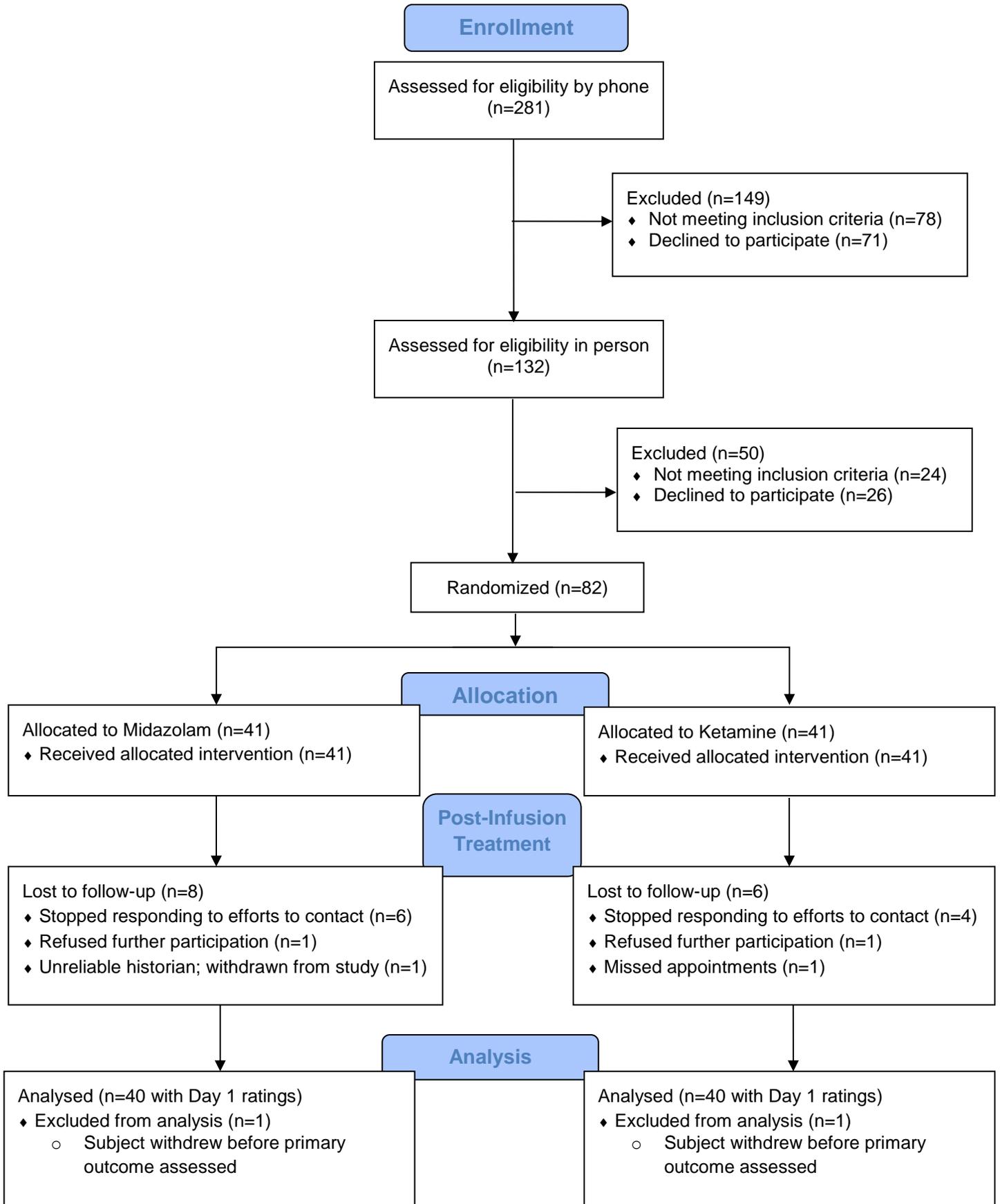
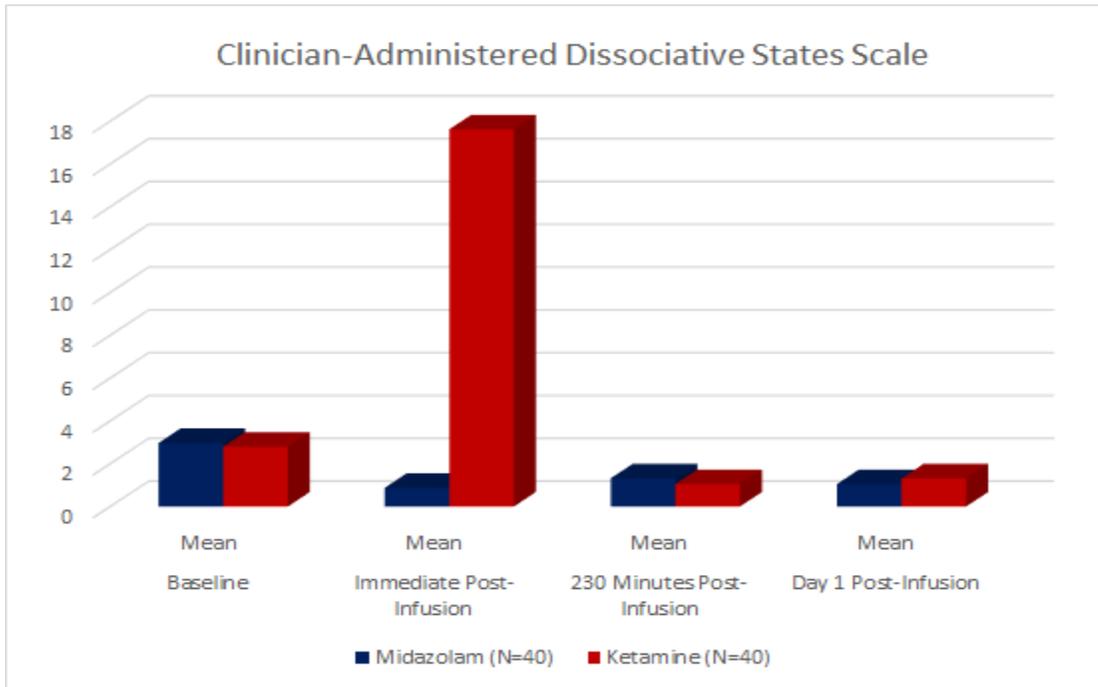


FIGURE S2. Dissociative Effects in Suicidal Patients With Major Depression Randomized to a Subanesthetic Infusion of Ketamine or Midazolam^a



^a Immediate postinfusion rating done by physician supervising infusion; 230-minute postinfusion rating done by clinical rater who was not present during infusion.

TABLE S1. Medication Classes at Baseline for Both Treatment Groups Combined (N=80)

Medication	N	%
Antidepressant	43	53.75
SSRI	14	17.5
SNRI	15	18.75
Tricyclic	6	7.5
MAOI	1	1.25
Other ^a	25	31.25
Anticonvulsant	21	26.25
Antipsychotic	14	17.5
Benzodiazepine	27	33.75
Lithium	2	2.5

^a Other antidepressants: bupropion, trazodone, mirtazapine, vortioxetine, vilazodone.

TABLE S2. Suicidal Ideation Severity During the Study for Both Treatment Groups Combined

Time Point	Scale for Suicidal Ideation			Change from Baseline		Test of Change						
						From Baseline			From Last Time Point			
	N	Mean	SD	Mean	SD	DF	t	p	DF	t	p	
Baseline ^a	80	14.98	6.64	.	.	.	.	.	.	.	.	.
230 minutes after randomized infusion	80	7.43	6.70	-7.55	7.10	465	-9.57	<0.0001	.	.	.	.
Day 1 after randomized infusion	80	8.84	7.07	-6.14	7.18	465	-7.78	<0.0001	465	-2.03	0.0427	
Week1	73	6.88	7.40	-7.95	8.49	465	-9.60	<0.0001	465	2.26	0.0243	
Week2	70	6.60	7.01	-8.11	8.61	465	-9.69	<0.0001	465	0.22	0.8252	
Week3	67	6.75	7.94	-8.15	9.25	465	-9.27	<0.0001	465	-0.35	0.7272	
Week4	60	7.40	7.75	-7.93	9.34	465	-8.71	<0.0001	465	-0.32	0.7467	
Week5	61	6.89	7.47	-7.75	9.02	465	-9.15	<0.0001	465	0.42	0.6727	
Week6	61	6.72	7.63	-8.52	8.60	465	-9.61	<0.0001	465	0.49	0.6255	

^a Baseline is within 24 hours before infusion.

TABLE S3. Depression Severity During the Study for Both Treatment Groups Combined

Time Point	17-Item Hamilton Depression Rating Scale			Change from Baseline		Test of Change						
						From Baseline			From Last Time Point			
	N	Mean	SD	Mean	SD	DF	t	p	DF	t	p	
Baseline ^a	80	22.43	4.31	.	.	.	.	.	.	.	.	.
Day 1 after randomized infusion	80	16.76	7.23	-5.66	6.86	382	-7.47	<0.0001	.	.	.	.
Week1	72	15.51	6.98	-6.93	7.03	382	-8.35	<0.0001	382	1.17	0.2428	
Week2	70	14.63	6.80	-7.86	6.94	382	-9.46	<0.0001	382	1.20	0.2320	
Week3	66	14.30	6.64	-7.92	6.79	382	-9.42	<0.0001	382	0.14	0.8873	
Week4	60	14.00	6.76	-8.25	7.52	382	-9.64	<0.0001	382	0.49	0.6277	
Week5	61	13.74	7.63	-8.64	7.81	382	-10.09	<0.0001	382	0.38	0.7008	
Week6	59	13.97	7.43	-8.58	7.37	382	-9.94	<0.0001	382	-0.05	0.9597	

^a Baseline is within 24 hours before infusion.

TABLE S4. Infusion-Related Cardiorespiratory Effects in Patients With Major Depressive Disorder and Clinically Significant Suicidal Ideation Given a Single Infusion of Ketamine or Midazolam^a

Variable	Midazolam N=40 Mean (SD)	Ketamine N=40 Mean (SD)	Open Ketamine N=34 Mean (SD)
Baseline systolic blood pressure (SBP)^b	120 (9.8)	120 (10.6)	120 (21.5)
Baseline diastolic blood pressure (DBP)	74 (7.0)	74 (9.1)	75 (7.2)
Peak SBP	124 (11.9)	135 (13.7)	140 (16.1)
Peak DBP	78 (7.5)	88 (9.9)	92 (10.1)
Minutes to return to baseline BP^c	0 (0)	5.3 (9.0)	5.7 (7.7)
Baseline oxygen saturation	98 (1.5)	98 (0.96)	98 (1.2)
Lowest oxygen saturation^d	96 (2.3)	97 (1.8)	97 (1.5)
Baseline respiratory rate	15 (3.3)	16 (4.0)	15 (3.9)
Lowest respiratory rate^d	12 (2.9)	11 (1.8)	11 (2.3)

^a Vital signs were measured every five minutes during treatment with ketamine 0.5 mg/kg or midazolam 0.02 mg/kg in 100 ml normal saline infused over 40 minutes, adjunctive to current, nonbenzodiazepine medications.

^b Blood pressure in millimeters mercury (mm Hg).

^c Return to baseline blood pressure was operationalized as DBP within 10mm Hg of baseline or DBP<85.

^d Midazolam was associated with a Mean=1.60 (SD=1.96) point decrease in oxygen saturation from baseline versus a 0.90 (SD=1.22) point decrease with ketamine (t=1.92, df=78, p=0.0584). Ketamine was associated with a decrease in respiratory rate of Mean=4.98 (SD=4.08) breaths per minute compared with 3.25 (SD=3.48) for midazolam (t=-2.04, df=78, p=0.0452).

TABLE S5. Systematic Assessment for Treatment Emergent Events–General Inquiry (SAFTEE) Ratings in a Study of Ketamine vs. Midazolam in Patients With Major Depression and Clinically Significant Suicidal Ideation^a

	Ketamine (N=40) N (%)			Midazolam (N=40) N (%)		
	Baseline	Immediate postinfusion	Day 1	Baseline	Immediate postinfusion	Day 1
SEVERITY OF EVENTS^b						
Patients with any severe event	2 (5)	3 (8)	0	1 (3)	1 (3)	0
Patients with any moderate event	3 (8)	6 (15)	3 (8)	8 (20)	6 (15)	3 (8)
Patients with any mild event	6 (15)	14 (35)	8 (20)	7 (18)	25 (63)	10 (25)
Patients with any event	11 (28)	21 (53)	10 (25)	15 (38)	32 (80)	12 (30)
TYPE OF EVENT						
Numbness		6 (15)			1 (3)	
Perceptual problems		5 (13)	2 (5)	1 (3)		1 (3)
Dizziness/faintness		5 (13)	1 (3)			
Drowsiness		5 (13)			16 (40)	
Headache	3 (8)	2 (5)	1 (3)	8 (20)	5 (13)	3 (8)
Dry Mouth		2 (5)	1 (3)			
Nausea		2 (5)			1 (3)	
Cold sensation		1 (3)			4 (10)	
Vomiting		1 (3)				
Rapid heartbeat		1 (3)				
Difficulty swallowing		1 (3)				
Musculoskeletal pain	4 (10)		3 (8)	2 (5)		2 (5)
Fatigue	3 (8)		2 (5)	2 (5)	11 (28)	2 (5)
Constipation	3 (8)		1 (3)			
Anxiety			1 (3)			
Memory problems			1 (3)			
Loss of consciousness					1 (3)	
Diarrhea	1 (3)			1 (3)		2 (5)
Stomach/abdominal discomfort				2 (5)		1 (3)
Irritability						1 (3)
Interrupted sleep						1 (3)
Tinnitus	1 (3)					
Concentration difficulty	1 (3)					
Sore throat	1 (3)					
Skin irritation				1 (3)		
Appetite increase				1 (3)		
Edema				1 (3)		

^a Comparisons between treatment groups: frequency of all events immediately postinfusion (U=615.50, p=0.0508) and on Day 1 (U=768.00, p=0.6932); severity of events immediately postinfusion (U=645.00, p=0.1162) and on Day 1 (U=771.00, p=0.7216).

^b Patients who experienced multiple events with varying severity are counted in more than one severity category.

TABLE S6. Serious Adverse Events Requiring Institutional Review Board Report

Randomized Group	Responder ^a	Remitter ^b	Open Infusion	Open infusion response	Timepoint of event	Brief Description
Midazolam	No	No	Yes	Remitter	Month 4	Zolpidem misuse without suicidal intent
Ketamine	Yes	No	No		Week 7 and Month 6	Medical illness unrelated to study
Midazolam	Yes	Yes	No		Month 6	Inpatient admission for increased suicidal ideation
Ketamine	Yes	No	No		Week 6	Inpatient admission for increased suicidal ideation
Ketamine	No	No	No		Month 5	Overdose resulting in inpatient admission
Midazolam	Yes	No	Yes	Remitter	Before study procedures	Overdose, discussed with therapist, did not lead to inpatient admission
Ketamine	Yes	No	No		Month 7	Overdose resulting in inpatient admission
Midazolam	No	No	Yes	Nonresponder	Month 4	Inpatient admission for increased suicidal ideation
Ketamine	Yes	Yes	No		Week 2	Overdose

^a Response=Day 1 Scale for Suicidal Ideation score \geq 50% lower than baseline.

^b Remission=Day 1 Scale for Suicidal Ideation score \geq 50% lower than baseline and $<$ 4.