Mortality associated with lithium and valproate treatment of US Veterans Health Administration patients with mental disorders

Eric G. Smith, Karen L. Austin, Hyungjin Myra Kim, Susan V. Eisen, Amy M. Kilbourne, Donald R. Miller, Kara Zivin, Claire Hannemann, Brian C. Sauer and Marcia Valenstein

Background
The mood stabilisers lithium and valproate might plausibly have differing associations with mortality because of differing effects on mental health and various physiological indicators.

Aims
To assess associations between lithium, valproate and non-suicide mortality.

Method
Intention-to-treat, propensity score-matched cohort study.

Results
Lithium was associated with significantly reduced non-suicide mortality in the intent-to-treat cohort over 0–90 days (hazard ratio (HR) = 0.67, 95% CI 0.51–0.87) but not longer. In secondary analyses, a sizeable reduction in mortality was observed during active treatment with lithium across all time periods studied (for example 365-day HR = 0.62, 95% CI 0.45–0.84), but significantly increased risks were observed among patients discontinuing lithium by 180 days (HR = 1.54, 95% CI 1.01–2.37).

Conclusions
Patients initiating lithium had lower non-suicide mortality over 0–90 days than patients initiating valproate and consistently lower non-suicide mortality among patients maintaining treatment, but elevated risk among patients discontinuing treatment by 180 days. Although residual confounding or selection effects cannot be excluded, this study suggests potential benefits to enhancing lithium treatment persistence and the monitoring of patients discontinuing lithium. There is a need for further research.

Declaration of interest
None.

Copyright and usage
© The Royal College of Psychiatrists 2015.

Method

Data sources
Demographic characteristics, in-patient and out-patient mental and non-mental health treatment records, and out-patient pharmacy prescription data were obtained from the VHA National Psychosis and Depression Registries. These registries are linked, de-identified healthcare databases of all VHA patients nationwide since 1997 with at least one psychotic or depressive disorder diagnosis. This study was approved by the Institutional Review Boards of the Bedford and Ann Arbor Veterans Affairs Medical Centers.

Study cohort
Incident users (≥ 6 months of no lithium or valproate use but with recent VHA utilisation) receiving at least one out-patient prescription for lithium or valproate from April 1999 to December 2008 were identified (online Fig. DS1). A broad cohort of patients with mood or psychotic diagnoses in the 30 days prior to medication initiation was examined since the limited prior literature concerning lithium and mortality is not restricted to bipolar disorder (online supplement DS1).

Patients with possible non-psychiatric indications for valproate or lithium (epilepsy, migraine or cluster headache, or neuropathy diagnoses in the past 30 days; dementia medication use in the past 180 days; cancer, dementia, skull fracture diagnosis, traumatic brain injury diagnosis or treatment, home care, or hospice care in the past year; or any nursing home residence or

Although a substantial literature exists concerning the potential association of lithium with reduced suicide mortality, very few studies have examined lithium's potential influence on non-suicide mortality. Many organ systems are exposed to lithium, and lithium produces diverse physiological effects. Some of these effects are potentially beneficial (for example leukocytosis, reduced heart rate and neurogenesis), whereas others are potentially hazardous (for example renal and thyroid insufficiency, QTc prolongation or arrhythmias). A limited number of studies, primarily but not exclusively, have examined associations between lithium treatment and non-suicide mortality. These studies are consistent with the possibility that lithium might reduce mortality risk in psychiatric patients. Determining the effects on non-suicide mortality of lithium or other psychiatric treatments is clearly important, especially since patients with serious mental illness are at particular risk for premature mortality.

We conducted a nationwide cohort study of the US Veterans Health Administration's (VHA) detailed clinical databases, employing two methods intended to increase the likelihood that observational studies will yield results similar to randomised trials: high-dimensional propensity score (hdPS) matching and intention-to-treat estimates. The hdPS matching permit inclusion of particularly detailed information concerning potential confounding while facilitating the assessment of the balance in these potential confounders that is achieved between treatment groups. Intent-to-treat estimates enhance interpretation of results by allowing assessment of whether benefits during active treatment are negated by risks upon discontinuation. Employing these approaches, we investigated whether initiation of lithium was associated with reduced non-suicide mortality compared with initiation of valproate, a treatment that has largely replaced lithium in many countries.
in-patient rehabilitation in the past 2 years) were excluded. Patients were also excluded if they initiated lithium or valproate on an ‘as needed’ basis or both medications simultaneously, or resided outside the USA.

**Exposure determination**

Receipt of lithium or valproate was defined by a patient filling an out-patient prescription for these medications. For the intent-to-treat analysis, all patients filling an initial out-patient prescription were followed until the end of the follow-up (i.e. 90, 180 or 365 days) or death. Secondary analyses stratified follow-up time by whether patients were still receiving initial treatment. Patients were considered ‘as-initially treated’ until a ≥15-day gap occurred between out-patient prescriptions (adjusting for early refills) or upon initiation of the other mood stabiliser (i.e. lithium or valproate). ‘Former users’ consisted of patients after initial treatment discontinuation until follow-up time was censored upon treatment resumption, treatment switching (for example patients receiving valproate as initial treatment who switch to lithium), death or the end of follow-up.

We will use the term ‘former users’ to designate patients within the period of time during which they have stopped their initial treatment and were not exposed to either lithium or valproate. (‘Former user’ exposure time was censored if the patient resumed either medication.) Given that this ‘former user’ follow-up period is free from exposure to either medication studied, former users have been advanced as a potential index of residual baseline confounding and/or selection occurring during treatment.31,32 However, risks among former users can be more fully conceptualised as representing the sum total of effects of residual confounding and selection along with any persistence of effects from active treatment, and any risks produced upon treatment discontinuation (online supplement DS2). This last category of ‘discontinuation-associated risks’ would include effects such as rebound mania or depression.

**Outcome**

Date and cause of death was obtained from National Death Index files for 1999–2009.33 This study was limited to non-suicide mortality, with follow-up time for patients dying of suicide censored at suicide death.

**Propensity score modelling**

In total, 948 covariates derived from VHA databases were included in an initial propensity score model generally following the hdPS approach14,15 (online supplement DS3). These covariates included potential risk factors for both non-suicide and suicide mortality86 (including demographic characteristics, diagnoses, general VHA mental and non-mental health services utilisation,24 admissions to hospital, clinic use, occurrence of diagnostic testing, current and recent prescriptions, recent injuries and diagnosed suicide attempts, and state-level and VHA-hospital subsystem mortality risk21) (online Table DS1 and online supplement DS4), often with multiple indicator variables to allow for non-linear covariate–mortality relationships. An ‘outcome-focused’ propensity score was then derived limiting covariates to the 523 covariates with substantial associations with outcome88 (i.e. ≥20% change in non-suicide mortality).89 Further details of how this covariate restriction was implemented are provided in online supplement DS4. This outcome-focused propensity score, intended to limit unintended amplification of confounding that remained uncontrolled,89,90,91 provided the basis for the results reported here. Results from analyses using the initial propensity score are provided in online supplement DS5. The results from the two models are generally similar but differ in a few important details, such as the time periods for which significant associations are detected.

**Statistical methods**

The propensity score was calculated using logistic regression. Patients initiating lithium and valproate were 1:1-matched (online supplement DS6) using callipers of 0.2 standard deviations of the propensity score logit42,43 resulting in 99.3% matching of lithium-initiated patients. Balance in covariates between treatment groups was assessed using standardised differences (equivalent to Cohen’s d effect sizes, with a difference of >0.10 indicating significant imbalance).44

Statistical significance was determined using techniques that reflected matching (stratified Cox regression with sandwich variance estimators) for the primary intent-to-treat analyses and the secondary as-treated analyses. Ordinary Cox regression was used for the secondary former user analysis (since matching was not preserved for this analysis). All analyses except standardised differences were performed using SAS, version 9.3. Standardised differences were calculated using Microsoft Excel 2010.

**Results**

The incident user cohort of 93 162 patients initiating lithium or valproate was generally balanced (i.e. standardised differences between the treatment groups <0.10)44 in virtually all non-mental health and mental health covariates studied, even prior to matching. After matching, substantial additional balance was achieved between treatment groups (n = 21 288 patients per group). As an end result, hdPS matching achieved a very close balance (standardised differences <0.019) for each one of the 523 covariates included in the outcome-focused analysis. Table 1 and 2 indicate the standardised differences in the matched cohort for two categories of covariates: (a) those few variables with a substantial imbalance (≥0.10 standardised difference) between treatment groups initially (8 of 523 covariates, or 1.5%, Table 1), and (b) a number of additional covariates with well-established or highly plausible relationships with non-suicide mortality (Table 2). These additional covariates include age, disability status, recent number and types of hospital admissions, diagnoses, medications, and attendance at certain out-patient clinics. Comparison of the unmatched and hdPS-matched treatment effect estimates indicate that hdPS-matching reduced effect sizes in a direction consistent with reducing baseline confounding biasing against valproate (i.e. reducing differences that placed patients initiating valproate at higher intrinsic risk of non-suicide mortality) (online supplement DS7).

It should be noted that the gender ratio of our sample (Table 1) differs substantially from that found for bipolar disorder in the general population because our sample is a Veteran sample, primarily made up of men. It is particularly important to note that the hdPS-matching procedure did not substantially change the prevalence of male or female gender in the final study cohort compared with the initial sample, or the prevalence of any of the other included covariates. Rather, the matching procedure led to the selection of a set of patients initiating valproate who were very similar to those initiating lithium. For instance, in the original study cohort prior to matching 13.9% of patients initiating lithium and 9.4% of patients initiating valproate were women. In the final cohort, 13.8% of patients initiating lithium and 13.9% of patients initiating valproate were women.

Impersistence with treatment was very common even within 180 days, but rates of treatment impersistence were highly similar between the treatment groups: approximately 76.5% of patients
Mortality associated with lithium and valproate treatment

initiating lithium and 76.1% of patients initiating valproate did not persist with initial treatment for 180 days (online Table DS4). Overall survival was greater among patients initiating lithium, with 274 deaths over 365 days observed among the lithium intent-to-treat cohort, compared with 296 deaths among the valproate intent-to-treat cohort. Greater differences (71 v. 101 deaths, respectively) were observed between the as-initially treated cohorts. Survival curves for the intent-to-treat and as-initially treated analyses are provided in Fig. 1.

Table 3 provides the primary, intent-to-treat analysis results, indicating that lithium was associated with substantially reduced mortality risks over 0–90 days (hazard ratio (HR) = 0.67, 95% CI 0.51–0.87), the period of greatest medication persistence, but not 0–180 days (HR = 0.97, 95% CI 0.82–1.15) or 0–365 days (HR = 0.92, 95% CI 0.82–1.04).

Secondary analyses by treatment status (Table 4) reveal large and significant associations with non-suicide mortality during active lithium treatment compared with valproate treatment over all time periods. Hazard ratios were consistently and considerably lower during the period of likely active use of lithium compared with likely active use of valproate (as-initially treated hazard ratios ranging from HR = 0.59, 95% CI 0.42–0.82 to HR = 0.62, 95% CI 0.45–0.84). However, significantly increased non-suicide mortality was also observed among lithium former users over 0–180 days (HR = 1.54, 95% CI 1.01–2.37), although not other time periods.

Table 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Lithium, n (%) (n = 21,288)</th>
<th>Valproate n (%) (n = 21,288)</th>
<th>Standardised difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender, femalea</td>
<td>2932 (13.8)</td>
<td>2952 (13.9)</td>
<td>–0.003</td>
</tr>
<tr>
<td>Bipolar I disorder, past 30 days</td>
<td>9630 (45.2)</td>
<td>9719 (45.7)</td>
<td>–0.008</td>
</tr>
<tr>
<td>Other psychosis, past 30 days</td>
<td>251 (1.2)</td>
<td>261 (1.2)</td>
<td>–0.004</td>
</tr>
<tr>
<td>Post-traumatic stress disorder, past year</td>
<td>4858 (22.8)</td>
<td>4849 (22.8)</td>
<td>0.001</td>
</tr>
<tr>
<td>Other mood stabiliser(s), current</td>
<td>2963 (13.9)</td>
<td>2894 (13.6)</td>
<td>0.006</td>
</tr>
<tr>
<td>Prior mood stabiliser treatment</td>
<td>7573 (35.6)</td>
<td>7473 (35.1)</td>
<td>0.010</td>
</tr>
<tr>
<td>Mild liver disease, past year</td>
<td>1795 (8.4)</td>
<td>1708 (8.0)</td>
<td>0.015</td>
</tr>
<tr>
<td>Angiotensin converting enzyme inhibitor, current</td>
<td>2772 (13.0)</td>
<td>2765 (13.0)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

a. See text for a discussion of the gender imbalance.

Table 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Lithium, n (%) (n = 21,288)</th>
<th>Valproate n (%) (n = 21,288)</th>
<th>Standardised difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yearsa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65–79</td>
<td>1358 (6.4)</td>
<td>1359 (6.4)</td>
<td>0.000</td>
</tr>
<tr>
<td>80+</td>
<td>164 (0.8)</td>
<td>154 (0.7)</td>
<td>0.005</td>
</tr>
<tr>
<td>Married</td>
<td>7455 (35.0)</td>
<td>7370 (34.6)</td>
<td>0.008</td>
</tr>
<tr>
<td>Disability (51–100%)</td>
<td>5473 (25.7)</td>
<td>5481 (25.7)</td>
<td>–0.001</td>
</tr>
<tr>
<td>Charlson Comorbidity index, past year: 1+</td>
<td>7601 (35.7)</td>
<td>7468 (35.1)</td>
<td>0.013</td>
</tr>
<tr>
<td>Myocardial infarction, past year</td>
<td>235 (1.1)</td>
<td>243 (1.1)</td>
<td>–0.004</td>
</tr>
<tr>
<td>Diabetes (uncontrolled), past year</td>
<td>2722 (12.8)</td>
<td>2691 (12.6)</td>
<td>0.004</td>
</tr>
<tr>
<td>Arrhythmia, past year</td>
<td>860 (4.0)</td>
<td>856 (4.0)</td>
<td>0.001</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease, past year</td>
<td>2968 (13.9)</td>
<td>2934 (13.8)</td>
<td>0.005</td>
</tr>
<tr>
<td>Total non-psychiatric medications, current: 5+</td>
<td>5670 (26.6)</td>
<td>5589 (26.3)</td>
<td>0.009</td>
</tr>
<tr>
<td>Beta-blockers, current</td>
<td>2757 (13.0)</td>
<td>2713 (12.7)</td>
<td>0.006</td>
</tr>
<tr>
<td>Opioid pain medication, current</td>
<td>2409 (11.3)</td>
<td>2374 (11.2)</td>
<td>0.005</td>
</tr>
<tr>
<td>Antiplatelet agent, current</td>
<td>221 (1.0)</td>
<td>218 (1.0)</td>
<td>0.001</td>
</tr>
<tr>
<td>Warfarin, current</td>
<td>200 (0.9)</td>
<td>187 (0.9)</td>
<td>0.006</td>
</tr>
<tr>
<td>Non-psychiatric admissions to hospital, past year: 1+</td>
<td>1842 (8.7)</td>
<td>1781 (8.4)</td>
<td>0.010</td>
</tr>
<tr>
<td>Latest discharge from medical intensive care unit</td>
<td>330 (1.6)</td>
<td>323 (1.5)</td>
<td>0.003</td>
</tr>
<tr>
<td>Latest discharge from neurology</td>
<td>54 (0.3)</td>
<td>54 (0.3)</td>
<td>0.000</td>
</tr>
<tr>
<td>Non-psychiatric discharge, against medical advice, past year</td>
<td>207 (1.0)</td>
<td>203 (1.0)</td>
<td>0.002</td>
</tr>
<tr>
<td>General surgery, past 180 days: 1+</td>
<td>705 (3.3)</td>
<td>697 (3.3)</td>
<td>0.002</td>
</tr>
<tr>
<td>Non-psychiatric visits, past 7 days: 1+</td>
<td>4479 (21.0)</td>
<td>4426 (20.8)</td>
<td>0.006</td>
</tr>
<tr>
<td>Specialty visits, past 180 days: 1+</td>
<td>3720 (17.5)</td>
<td>3619 (17.0)</td>
<td>0.013</td>
</tr>
<tr>
<td>Cardiology clinic, past 180 days: 1+</td>
<td>594 (2.8)</td>
<td>599 (2.8)</td>
<td>–0.001</td>
</tr>
<tr>
<td>Pain clinic, past 180 days: 1+</td>
<td>447 (2.1)</td>
<td>467 (2.2)</td>
<td>–0.006</td>
</tr>
<tr>
<td>Chaplain service, past 180 days: 1+</td>
<td>547 (2.6)</td>
<td>540 (2.5)</td>
<td>0.002</td>
</tr>
<tr>
<td>Nuclear medicine, past year: 1+</td>
<td>837 (3.9)</td>
<td>812 (3.8)</td>
<td>0.006</td>
</tr>
<tr>
<td>Alcohol dependence</td>
<td>4440 (20.9)</td>
<td>4449 (20.9)</td>
<td>–0.001</td>
</tr>
<tr>
<td>Heroin/opiate dependence</td>
<td>824 (3.9)</td>
<td>810 (3.8)</td>
<td>0.003</td>
</tr>
</tbody>
</table>

a. Age is presented in this format (65–79 years old and 80+ years old) because these were the age groups with highest mortality. Age was actually modelled using 11 indicator variables reflecting age groups from <35, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79 and 80+ years old.
During subsequent non-exposure (former users) Smith et al

4.36–1.01) associations among as-initially treated individuals. Borderline significant (cardiovascular disease, HR = 0.60, 95% CI

significant (all other causes, HR = 0.50, 95% CI 0.28–0.91) or examination, these categories were also the only categories to have vascular disease and deaths from all other causes. Upon further associations the closest to statistical significance, were cardio-
simple chance fluctuations. The mortality categories with above or below the null for each cause of death, possibly represent death at 365 days. Therefore, the observed hazard ratios, modestly existed between treatment and specific categories of causes of death at 365 days. Therefore, the observed hazard ratios, modestly above or below the null for each cause of death, possibly represent simple chance fluctuations. The mortality categories with associations the closest to statistical significance, were cardiovascular disease and deaths from all other causes. Upon further examination, these categories were also the only categories to have significant (all other causes, HR = 0.50, 95% CI 0.28–0.91) or borderline significant (cardiovascular disease, HR = 0.60, 95% CI 0.36–1.01) associations among as-initially treated individuals.

Discussion

Main findings

In a nationwide cohort study of 42,576 VHA psychiatric patients initiating lithium and valproate, significant intent-to-treat associations of lithium initiation with lower mortality risk were observed over 0–90 days but not over 0–180 days or 0–365 days. In contrast, secondary analysis of patients who persisted with treatment, indicated strong associations with reduced mortality for lithium, compared with valproate, treatment across all time periods. However, the reduction in the intent-to-treat association from 0–90 to 0–180 days is very rapid, and our secondary analysis indicates significantly increased mortality risk associated with discontinuing lithium, compared with valproate, over 0–180 days of treatment. Both findings suggest a possible increase in mortality risk associated with lithium, compared with valproate, among patients who discontinue the medication (online supplement DS8). These findings, combined with the possibility that at least some level of confounding (most likely biasing towards worse outcomes in patients initiating valproate) may remain in our analyses, prevent firm conclusions concerning whether the initiation of lithium is associated with a net mortality benefit or harm. Regardless of this uncertainty, however, one clear and important clinical recommendation results from this mortality study: once lithium is initiated, persistence with lithium treatment should be monitored and, if clinically reasonable, maintained.

Confounding

Risks associated with lithium discontinuation could, in theory, potentially limit, eliminate, or even exceed mortality benefits associated from active lithium treatment when compared with valproate. Determining whether this occurs is difficult even though the intent-to-treat estimates significantly favour lithium treatment from 0–90 days and numerically, although not significantly, favour lithium treatment over longer time periods. Although intent-to-treat estimates are intended to reflect the balance of benefits and harms among all patients, regardless of whether continuing on or discontinuing treatment, even relatively small amounts of confounding biasing against valproate could alter risk–benefit judgements. Propensity score matching can achieve very close balance on measured factors (and did so here), however, factors that are either incompletely modelled or unmeasured in the analysis are intrinsically not able to be balanced by propensity score methods. Such factors might include provider tendencies to prescribe valproate to individuals who are more severely ill within the categories of illness that are balanced through the propensity score matching. Thus, not only does random error (as indicated by the lack of statistical significance) limit interpretation of the intent-to-treat hazard ratios after 90 days, but so does possible residual confounding (online supplements DS8 and DS9).

Although our hdPS successfully achieved close balance on a large variety of important potential confounders, some degree of periods. However, the reduction in the intent-to-treat association from 0–90 to 0–180 days is very rapid, and our secondary analysis indicates significantly increased mortality risk associated with discontinuing lithium, compared with valproate, over 0–180 days of treatment. Both findings suggest a possible increase in mortality risk associated with lithium, compared with valproate, among patients who discontinue the medication (online supplement DS8). These findings, combined with the possibility that at least some level of confounding (most likely biasing towards worse outcomes in patients initiating valproate) may remain in our analyses, prevent firm conclusions concerning whether the initiation of lithium is associated with a net mortality benefit or harm. Regardless of this uncertainty, however, one clear and important clinical recommendation results from this mortality study: once lithium is initiated, persistence with lithium treatment should be monitored and, if clinically reasonable, maintained.

Confounding

Risks associated with lithium discontinuation could, in theory, potentially limit, eliminate, or even exceed mortality benefits associated from active lithium treatment when compared with valproate. Determining whether this occurs is difficult even though the intent-to-treat estimates significantly favour lithium treatment from 0–90 days and numerically, although not significantly, favour lithium treatment over longer time periods. Although intent-to-treat estimates are intended to reflect the balance of benefits and harms among all patients, regardless of whether continuing on or discontinuing treatment, even relatively small amounts of confounding biasing against valproate could alter risk–benefit judgements. Propensity score matching can achieve very close balance on measured factors (and did so here), however, factors that are either incompletely modelled or unmeasured in the analysis are intrinsically not able to be balanced by propensity score methods. Such factors might include provider tendencies to prescribe valproate to individuals who are more severely ill within the categories of illness that are balanced through the propensity score matching. Thus, not only does random error (as indicated by the lack of statistical significance) limit interpretation of the intent-to-treat hazard ratios after 90 days, but so does possible residual confounding (online supplements DS8 and DS9).

Although our hdPS successfully achieved close balance on a large variety of important potential confounders, some degree of
remaining confounding is plausible. Risk estimates indicating greater mortality risk among patients initiating valproate in the unmatched sample (online supplement DS7) become less pronounced after hdPS-matching, suggesting overall confounding initially biases against valproate. Also, the former-user hazard ratio for patients initiating, then stopping, lithium over 0–90 days compared with patients initiating, and then stopping, valproate, is <1.0 (although random error cannot be excluded). (‘former users’ are those patients no longer receiving either mood stabiliser, thus, this ‘former user’ period represents time not exposed to either lithium or valproate). This observation is consistent with the possibility that, if residual confounding does exist to at least some degree, then patients initiated on lithium were likely at lower baseline mortality risk on average than patients initiated on valproate. Finally, even though significantly increased mortality risk is observed among lithium former users from 0 to 180 days, the possibility of some confounding against valproate persisting throughout the analysis is suggested by the subsequent sharp decrease in former user risks from 0–180 to 0–365 days (central estimate HR = 1.54 changing to HR = 1.02) (online supplement DS8). Although, again, random error cannot be excluded, if any confounding does generally bias against valproate, this suggests that the mortality risk associated with patients who discontinued lithium over 0–180 days compared with patients who discontinued valproate may be even greater than indicated.

Nevertheless, even if confounding biasing against valproate exists, the effect estimates for active lithium treatment compared with active valproate treatment are of such size (central estimate HR = 0.59–0.62) as to command attention. Such as-initially treated estimates are often the only type of effect estimate typically provided in non-randomised treatment studies. In this study, these ‘as-initially treated’ estimates may provide only part of the important information to consider, given the possibilities of confounding and discontinuation-associated risks. Nevertheless, even if some level of confounding persists after matching, it is unclear whether such confounding persists to such an extent to fully account for the significant intent-to-treat association observed early during follow-up, or as-initially treated associations observed throughout follow-up. This becomes a question for further research. Not focused upon here, but also a potential contributor to the secondary analysis results is differential selection of patients, once they have initiated treatment, to stop one medication (e.g. lithium) compared with the other medication (e.g. valproate). Such differential selection could occur from either providers or patients relying on different reasons when deciding to discontinue their initial treatment, depending on whether that initial treatment was lithium or valproate. This possibility is consistent with some, but not all, of the study findings (online supplement DS10).

### Importance of treatment persistence

Regardless of these uncertainties, one clear clinical recommendation can be made: once initiated, persistence with lithium treatment should be monitored and, if clinically indicated, maintained.

### Findings from other studies

Our results are generally consistent with a limited prior literature. A clinical trial meta-analysis of both placebo and comparator-controlled trials reported significant reductions in overall mortality with lithium treatment (HR = 0.42, 95% CI 0.27–0.81); however, restriction to non-suicide mortality from active comparator trials results in the findings being informed by just 4 deaths among lithium recipients and 12 deaths among comparator recipients (see Cipriani et al Figures 2 and 420). Non-randomised studies of lithium’s effects on non-suicide mortality are few but generally indicate reduced risks with active lithium treatment, although they typically lack active comparators, intent-to-treat designs or detailed controls for potential confounding.12–19 Our study is, to our knowledge, the first non-randomised study to examine non-suicide mortality risks associated with lithium discontinuation in a study with an active comparator, but is consistent in a general sense with limited prior uncontrolled studies. These studies observed that lithium discontinuation is a high-risk period for overall mortality.15,46 Our study’s findings potentially may also be broadly consistent with prior randomised47 and non-randomised48,49 literature indicating that lithium discontinuation substantially increases the risk of mood episodes. These risks for mood-episode recurrence were sufficiently pronounced that one author reviewing these studies even recommended that lithium not be initiated unless a patient was likely to complete 2 years of continuous treatment.48 Finally, our conclusions concerning the importance of persistence with lithium treatment are generally consistent with multiple prior studies reporting substantial lithium treatment impersistence.51–57

### Future directions

In our judgement, this study clearly establishes high-priority clinical and research agendas. The data from this study clearly suggests a need for clinical systems and providers to encourage patients to continue with their lithium treatment once it is initiated. A limited literature exists concerning psychosocial interventions that might help accomplish this task.58 In addition, two trials that have included group psychoeducation on the importance of medication treatment and/or adherence for successful management of bipolar disorder have shown superior outcomes to standard care.59,60 Our data also supports monitoring patients closely upon discontinuation when feasible, a practice already recommended in some guidelines to limit mood-episode recurrence.61 Finally, some approaches such as gradual discontinuation62 have been proposed to limit the adverse psychiatric effects of lithium discontinuation.

From a research perspective, this study establishes a need for further non-randomised studies to elucidate the balance of risks and harms associated with lithium initiation. This might include evaluating cohorts with different demographics, treatment persistence rates, or psychiatric or non-psychiatric comorbidities. If additional methodological innovations could be combined with the approaches used here, further reductions in confounding or selection during treatment might result. For instance, if valid instrumental variables can be identified, these might reduce

---

**Table 5**

<table>
<thead>
<tr>
<th>Cause of death</th>
<th>Deaths, n</th>
<th>Intent-to-treat hazard ratio (lithium/valproate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiovascular</td>
<td>171</td>
<td>0.86 (0.70–1.06)</td>
</tr>
<tr>
<td>Injury</td>
<td>105</td>
<td>0.94 (0.72–1.24)</td>
</tr>
<tr>
<td>Cancer</td>
<td>54</td>
<td>1.25 (0.85–1.83)</td>
</tr>
<tr>
<td>Stroke</td>
<td>21</td>
<td>1.20 (0.66–2.18)</td>
</tr>
<tr>
<td>All other causes</td>
<td>231</td>
<td>0.87 (0.71–1.09)</td>
</tr>
</tbody>
</table>
confounding from imperfectly measured or unmeasured factors. Marginal structural models might reduce the impact of differential selection during treatment, and allow the impact of additional treatments commenced during follow-up to be evaluated. Research consortiums have been recently developed to rapidly conduct research along such lines. Our findings suggest that the mortality effects of lithium and comparators should be a high-priority target for these consortiums. Such non-randomised research could also help determine the need for subsequent randomised trials, although the acceptability of such trials is uncertain. The need for additional, rapidly initiated research arises from the obvious health relevance of even small differences in non-suicide mortality between these commonly used medications.

Limitations

Study limitations include our lack of in-patient prescription information, lack of serum medication levels as an alternative method to assess persistence with treatment and the inherent inability to completely model potentially important covariates such as admissions to hospital (online supplement DS12). A few variables found to be important in past mortality studies (income and ethnicity) that are sometimes poorly measured in Veterans Affairs data were not included in the outcome-focused propensity score. Although available medical information was extensively represented, this information was only present for treatment received at the VHA. Although we employed multiple methods to attempt to balance the treatment groups in VHA medical utilisation (including indicators such as the presence and number of recent non-psychiatric medications, overall visits and specialist visits a patient received), this lack of outside healthcare data may be particularly relevant for patients receiving emergency care (which is more likely to occur at the nearest available hospital) or for older patients with Medicare. We also did not rebalance our treatment groups during follow-up for time-varying factors such as the use of other medications through methods such as marginal structural models, although the treatment groups were closely balanced on a very extensive set of psychiatric and non-psychiatric medications present at treatment initiation. Given that a very large majority of patients had stopped or modified their initial treatment by 365 days, we did not examine patient outcomes occurring over longer than 365 days in our primary analyses. A follow-up period of 1 year or even briefer is fairly standard for studies examining overall or cause-specific mortality in relation to psychiatric medication initiation, even in cohorts with greater medication adherence. Nevertheless, to the degree that either lithium or valproate is associated with health risks or benefits that accrue over > 1 year of treatment, the impact of these risks and benefits upon mortality will not be reflected in this study. As a pilot analysis, we extended the follow-up time we investigated from 0–365 days to 0–1095 days (3 years), and found this made minimal difference in the results (intention-to-treat HR = 0.93, 95% CI 0.87–1.00, P = 0.04, as-initiately treated HR = 0.64, 95% CI 0.48–0.87, P = 0.004), although the intent-to-treat findings were now significant at the 0.05 level. Very little of the additional intent-to-treat follow-up time, however, relates to patients still receiving initial treatment, and very little of the as-initiately treated follow-up time relates to treatment exposure after the first year of treatment.

Patients with several major mental health diagnoses were included to achieve sufficient power (for example depression, bipolar and psychotic diagnoses). Although the psychiatric diagnoses were each balanced closely between treatments by hdPS-matching, this may have introduced some heterogeneity in the associations between treatments and mortality. Suicide deaths, which some studies have reported as strongly influenced by lithium treatment and/or its discontinuation, may have been miscoded to some extent as accidents/injuries, resulting in an outcome not completely specific for non-suicide mortality. Studies of overall mortality have also been criticised in general for their lack of specificity. However, an overall non-suicide mortality focus for this study appears appropriate, given that lithium and valproate affect so many organ systems that a priori cause-specific hypotheses are difficult.

One potential limitation that can affect some non-randomised cohort studies are biases arising from inclusion of patients either in the midst of treatment (‘prevalent users’) or who have been exposed to either study agent in the past (‘past users’) (online supplement DS13). We sought to minimise these potential biases through an ‘incident first-user design’, whereby we only examined patients during their first use of either lithium or valproate after achievement of a 6 month or longer ‘clean period’ of no exposure. However, a small, extremely similar fraction of patients in each treatment group did have record of past (but not recent exposure) to lithium or valproate (12.0% vs 11.9%, respectively). Excluding these individuals produced little change to the effect estimates (365-day intention-to-treat HR = 0.89, 95% CI 0.82–1.03, P = 0.11; 365-day as-treated HR = 0.66, 95% CI 0.46–0.95, P = 0.02). Unfortunately, it is not possible to similarly control for the possibility that some uncertain number of patients may have received one of these medications prior to 1999 (when VHA medication dispensing began to be electronically recorded), or received either medication from outside sources (either recently or in the past). To reduce the concern about recent outside use of lithium or valproate, we only included the patients that we judged were particularly unlikely to have unrecorded outside use by requiring all patients to have more than a year of prior VHA system use. In addition, almost all patients (approximately 95%) had already been using VHA pharmacy services as well.

The rates of treatment impersistence among patients initiating lithium and valproate were quite high (median time to discontinuation of initial treatment approximately 90 days). Possible reasons for this high rate of treatment impersistence may relate to the high rates of psychiatric comorbidities (for example post-traumatic stress disorder), substance use disorders and homelessness in our Veteran sample compared with other patient samples. However, the treatment impersistence rates appear to be consistent with those observed in the only other incident cohort from a broad sample of US patients that we were able to identify. Johnson & McFarland reported a median time to discontinuation of the first episode of treatment with lithium of only 72 days in a US Health Maintenance Organization sample. In contrast, findings from a non-US incident cohort (a nationwide sample from Denmark) indicated higher rates of persistence with lithium treatment (median time to discontinuation of 181 days). However, the authors note that their sample may have had less severe mental illness than many cohorts, since > 50% of the lithium prescriptions were apparently initiated by practitioners, not psychiatrists. Our findings suggests that the mortality effects of lithium and comparators should be a high-priority target for these consortiums. Such non-randomised research could also help determine the need for subsequent randomised trials, although the acceptability of such trials is uncertain. The need for additional, rapidly initiated research arises from the obvious health relevance of even small differences in non-suicide mortality between these commonly used medications. Although available medical information was extensively represented, this information was only present for treatment received at the VHA. Although we employed multiple methods to attempt to balance the treatment groups in VHA medical utilisation (including indicators such as the presence and number of recent non-psychiatric medications, overall visits and specialist visits a patient received), this lack of outside healthcare data may be particularly relevant for patients receiving emergency care (which is more likely to occur at the nearest available hospital) or for older patients with Medicare. We also did not rebalance our treatment groups during follow-up for time-varying factors such as the use of other medications through methods such as marginal structural models, although the treatment groups were closely balanced on a very extensive set of psychiatric and non-psychiatric medications present at treatment initiation. Given that a very large majority of patients had stopped or modified their initial treatment by 365 days, we did not examine patient outcomes occurring over longer than 365 days in our primary analyses. A follow-up period of 1 year or even briefer is fairly standard for studies examining overall or cause-specific mortality in relation to psychiatric medication initiation, even in cohorts with greater medication adherence. Nevertheless, to the degree that either lithium or valproate is associated with health risks or benefits that accrue over > 1 year of treatment, the impact of these risks and benefits upon mortality will not be reflected in this study. As a pilot analysis, we extended the follow-up time we investigated from 0–365 days to 0–1095 days (3 years), and found this made minimal difference in the results (intention-to-treat HR = 0.93, 95% CI 0.87–1.00, P = 0.04, as-initiately treated HR = 0.64, 95% CI 0.48–0.87, P = 0.004), although the intent-to-treat findings were now significant at the 0.05 level. Very little of the additional intent-to-treat follow-up time, however, relates to patients still receiving initial treatment, and very little of the as-initiately treated follow-up time relates to treatment exposure after the first year of treatment.

Patients with several major mental health diagnoses were included to achieve sufficient power (for example depression, bipolar and psychotic diagnoses). Although the psychiatric diagnoses were each balanced closely between treatments by hdPS-matching, this may have introduced some heterogeneity in the associations between treatments and mortality. Suicide deaths, which some studies have reported as strongly influenced by lithium treatment and/or its discontinuation, may have been miscoded to some extent as accidents/injuries, resulting in an outcome not completely specific for non-suicide mortality. Studies of overall mortality have also been criticised in general for their lack of specificity. However, an overall non-suicide mortality focus for this study appears appropriate, given that lithium and valproate affect so many organ systems that a priori cause-specific hypotheses are difficult.

One potential limitation that can affect some non-randomised cohort studies are biases arising from inclusion of patients either in the midst of treatment (‘prevalent users’) or who have been exposed to either study agent in the past (‘past users’) (online supplement DS13). We sought to minimise these potential biases through an ‘incident first-user design’, whereby we only examined patients during their first use of either lithium or valproate after achievement of a 6 month or longer ‘clean period’ of no exposure. However, a small, extremely similar fraction of patients in each treatment group did have record of past (but not recent exposure) to lithium or valproate (12.0% vs 11.9%, respectively). Excluding these individuals produced little change to the effect estimates (365-day intention-to-treat HR = 0.89, 95% CI 0.82–1.03, P = 0.11; 365-day as-treated HR = 0.66, 95% CI 0.46–0.95, P = 0.02). Unfortunately, it is not possible to similarly control for the possibility that some uncertain number of patients may have received one of these medications prior to 1999 (when VHA medication dispensing began to be electronically recorded), or received either medication from outside sources (either recently or in the past). To reduce the concern about recent outside use of lithium or valproate, we only included the patients that we judged were particularly unlikely to have unrecorded outside use by requiring all patients to have more than a year of prior VHA system use. In addition, almost all patients (approximately 95%) had already been using VHA pharmacy services as well.

The rates of treatment impersistence among patients initiating lithium and valproate were quite high (median time to discontinuation of initial treatment approximately 90 days). Possible reasons for this high rate of treatment impersistence may relate to the high rates of psychiatric comorbidities (for example post-traumatic stress disorder), substance use disorders and homelessness in our Veteran sample compared with other patient samples. However, the treatment impersistence rates appear to be consistent with those observed in the only other incident cohort from a broad sample of US patients that we were able to identify. Johnson & McFarland reported a median time to discontinuation of the first episode of treatment with lithium of only 72 days in a US Health Maintenance Organization sample. In contrast, findings from a non-US incident cohort (a nationwide sample from Denmark) indicated higher rates of persistence with lithium treatment (median time to discontinuation of 181 days). However, the authors note that their sample may have had less severe mental illness than many cohorts, since > 50% of the lithium prescriptions were apparently initiated by practitioners, not psychiatrists.

Although methodological work in comparative effectiveness research has been steadily advancing, it has not been determined whether outcome-focused propensity scores should be favoured over larger propensity scores in all circumstances. Of note, the results given here for the outcome-focused model and in online supplement DS5 for the initial model are generally consistent in many aspects. These aspects include a significant intent-to-treat difference between lithium and valproate at 90 days and substantial effect sizes for as-treated and former users that are almost uniformly consistent in direction of effects, although not always identical in significance. There are a number of reasons, both
Theoretical and specifically from the data itself, that suggest the outcome-focused approach, designed to limit unintended amplification of confounding, is likely less biased and more valid (online supplement DS5). However, because these methods are still being refined, a definite conclusion cannot be reached.

Our study examines a US Veteran sample, so its generalisability to non-Veteran samples is uncertain. For instance, 86% of our sample is male. To the extent that the association of lithium or valproate might be modified by a patient’s gender, the results here might differ from those observed in patient samples with a more typical gender distribution. Investigating such a possibility, however, will likely require even larger patient samples than examined here). Perhaps less obviously, intent-to-treat estimates (essential for developing a full view of the possible risks and benefits of treatment) produce potential limitations to generalisability. For intent-to-treat estimates to likely generalise to other patient samples, that patient sample would need to also exhibit a similar rate of treatment persistence. If active lithium treatment does have a genuine association with lower mortality risks, however, then cohorts with greater treatment persistence than the patients studied here would generally be expected to show greater benefits. Nevertheless, given that residual confounding appears to bias in the direction of patients being initiated on lithium being at some degree of lower mortality risk, the significant risks observed after lithium discontinuation over 0–180 days (albeit time-limited, in that they are no longer significant over 0–365 days) are actually the mortality findings least likely to be attributable to baseline confounding.

Indirect v. direct effects of lithium on mortality

Whether any non-suicide mortality differences between lithium and valproate are primarily as a result of their direct psychiatric effects (stabilising mood and/or destabilising mood on discontinuation), indirect effects on physical health (for example mood stability possibly leading to better adherence to medical treatment) or direct effects on physical health (both medications affect many organ systems) remains to be elucidated. The possibility of associations between lithium treatment and mortality operating through lithium’s effect on psychiatric status might unify the observations of decreased risks associated with active treatment and increased risks associated with discontinuation, given lithium’s established impact upon mood in both circumstances. Of note, some recent randomised73 and non-randomised74 studies have suggested lithium may have greater efficacy in bipolar disorder than valproate. In the BALANCE trial, the valproate treatment arm underperformed both the lithium–valproate combination and lithium alone treatment arms.73 In Denmark, lithium was found to be associated with fewer subsequent admissions to psychiatric hospital than valproate.74

Implications

This cohort study of US VHA patients observed significantly reduced non-suicide mortality among all patients initiated on lithium compared with valproate over 0–90 days but not beyond this period. Furthermore, significant associations were observed in opposite directions in secondary analyses: reduced mortality associated with individuals receiving lithium treatment, and increased mortality associated with individuals discontinuing lithium treatment (over 0–180 days), relative to valproate. This pattern suggests a potential dual nature to the mortality risk associations observed between lithium and valproate: mortality benefits associated with active lithium treatment that potentially exceed or are exceeded by counterbalancing risks associated with lithium discontinuation. Intrinsic uncertainties common to non-randomised studies (for example confounding), despite our efforts to minimise them, preclude a definitive judgement of whether lithium, compared with valproate, initiation was associated with net mortality benefit or net harm. One clear and important clinical conclusion nevertheless emerges: once lithium treatment has been initiated, patients and providers should strive to maximise persistence with lithium treatment when feasible and clinically indicated. Such a conclusion results regardless of whether lithium is associated with benefits during active treatment or harms after discontinuation. Given the problem of premature mortality in patients with serious mental illness,21–24 the potential mortality differences between lithium and valproate should immediately become a greater research and clinical focus.

Funding

This work was financially supported by a Health Services Research and Development Service (HSR&D) Career Development Award (CDA-09-216, E.G.S), by funding from the VHA HSR&D Center for Healthcare Organization and Implementation Research and by technical and programming support from the VHA Serious Mental Illness Treatment, Resource, and Evaluation Center, Ann Arbor, Michigan. Databases were constructed in part through funding from VHA HSR&D MRP 03-330 and the VHA Serious Mental Illness Treatment, Resource, and Evaluation Center. The sponsor had no role in the design and conduct of the study; collection, management, analysis and interpretation of the data; and preparation, review or approval of the manuscript. The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the Department of Veterans Affairs or the United States government.

Acknowledgements

We would like to thank two anonymous reviewers whose comments significantly improved this manuscript. The work reported here served as partial fulfilment of the requirements for E.G.S.’s PhD thesis.

References


**Online Supplements**

Online Figure DS1  Flowchart of Study Cohort Derivation

Online Supplement DS1  Diagnostic Codes Included in Cohort

Online Supplement DS2  Components of Former User Risk

Online Supplement DS3  Aspects of the High-Dimensional Propensity Score Implementation

Online Table DS1  Summary of Variables

Online Supplement DS4 Derivation of Variables

Online Supplement DS5  Initial Propensity Score Matching Results (including Online Table DS2)

Online Supplement DS6  Propensity Score Matching Details

Online Supplement DS7  Mortality by Treatment in the Unmatched Cohort and Implications for Confounding (including Online Table DS3)

Online Table DS4  Persistence with Treatment

Online Supplement DS8  Expected versus Observed Decrease over Time of Intent-to-Treat Effect Sizes

Online Supplement DS9  Possible Implications of Even Relatively Modest Residual Confounding on Assessment of Overall Comparative Benefit of Lithium versus Valproate

Online Supplement DS10 Evidence for and against Selection during Treatment

Online Supplement DS11 Value of Lithium Treatment Persistence

Online Supplement DS12 Challenges in Completely Modeling Important Risk Factors

Online Supplement DS13 The Importance of Identifying Incident Users
ALL VHA PATIENTS w/ MOOD or PSYCHOTIC DISORDERS RECEIVING Li or VAL, 1999-2008
TOTAL= 304,627
Lithium (Li)= 64,850 Valproate (VAL)= 239,777

EXCLUDED: PREVALENT USERS
TOTAL= 62,540 (20.5%)
Li = 18,396 (28.4%)   VAL = 44,144 (18.4%)

INCIDENT USERS OF Li OR VAL
TOTAL=242,087
Li = 45,706 (71.6%)   VAL = 196,381 (81.6%)

EXCLUDED: INADEQUATE RECENT VHA USE
TOTAL= 64,113 (26.5%)
Li = 15,328 (33.5%)   VAL = 48,785 (24.8%)

INCIDENT USERS w/ ADEQUATE VHA USE
TOTAL= 177,984
Li = 30,378 (46.8%)   VAL = 147,596 (61.6%)

EXCLUDED: NO MOOD or PSYCHOSIS DX w/in PRIOR 30d
TOTAL= 57,916 (32.5%)
Li = 5,333 (17.6%)   VAL = 52,583 (35.6%)

INCIDENT USERS w/ ACTIVE MOOD or PSYCHOSIS DX
TOTAL= 120,058
Li = 25,045 (38.6%)   VAL = 95,013 (39.6%)

EXCLUDED: DUAL USERS, PRN USERS, or POTENTIALLY NONPSYCHIATRIC USERS
TOTAL= 11,694 (9.8%)
Li = 1,116 (4.3%)   VAL = 10,578 (11.3%)

INCIDENT PRESUMED PSYCHIATRIC USERS
TOTAL= 108,364
Li = 23,928 (36.9%)   VAL = 84,436 (35.2%)

EXCLUDED: SERIOUSLY ILL or POSSIBLY NEUROLOGICALLY SERIOUSLY ILL PATIENTS
(Receiving home care, or suffering Cancer, Dementia, TBI/paralysis/other select neurologic conditions)
TOTAL= 15,029 (13.9%)
Li = 2,460 (10.3%)   VAL = 12,549 (14.9%)

FINAL COHORT: Clinic-Attending Outpatients w/o Serious Conditions potentially affecting Nervous System
TOTAL= 93,162*
Li = 21,433 (33.1%)   VAL = 71,729 (29.9%)

*excludes 193 patients residing outside the 50 US states
Online supplement DS1 Diagnostic Codes Included in the Cohort

The databases used in this study were initially developed for use in tracking care delivered to a broad collection of Veterans Health Administration (VHA) patients with depressive or psychotic disorders. Because of this, a considerable range of diagnostic codes were included during database construction. To maximize power and because existing literature suggested than any mortality advantages for lithium might span a variety of diagnoses, we decided to retain this broad group of included diagnoses. Patients could enter the cohort if they had received any one of the following ICD-9 codes in the 30 days prior to lithium or valproate initiation: (more common) 296.0-296.99, 311, and 295.0-295.9; (less common) 297.0-297.3, 297.8-297.9, 298.0-298.4, 298.8, 300.4, 301.12, 309.0-309.1, and 293.83. However, virtually all cohort members had received a diagnosis of bipolar I, II, NOS, Depression NOS, major depressive disorder, schizophrenia, schizoaffective disorder, or “other psychoses” within the past 30 days. Furthermore, these eight diagnostic categories, while still somewhat diverse, were balanced extremely closely in the two matched treatment groups (i.e., within a standardized difference of < 0.019).

Online supplement DS2 Components of Former User Risk

“Former user” risks have been proposed as a potential indicator of confounding at baseline or arising during treatment (i.e., confounding arising due to more frequent selection of higher-risk patients in one of the treatment groups to discontinue treatment, also termed here “selection during treatment”). However, in actuality differences in former user risks between treatment groups have the potential to be composed of a complex combination of residual baseline confounding, confounding arising during treatment, differential discontinuation-associated risks, and any difference in persistent effects from treatment. How often all of these components substantively contribute to former user risk is unclear.

Stated another way, a former user risk (e.g., odds ratio, hazards ratio) of 1.0 is compatible with an absence of confounding, but does not establish this. Similarity in former user risks cannot establish an absence of confounding if substantial selection during follow-up, discontinuation-associated risks, or persistent effects from active treatment is present. Since two or more strong biases or effects can potentially co-occur in opposite directions even if the former user risk approximates 1.0, a lack of strong biases can never be definitively concluded on the basis of former user risks alone. However, former user risks can still have considerable investigative value. As former user risks gets further from a null value (1.0), it is clear that the presence of confounding, selection, and/or persistence and discontinuation effects becomes increasingly likely, while analyses that achieve former user risks of close to 1.0 may or may not have these substantial effects or biases.

Online supplement DS3 Aspects of the High-Dimensional Propensity Score Implementation

Our approach generally followed the overall approach used to develop the original high-dimensional propensity score (hdPS) of Schneeweiss and colleagues, with the following exceptions:

1) No automated variable construction or selection based on a combined measure of association with exposure and outcome was performed. Instead initial variables were constructed from most entries in a category (e.g. clinic visits, medications, etc.), except those that were the least common (see below). Selection was later imposed for the outcome-focused propensity score based solely on associations with outcome, not with exposure. A few variables were also removed, as described in Online Supplement DS4, relating to very specific measures of past mood stabilizer use which appeared to have the potential to act as instrumental variables.

2) Although limited screening for covariate prevalence was done (few variables were included if present in <1% of the sample), no limitation was placed on whether that a covariate needed to be present in 5% of the patient sample as in the original hdPS method. This was because mortality is an infrequent outcome affecting only a small subsample of the cohort, thus even a covariate of low overall prevalence may
contribute to a substantial portion of deaths. Some important covariates judged particularly important \textit{a priori} (e.g. current warfarin prescription, cardiac catheterization in the last 180 days, or age $\geq 80$ years old) were included even if present in an overall prevalence of 1\% or less.

3) For clearly important variables, a more detailed coding of frequency of occurrence was undertaken than just the absence, presence at $< \text{median frequency}$, presence at $> \text{median frequency}$, and presence at $> 75^{\text{th}}$ percentile frequency categories that were used in the original hdPS method.

4) Greater temporal detail than in the original hdPS method was included for some variables by coding several different time periods for hospitalizations, total provider visits, and other general utilization variables, as well as coding frequency in two time periods for specific clinic visits (0-180 days and 181-365 days) and medications (current prescriptions and recent, but not current, prescriptions [last days’ supply ending within the last 180 days]). This strategy was implemented to make information about recent care that might contribute baseline mortality risk less dependent on the exact relationship of the medication initiation date to receipt of medications or services. In addition, this approach might include more detailed information that may be relevant to recent adherence behavior.

Online Table DS1 Summary of Variables Included in the Initial High-Dimensional Propensity Score (forming the basis of those variables selected for the Outcome-Focused Propensity Score)

(Prevalence of each balanced within a standardized difference of $< 0.019$ in the final matched cohort for both the Initial and Outcome-Focused High-Dimensional Propensity Scores)

\begin{tabular}{|l|l|}
\hline
Type of Patient Characteristic & Covariates \\
\hline
\textbf{General Covariates} & \\
\hline
Demographics & 10 Covariates (49 indicators) including age (eleven 5-year categories), sex, self-reported race (6), ethnicity, marital status (4), income(6), disability status (4), distance to VHA facility (4), urban/rural hospital location, and fiscal year of medication start (11) \\
\hline
Presenting Diagnosis & 9 Covariates denoting psychiatric diagnosis in the past 30 days: Bipolar I, Bipolar II, Bipolar NOS, Major Depression, Depression NOS, Schizophrenia, Schizoaffective Disorder, Other Psychoses, and $\geq 2$ of these diagnoses \\
\hline
\textbf{NonMental Health Covariates} & \\
\hline
General Utilization & Total number of current prescriptions, possibly discontinued prescriptions (expired in last 30 days) and recently discontinued prescriptions (expired from 31-180 days), Total number of Provider, Specialist, Surgical, ER Visits, and Inpatient Stays (over from 1- 3 different time periods), number of lab visits in last year, receipt of a flu shot in last year \\
\hline
Diagnoses & 41 Variables (44 indicators) relating to diagnoses in the past year, including Total Charlson Comorbidity (CCM) conditions (4 levels), 13 individual CCM Categories (MI, CHF, PVD, CEVD, COPD, Conn Tissue Dz, Peptic Ulcer, Mild Liver Dz, Mod/Sev Liver Dz, DM w/o complications, DM w/ complications, Renal Dz, AIDS/HIV), 11 individual Elixhauser comorbidity categories nonredundant with CCM categories (Arrhythmia ,Weight Loss, Coagulopathy, Pulmonary Circulation Dz, HTN, Valve Dz, Neurodegenerative Dz, Hypothyroid, Obesity, Anemia from Blood Loss, Deficiency Anemia), and 16 additional diagnostic categories (e.g. any fracture, hip fracture, neuropathic pain, back pain, internal injuries, open wounds, etc.), and a Recent Smoking indicator combining Tobacco Dependence diagnosis or treatment \\
\hline
\end{tabular}
### Online Table DS1 (continued)

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Medications</strong></td>
<td>54 covariates representing current prescriptions for specific medications or medication categories, including antiarrhythmics, several antibiotics and antihypertensives classes, warfarin, antiplatelet agents, statins, oral diabetes medications, HepC medications, opiate pain medication, low and high dose aspirin, NSAIDS, acetaminophen, inhalers, GI protectants, and other medications</td>
</tr>
<tr>
<td><strong>Recent Medications</strong></td>
<td>55 Covariates representing medication/medication categories prescribed in last 180 days but not active on initiation date. Includes 52 of the 54 Current Medication classes, plus vancomycin, antinausea medications, and bandages</td>
</tr>
<tr>
<td><strong>Hospitalizations</strong></td>
<td>41 Covariates denoting both the presence of specific types of VHA discharges in the last two years (e.g., Medical ICU, Surgical ICU, Cardiology, Cardiac Stepdown, Telemetry, General Medicine, 8 types of surgical hospitalizations, etc.). An additional set of variables were constructed to indicate the specific type of discharge which constituted the most recent VHA discharge. Additional covariates addressed how recently the latest VHA hospitalization preceded medication initiation and the presence of any discharges against medical advice in the past year</td>
</tr>
<tr>
<td><strong>Outpatient Providers Visited</strong></td>
<td>156 Covariates (300 indicators) denoting frequency (typically 0/1/2+ visits) of a large variety of outpatient clinics visited in the last 180 days and in days 181-365 prior to initiation. These include specific medical specialties, specific surgical specialties, anticoagulation clinic, outpatient pharmacy consultation, physical therapy, pacemaker and cardiac catheterization clinics, weight loss clinics, and nonmedical specialty services such work therapy and chaplain visits</td>
</tr>
<tr>
<td><strong>Diagnostic Tests</strong></td>
<td>9 covariates (16 indicators) for frequency of tests in prior year, including X-Ray (3), CT/MRI(3), EKG (3), Echocardiogram, Ultrasound, Endoscopy, Nuclear Medicine, PFT, and Angiogram</td>
</tr>
<tr>
<td><strong>Substance Abuse Diagnoses</strong></td>
<td>41 variables diagnoses in the past year of alcohol, amphetamine, cannabis, cocaine, opioid, sedative, stimulant, hallucinogen, and other/unspecified substance categories abuse or dependence. For each substance, 4 variables were constructed reflecting the diagnoses categories of abuse, dependence, remission from abuse, and remission from dependence. In addition, variables were constructed to reflect combined drug dependence (with or without opioids), alcohol intoxication, and alcohol psychosis</td>
</tr>
<tr>
<td><strong>Substance Abuse Treatment</strong></td>
<td>11 variables (19 covariates), including frequency of individual or group substance abuse treatment in last 180 days or days 181-365 prior to initiation, and current or recent prescription of disulfiram, naltrexone, buprenorphine, or methadone</td>
</tr>
<tr>
<td><strong>Other Psychiatric Covariates</strong></td>
<td>Numerous covariates including General Mental Health Utilization variables, comorbid psychiatric diagnoses, current psychiatric medications, recent psychiatric medications, number, type and timing of recent psychiatric hospitalizations, recent diagnosed suicide attempts, and types of psychiatric outpatient clinic utilization (e.g., psychiatry, psychotherapy, PTSD-focused, etc.)</td>
</tr>
<tr>
<td><strong>Aggregate Mortality</strong></td>
<td>5 indicators denoting age and sex-adjusted state mortality risk, derived from CDC data, grouped into 5 categories (approximate quintiles)</td>
</tr>
<tr>
<td><strong>VHA Hospital Network Mortality/Quality of Care</strong></td>
<td>6 indicators denoting categories of rate of risk-adjusted mortality for the VA Hospital Network (VISN) where patient received care. (Categorization based on data reported in Reference 81)</td>
</tr>
</tbody>
</table>
Online Supplement DS4 Derivation of Variables

This appendix is provided to document for interested readers how the 948 covariates* in the initial high-dimensional propensity score were derived. These variables form the basis from which the 523 covariates in the outcome-focused propensity score were selected.

DEMOGRAPHICS AND YEAR OF ENTRY

Demographics: Indicator variables were used for age (< 35 years old, ≥ 80 years old, and intervening 5-year age intervals), sex, race, and ethnicity as recorded in Veterans Health Administration (VHA) system. Where information on race was missing it was imputed using methods previously developed. Marital status, income, disability status (as indicated by percent of “service connection” of a particular disability), distance to VHA facility, urban/rural location of the facility where patients’ obtained care, and fiscal year of medication start was also included.

UTILIZATION

Utilization variables are derived from VHA clinic stop codes, a set of approximately 500 codes used to categorize each outpatient encounters. These codes result in classifying care provided into considerably broader categories of care than CPT codes used in other high dimensional propensity scores, reducing the need to consider whether codes should be aggregated or whether information is lost without such aggregation.

General Mental Health and NonMental Health Utilization: We calculated the total number of VHA clinic stop codes relating to encounters with providers (as opposed to Telephone visits, lab tests, etc.) over specific time periods. We then used multiple indicator variables to categories the frequency with which mental health and nonmental health encounters occurred in the last 7 days before medication initiation and longer time periods over the previous two years.

For general mental health utilization, we also constructed variables reflecting the total number of hospitalizations (as indexed by discharge dates), and variables dividing total MH provider visits into four subtypes (diagnostic interviews, medical management visits, and individual and group psychotherapy visits) over different time periods. For general nonmental health utilization, we also included counts for total nonmental health hospitalizations and the number of surgery clinic and specialist visits (based on stop codes) during particular time periods. Also, variables were constructed reflecting the total ER/Urgent care visits, lab visits, and presence and absence of a flu shot in the last year (one possible indicator of preventative care).

Finally, for both general mental health and nonmental health utilization, we included indicator variables for the total number of mental health and nonmental health medications. Different sets of indicator variables accounted for the number of medications that people were receiving on the lithium/valproate start date, the number of medications that they had very recently been taking but for which an active prescription did not exist on the date of lithium/valproate start (termed “Possibly Discontinued”), and the number of medications recently received (within the last 180 days) but not received in the last 30 days (“Recently Discontinued”). A description of the derivation of the covariates designating various specific medications or medication classes which were then summed into these separate counts of total mental health and nonmental health medications is provided in the “Medications” section further below.

*NOTE concerning covariate count: In the manuscript and here, we use the term “number of covariates” (e.g., 948, 523) to refer to the number of separate, unique quantities balanced through the hdPS-matching. This includes “0 count” quantities for multilevel variables (for these variables, but not dichotomous variables, the number of individuals lacking a positive count for that indicator is a separate quantity, rather than simply information that also can be obtained from the count of individuals scoring “1” for the indicator). Thus, depending on whether one is considering distinct patient characteristics, number of variable terms entered, or number of unique values balanced
by the model, counts vary. For example, 546 unique patient qualities were modeled in the initial propensity score using 788 total variables resulting in 948 distinct, unique values, termed here as “covariates”.

**Mental Health and NonMental Health Outpatient Utilization:** Clinic stop codes were classified with indicator variables to reflect whether a patient had attended no visits of that type, a single isolated visit, or repeated visits (2 or more visits of that type) within a time period. The two time periods examined were the last 180 days prior to lithium/valproate start, and the prior 181 to 365 days before lithium/valproate start. For mental health outpatient utilization, visits were classified as occurring with psychiatrists, psychotherapists, in the general mental health clinic, primary care behavioral health clinic, substance use disorder clinic, or the Health Care for Homeless Veterans clinic, with additional indicators for visits involving group treatment.

A much greater variety of stop codes exists for nonmental health outpatient utilization. We chose all stop codes appearing for ≥ 5% of either treatment group in either the last 180 days or days 181 to 365 prior to medication start and other, lower prevalence clinic stop codes thought *a priori* to be of importance (e.g., pacemaker clinic, etc.) In addition, nonmental health stop codes also were also used to construct the diagnostic testing module described below.

**Mental Health and NonMental Health Hospitalizations:** The VHA uses approximately 90 bedsection codes to classify hospitalizations by the type of care received (e.g., Specialty of Ward where patient is admitted). The 30 bedsections that relate to mental health hospitalizations were classified into 4 larger classes: Psychiatric-focused hospitalizations, Substance Abuse-focused hospitalizations, Residential/Day program, and Domiciliary Program (longer-term housing). With regard to bedsection codes for NonMental Health hospitalizations, a few codes were consolidated when counts were observed to be particularly low (e.g., dermatology bedsection discharges), but in most cases a simple indicator variable was developed to reflect either that the patient’s most recent hospitalization had been that bedsection, or that any of their hospitalization bedsections in the two years prior to medication start had been in that bedsection. These latter variables were constructed both as a measure of overall disease burden (of conditions of a severity requiring hospitalization), because for some progressive conditions earlier hospitalizations or diagnoses can actually reflect worse health prognosis, and because failing health is an obvious risk factor for mortality. These variables included ICU Bedsections, Step Down Bedsections, Telemetry Bedsections, General Medicine Bedsections, Specialty Medicine (e.g., Neurology, Cardiology) Bedsections, Surgery Bedsections, etc.

Because mortality risks with relation to mental and nonmental health hospitalizations appear to be time-dependent, we coded hospitalizations to whether hospitalizations of any particular type were present in the last 2 years, what the nature of the most recent hospitalization was, and whether the most recent hospitalization was focused on Mental Health or NonMental Health conditions. We also constructed multiple indicators to reflect the timing of the latest psychiatric discharge date relative to medication initiation to partially reflect the severity of the patients’ psychiatric condition, was well as also having an indicator of the total number of nonmental health VHA hospitalizations total in the last year.

**DIAGNOSES**

**Comorbid Mental Health and NonMental Health Diagnoses and Indicating Diagnoses:** Indicator variables were used to reflect a variety of specific mental health diagnoses given in the past year, based on ICD-9. We required all cohort members to have VHA service use in the past year as well as a prior year, so use of this past year time period helped maximize information about what diagnoses a patient likely actually had. The one exception were the diagnoses presumed to serve as an indication for lithium/valproate treatment (mood or psychotic diagnoses), for which we required the diagnosis to be entered in the last 30 days. This briefer period was used in order to maximize the likelihood that this was the reason the patient was receiving lithium or valproate.

Nonmental health diagnoses were aggregated into larger categories based on the comorbid illness categories that make up the Charlson Comorbidity Index and the Elixhauser Comorbidity Index, as per a classification procedure developed for use with administrative databases. For the Charlson index categories, the following 13 (out of the total 17) comorbidity categories were used: Myocardial infarction, Congestive Heart
Failure, Peripheral Vascular Disease, Cerebrovascular Disease, Chronic Obstructive Pulmonary Disease, Connective Tissue Disease, Peptic Ulcer, Mild Liver Disease, Moderate or Severe Liver Disease, Diabetes Mellitus without complications, Diabetes Mellitus with complications, Renal Disease, AIDS/HIV Infection.

Elixhauser Comorbidity categories were also included, based on the same reference,79 when these categories were judged not to overlap with the Charlson index categories. The eleven categories included were: Arrhythmias, Weight Loss, Coagulopathies, Pulmonary Circulation Disease, Valvular Disease, Neurodegenerative Diseases, Hypothyroidism, Obesity, Anemia from Blood Loss, Deficiency Anemia, and Hypertension with or without Complications.

Multiple indicators were also included to reflect the total number of Charlson Comorbidity Index conditions, considering all diagnoses received in the past year.

In addition, indicators for other injury-related and a few specific diagnoses related to progressive neurodegenerative or autoimmune conditions and pain diagnosis were included. Finally, an aggregated smoking indicator was included in this category. Tobacco dependence is recognized as being underdiagnosed in VHA administrative/clinical coding, so we constructed a “recent smoking” variable which assumed a value of “1” if a patient had any of the three in the past year: a diagnosis of Tobacco Dependence, at least one visit to a smoking cessation clinic, or prescription of nicotine replacement therapy or varenicline.

**Comorbid Substance Abuse Diagnoses:** Seven categories of legal/illicit substance use (alcohol, amphetamine, cocaine, marijuana, opioids, sedatives, other substances) were coded as four different indicators reflecting diagnoses received in the last year: dependence on that particular substance, abuse of that particular substance, remission from dependence of that substance and remission from abuse of that substance. The eighth category, hallucinogens, was coded as only 3 indicators (dependence, abuse, and remission from dependence) because there were insufficient numbers of patients (≤ 5 in one of the treatment groups) diagnosed with remission from hallucinogen abuse in the past year. In addition, indicators were included for combined substance dependence and remission from combined substance dependence, including separate indicators denoting whether this combined dependence included opioids or not. Two indicators were also included for “unspecified” substance dependence. Lastly, indicators were included in this category for alcohol intoxication (both a narrow and broad definition) and alcohol or drug psychoses.

**Recent Nonfatal Suicidal Behavior Diagnoses:** Episodes of nonfatal suicidal behavior, especially those occurring recently, are a strong risk factor for suicide80,81 which might plausibly be associated with nonsuicide mortality if any miscoding of suicide deaths occurred.82 However, there are concerns that outpatient diagnoses sometimes may reflect a history of more remote suicidal behavior rather than reflecting behavior always occurring close to the time the diagnoses were entered. To address these concerns a hierarchy was imposed to avoid double-counting of nonfatal suicide behavior episodes between types of inpatient, or inpatient and outpatient diagnoses. Indicator variables were developed reflecting the occurrence of a diagnosis of an episode of nonfatal suicidal behavior over the last 30 days, days 31 to 180 and days 181 to 365 prior to lithium/valproate start. This approach is expected to result in only an approximate indicator of recent suicide attempts, since a patient could have two separate attempts within a time period that were diagnosed in different settings, and this occurrence would not be reflected in our coding scheme. In addition, the same attempt, if a diagnosis occurred close to the end of a time interval in one setting (e.g., during a non-MH hospitalization), may have been rediagnosed in a second setting in the next time interval. Thus this single behavior episode would appear as two distinct episodes in our coding scheme, not one. Some imprecision of this type is likely unavoidable.

Despite such uncertainties, we felt it was important to incorporate this information when available in our high-dimensional propensity score. Similarly, it was considered important to maintain a distinction concerning the setting of the nonfatal suicidal behavior diagnosis, since an episode diagnosed in a non-mental health hospitalization is likely to be, on average, considerably more serious than diagnoses simply recorded as outpatient diagnoses. It should be recognized that in general diagnoses of nonfatal suicidal behavior are specific but very insensitive,82 although sensitivity is expected to increase for inpatient diagnoses compared with outpatient (another reason that we made this distinction).
MEDICATIONS

Current and Recent Mental Health Medications: Mental health medication prescriptions active at the time of lithium/valproate start or recently filled (within the last 180 days) were designated into general classes by 24 indicator variables, using a classification system previously developed. This system already used multiple categories to index antidepressants. For this study we also classified second generation antipsychotics into individual medications (clozapine, olanzapine, risperidone/paliperidone, quetiapine, aripiprazole, ziprasidone). Such an enhanced classification was important given the differential impacts of these medications on mortality and general health (obesity, diabetes, etc.) risk. An identical number of indicator variables were used to reflect recent but not current prescriptions of medications from these same classes, designating receipt of one or more prescription of that type of medication in the last 180 days in the absence of a prescription whose days’ supply includes the start date for lithium/valproate treatment.

For nonmental health medications, a system was developed using medication class code information assigned by the VHA by the VHA national formulary. Along with individual medication names and codes, the VHA categorizes every medication administered from the pharmacy into one of more than 1000 classes of medication denoted by a 5 character “medication class” codes, which is further organized into larger 3-character class code categories (using the first 3 digits of the 5 character code). We took advantage of this classification as an approach to logically aggregate prescriptions for related medications (e.g., different loop diuretics were aggregated into the category “Loop Diuretics”). In many cases, we used the broader 3 character code, but in other cases, in which further distinctions were judged important, specific medications were sometimes coded individually (e.g., warfarin). This process condensed the approximately 1000 VHA medication classes used by our cohort down to approximately 225 medication categories. Then all the medication categories present with a prevalence of ≥ 5% in either treatment group (reflecting number of patients with at least one prescription in the last 180 days, or with a current prescription on start date of lithium/valproate) were included. Finally, any medication categories of < 5% prevalence but > 1% prevalence that were judged a priori particularly relevant to mortality risk (e.g., warfarin, digoxin, etc.) were included as propensity score covariates (this eliminated many of the medication categories, reducing the 225 categories down to 54-55 medication categories [covariates] of clear relevant to our treatment groups).

Indicators for “Current” medication categories required the patient to have an active prescription with a number of days of medication supplied that included the start date of lithium/valproate, while indicators for “Recent” (but not current) revised medication categories required the patient to have had at least one prescription filled in the last 180 days but no active supply at time of lithium/valproate start. A list of some important nonmental health medications or medication categories coded as “Current” and “Recent” medications is included in Online Table DS1. The “Possibly Discontinued” distinction (for medications whose supply ended in the last 30 days prior to lithium/valproate initiation) that was used for the variables reflecting total nonmental health and mental health medications (see “Utilization” above) was not retained for these covariates designating individual medication categories. Instead, medications prescribed in this fashion, with their supply ending in the last 30 days prior to lithium valproate initiation, were classified as “Recent” medications, along with the medications with a prescribed number of days of medication supplied that had ended earlier in the 180 day period prior to medication initiation.

In the rare cases when fewer than 5 individuals within a treatment group after matching had received medications of a particular category currently or recently, this category was either removed from the propensity score model or consolidated with other medication classes. This resulted in small differences, for instance, in the number of nonmental health current medication (54 variables) versus recent medication categories included as propensity score covariates (55 variables).

Prior Mood Stabilizer Treatment History: Although we sought to identify incident users through the requirement of a “clean period”, some patients, although a clear minority (≤ 36% of a treatment group), had had more remote treatment with either mood stabilizers of any type or specifically with lithium or valproate. Two indicator variables were included, reflecting past history of treatment with mood stabilizers in general and past history of treatment with lithium or valproate specifically. Additional variables were considering indexing whether the patient had ever
received the same or opposite mood stabilizer previously or whether the patient’s most recent past prescription had been the same or opposite mood stabilizer, but these variables displayed a somewhat strong correlation with which medication (lithium or valproate) the patient initiated in the study. Because these variables also related to past treatment, rather than current treatment, it was judged that these variables, while likely helping to explain assignment to lithium or valproate, would be prime candidates to act as instrumental variables, potentially adding bias to our analysis. These variables were not included in the final high-dimensional propensity score model.

OTHER

NonMental Health Diagnostic Testing: Clinic stop codes reflecting diagnostic procedures over the last 180 days and days 181 to 365 prior to lithium/valproate start were used to construct indicators of the frequency of diagnostic tests over the past year: X-Rays, CT or MRI scans, EKGs, Ultrasound, Echocardiograms, Endoscopy, PFTs, Nuclear Medicine, and Angiograms (for Angiograms, tests were divided as occurring within the last 180d days and in days 181 to 365 prior to lithium/valproate start).

Geographic All-Cause Mortality Risk: Indicator variables were constructed to classify patients into 5 categories (approximate quintiles) of age-adjusted regional (state-level) mortality risk, based on publically available data from the Centers of Disease Control for the years 2000 and 2007. Because these statistics would include the deaths of Veterans occurring in this period, there is the potential for control for “predictors” that include outcome-related information, but this bias is expected to be exceedingly small, given the large number of deaths that occurred across these states over eight years, and the fact that our sample accounted for less than 600 nonsuicide deaths over that period. A geographic all-cause mortality indicator was included to guard against the possibility of regional differences in prescribing patterns creating a spurious association between treatment and mortality.

VHA Hospital System (VISN) Mortality Risk: Indicator Variables were used to classify patients into 6 categories of risk-adjusted all-cause mortality risk (based on age, gender, Charlson Comorbidity Index, perceived physical health, and perceived mental health), using information from VA surveys administered in 1998 and 1999. Although this information is most accurate for the very beginning of the study period (mid-1999), it was judged that having some indicator of both mortality variation among VA Hospital Systems and potential quality of care in general would be useful to help limit possible spurious associations between a treatment and mortality due to general tendency for hospitals providing higher or lower quality care to have providers who favored one or the other treatment.

Three additional variables were included to help balance the extensiveness of pharmacy records among our recipients: any prior use of VA pharmacy, use > 180days prior to LI/VAL start, and use > 365d prior to LI/VAL start.

Selection of Covariates for the Outcome-Focused Propensity Score: Covariates were selected with an association with mortality of +/- 20 percent (odds ratio of ≥ 1.2 or ≤ 0.83), as has been done previously. Determining whether a dichotomous variable has a 20% association with mortality is generally straightforward, however for covariates with more than two possible levels (e.g., age), determining which variables are included or excluded becomes more of a matter of judgment. Either highly restrictive (requiring all categories of the variable to have an association with mortality of ≥ 20%) or highly permissive criteria (requiring only 1 category of the multilevel variable to have an association of ≥ 20%) could be envisioned. We adopted a compromise approach in which multilevel variables were included in the outcome-focused propensity score only if a majority of level of that variable had a +/- 20% odds ratio association with nonsuicide mortality, except for a very few limited exceptions.
Online Supplement DS5  Initial Propensity Score Results

Matching upon the initial propensity score produced results that appear to be consistent with some degree of “amplified confounding”.\textsuperscript{40,41} For this reason we chose to report the outcome-focused propensity score results throughout the manuscript as likely more unbiased. However, for completeness, we report the initial propensity score results here (Online Table DS2) and compare these results with Tables 4 and 5 of the manuscript.

Online Table DS2 Risk of Nonsuicide Mortality (Intent-to-Treat Cohort, Initial Propensity Score-Matched)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Intent-to-Treat Hazard Ratio (Lithium/Valproate)</th>
<th>During Initial Exposure Hazard Ratio (As-Treated)</th>
<th>Subsequent Nonexposure Hazard Ratio (Former User)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-90 Days</td>
<td>0.72\textsuperscript{a} (0.55-0.95)</td>
<td>0.81 (0.57-1.14)</td>
<td>0.67 (0.35-1.25)</td>
</tr>
<tr>
<td>0-180 Days</td>
<td>0.97\textsuperscript{b} (0.82-1.15)</td>
<td>0.83 (0.61-1.12)</td>
<td>1.19 (0.80-1.77)</td>
</tr>
<tr>
<td>0-365 Days</td>
<td>0.87\textsuperscript{c} (0.77-0.97)</td>
<td>0.77 (0.57-1.03)</td>
<td>0.84 (0.65-1.07)</td>
</tr>
</tbody>
</table>

Comparing the former user values between the initial and outcome-focused propensity score-matched analyses suggests that the outcome-focused propensity score is less confounded than the initial propensity score: at 90 and 365 days the former user hazard ratios are closer to 1.0 for the outcome-focused propensity score than the initial propensity score (central estimate HRs 0-90 day: 0.88 (outcome-focused score) versus 0.67 (initial score); 0-365 days: 1.02 (outcome-focused score) versus 0.84 (initial score). This pattern does not hold for 0-180 days, but in this case the results are consistent with potential discontinuation risks being attenuated by the presence of greater confounding for the initial propensity-score matched cohort in the direction of better outcomes for lithium (central estimate HR = 1.19 versus 1.54 for the outcome-focused score). In addition, the initial propensity score intent-to-treat and former user hazard ratios over 0-90 and 0-365 days are more similar to the hazard ratios observed prior to propensity score matching than the outcome-focused propensity score hazard ratios (Online Supplement DS7). This suggests greater residual confounding for the initial propensity score matched cohorts. Since this analysis includes more covariates, this suggests a greater amplification of unmeasured/incompletely measured confounding as some have suggested can occur with control of measured covariates not substantially associated with outcome.\textsuperscript{38,40}

Interestingly, the as-treated initial propensity score results are not closer to the unmatched results than the outcome-focused results, a finding that suggests some contribution from random error or that the effects of amplified confounding/less important covariates may warrant more theoretical or empirical investigation.

Also of note, the former user risk of HR = 0.84 over 0-365 days actually exceeds in magnitude the intent-to-treat risk estimate. This same pattern is observed over 0-90 days. This pattern of risk suggests that the initial propensity score intent-to-treat risks may be largely or even entirely explained by confounding, and that the former user risks is made up of substantial confounding combined with an additional element (e.g., random error).
Online Supplement DS6  Propensity Score Matching Details

Our propensity score matching was performed using greedy-matching involving freely available SAS code from the Mayo Foundation for Medical Education and Research\textsuperscript{36} as well as SAS code from Fairies et al., Chapter 3 of the SAS Press book “Analysis of Observational Health Care Data Using SAS”.\textsuperscript{43} Because it is not part of this published code, we did not trim our propensity score cohorts to a “Common Support Area” prior to matching. Perhaps due to the large preponderance of patients initiating valproate compared to lithium and the wide, overlapping propensity score distribution for both medications, very few patients fell outside the “Common Support Area”. This is reflected by the fact that use of fairly standard 0.2 propensity score logit calipers resulted in a narrow propensity score range while including virtually all lithium-treated patients. We more precisely established this for our highly similar analysis of suicide mortality. This analysis also involved nearly complete matching of lithium-treated patients, and these patients were matched using a propensity score that included 98% of the covariates included in the initial propensity score for this study. For this similar analysis, we established that exceedingly few patients fell outside of a Common Support Area (only 0.05% [lithium-treated patients] to 0.12% [valproate-treated patients] of the entire unmatched cohort).

Online Supplement DS7  Mortality by Treatment in the Unmatched Cohort and Implications for Confounding

See online Table DS3 below. Of note, for each effect estimate the outcome-focused high-dimensional propensity-score matched cohort produced estimates in the direction of reducing the effect sizes from the unmatched analysis each of which indicated a stronger association with worsened outcomes among patients initiating valproate. (However, this change in estimates between the unmatched and matched analyses was minimal for the as-treated effect estimate). These findings suggest confounding in the overall cohort is in the direction of patients who are less medically ill preferentially receiving lithium (i.e., patients having less risk of nonsuicide mortality at baseline, prior to treatment initiation). As a result, the unmatched associations show stronger effect sizes favoring lithium treatment than the matched analysis.

Online Table DS3 Risk of Nonsuicide Mortality over 365 days, by Treatment

<table>
<thead>
<tr>
<th>Analysis (Incident Users)</th>
<th>Intent-to-Treat Sample</th>
<th>During Initial Exposure (As-Treated)</th>
<th>During Subsequent NonExposure (Former Users)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmatched Cohort</td>
<td>0.74\textsuperscript{a}</td>
<td>0.58\textsuperscript{a}</td>
<td>0.77\textsuperscript{a}</td>
</tr>
<tr>
<td></td>
<td>(0.65-0.84)</td>
<td>(0.45-0.74)</td>
<td>(0.63-0.94)</td>
</tr>
<tr>
<td>Outcome-Focused High-Dimensional Propensity-Score Matched Cohort</td>
<td>0.92\textsuperscript{b}</td>
<td>0.62\textsuperscript{b}</td>
<td>1.02\textsuperscript{b}</td>
</tr>
<tr>
<td></td>
<td>(0.82-1.04)</td>
<td>(0.45-0.84)</td>
<td>(0.79-1.32)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} P values are: p < 0.0001 (Intent-to-Treat), p < 0.0001 (Current Users); p = 0.011 (Former Users)

\textsuperscript{b} P values are: p = 0.173 (Intent-to-Treat); p = 0.002 (Current Users); p = 0.888 (Former Users)
Online Table DS4 Persistence with Treatment: Censoring of Patient Cohorts at 90, 180 and 365 days (outcome-focused Propensity Score-Matched Cohort)

<table>
<thead>
<tr>
<th>Treatment Status</th>
<th>0-90 Day Follow-up</th>
<th>0-180 Day Follow-up</th>
<th>0-365 Day Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lithium</td>
<td>Valproate</td>
<td>Lithium</td>
</tr>
<tr>
<td></td>
<td>N (%)</td>
<td>N (%)</td>
<td>N (%)</td>
</tr>
<tr>
<td>Still Receiving Initial Treatment</td>
<td>9967 46.8</td>
<td>9852 46.3</td>
<td>5012 23.5</td>
</tr>
<tr>
<td>Discontinued Initial Treatment</td>
<td>10501 48.7</td>
<td>11046 51.3</td>
<td>15220 71.5</td>
</tr>
<tr>
<td>Initiated Opposite Mood Stabilizer&lt;sup&gt;b&lt;/sup&gt;</td>
<td>773 3.6</td>
<td>321 1.5</td>
<td>987 4.6</td>
</tr>
<tr>
<td>Suicide Mortality</td>
<td>15 0.07</td>
<td>15 0.07</td>
<td>17 0.08</td>
</tr>
<tr>
<td>Nonsuicide Mortality&lt;sup&gt;c&lt;/sup&gt;</td>
<td>32 0.15</td>
<td>54 0.25</td>
<td>52 0.24</td>
</tr>
</tbody>
</table>

<sup>a</sup> n = 21288 propensity-score matched pairs

<sup>b</sup> i.e., switched directly from lithium to valproate, or directly from valproate to lithium

<sup>c</sup> Because this Table row reflect patients censored due to nonsuicide death occurring before any treatment impersistence, they are equivalent to the “as-treated” counts

Online Supplement DS8   Expected versus Observed Decrease over Time of Intent-to-Treat Effect Sizes

It is important to note that if a genuine medication effect exists during active treatment, it can usually be expected that intent-to-treat estimates will progressively weaken over time if the analysis is largely unconfounded. This occurs because fewer and fewer of the intent-to-treat sample over time remain on the treatment that provides the genuine effects. (This pattern can be different in studies in which patients predominantly switch, rather than discontinue, treatment).

The pattern observed in this study, however, is somewhat different. First, while the intent-to-treat central estimate does move towards the null (and become nonsignificant) as followup time increases to 0-180 days (HR = 0.97, [0.82-1.15]), the central estimate moves away from the null over 0-365 days (HR = 0.92, [0.82-1.04]). Second, marked changes in the central estimate of risk among former users is observed, becoming substantially elevated and statistically significant at 0-180 days (HR=1.54, [1.01-2.37), but then returning almost to an entirely null value over 0-365 days (HR = 1.02, [0.79-1.32]).

The lack of statistical significance for many of these estimates limits interpretation, because random variation can explain many of these findings. Nevertheless, integrating the pattern of central estimate findings appears to indicate that the most parsimonious interpretation of our study (although far from conclusive) would suggest that our results include both genuine, although transient, increased mortality risk occurring shortly after lithium discontinuation, and residual confounding biasing against valproate (i.e., towards the observation of lower risks with lithium). The possibility of transient “emergent” risks occurs after lithium discontinuation (compared to
valproate) discontinuation is suggested by the magnitude of the intent-to-treat estimate change from 0-90 days to 0-180 days and by the statistically significant former user mortality risks over 0-180 days. The magnitude of the intent-to-treat estimate change from 0-90 days to 0-180 days, since the 0-180 days include the 0-90 day findings, suggest that the overall intent-to-treat central estimate hazard ratio would actually show increased risk over 91-180 days among all patients who had originally initiated lithium. Interestingly, this is the general pattern of risk that our research team observed in a related study of suicide mortality drawn from the same unmatched cohort. Our secondary analyses risk suggests a possible reason for this increased risk associated with lithium initiation: a sufficient number of former users experience some substantial mortality risk associated with lithium discontinuation to potentially outweigh any benefits experienced by the minority of patients who remain on initial lithium treatment during this period. The risks upon lithium discontinuation over 0-180 days deserve particular attention not only because they are statistically significant, but also because they appear to be in the opposite direction of baseline confounding. Both the risks observed prior to matching (more strongly in favor of lithium treatment [online supplement DS7]) and the tendency for both the intent-to-treat and former user hazard ratios to move in the direction of favoring lithium treatment as follow-up time is extended to 365 days suggests that an underlying confounding bias favor lithium exists in our study.

Again, while none of these conclusions can be made definitively, this interpretation suggests that more weight should be put on the significantly increased risk among former users over 0-180 days, both because of its statistical significance and because the association appears to be observed in contrast to some level of confounding (at least baseline confounding) biasing against observing this association. In addition, caution placed on conclusions about lower risks associated with lithium active treatment and the overall balance of intent-to-treat risks and benefits, given that estimates of risk may be biased by at least some confounding in the direction of favoring lithium treatment. This is particularly true for conclusions about the net balance of risks and benefits from initiating lithium compared to valproate treatment over the first 365 days of treatment. These intent-to-treat associations are both not statistically significant and, as discussed further in the next supplement, would require only relatively small amounts of residual confounding for the presumed unconfounded central estimate hazard ratios to favor valproate, rather than lithium.

Online Supplement DS9 Possible Implications of Even Relatively Modest Residual Confounding on Assessment of Overall Comparative Benefit of Lithium versus Valproate

As an example, at 180 days the intent-to-treat HR (central estimate) of 0.97 suggests that residual confounding of only approximately 3-4% lower baseline hazard of mortality at baseline (prior to medication initiation) among patients initiating lithium would be sufficient to yield a central estimate of increased, rather than decreased, mortality risk among all lithium initiators over the first 180 days of treatment. Slightly more confounding would be necessary to yield a central estimate of increased risk over 0-365 days. Statistically, the confidence intervals already preclude definitive conclusions concerning net harms or benefits of lithium compared to valproate for these periods. Notably, the intent-to-treat associations over 0-180 days includes the period of strong, statistical significant intent-to-treat associations between lithium initiation and lower mortality risks from 0-90 days. This implies despite the strong (and statistically significant) protective association between lithium and decreased overall mortality in the first 90 days, increased risks over the 91-180 day period must be sufficient to largely eliminate this association.

Of course, since the increased risks are apparent almost exclusively among patients who have discontinued lithium treatments, our data also suggests that if persistence with lithium could be increased, the balance of benefit to risk for lithium compared to valproate might shift further in the direction of favoring lithium.

Online Supplement DS10 Evidence for and against Substantial Confounding Arising During Treatment

On theoretical grounds, confounding arising during treatment (also referred to here as selection during treatment) could plausibly explain the reduced risks in as-treated patients and enhanced risk among patients
discontinuing lithium. This would occur if a greater number of medically ill patients had their lithium treatment stopped because of their deteriorating condition than medically ill patients receiving valproate. In essence, this differential selection would serve to transfer a greater number of high-risk “as-treated” individuals receiving lithium treatment than receiving valproate treatment to the category of “former users” having discontinued treatment.

However, this phenomenon, unless the selection was based primarily on adverse medical risks caused by the medications themselves, would not easily explain the changes in intent-to-treat risks, nor the consistency of the as-treated risks observed. Finally, this possibility is also rendered less likely by the very similar rates of medication discontinuation observed between the treatment groups receiving the two medications over time. However, as others have pointed out, this line of reasoning is not firmly conclusive since patients may discontinue medications at the same rate but for different reasons.31

Furthermore, a simple model combining both confounding at baseline and arising during treatment (i.e., positing no medication effects on either risks during active treatment or after discontinuation) does not appear sufficient, since in such a model, in order to explain the intent-to-treat findings, confounding would have to change direction from 0-90 and 91-180 days, and then change direction again over 181-365 days, to explain the 0-90, 0-180, and 0-365 day intent-to-treat estimates observed.

It is possible, of course, that random variation does contribute to the 90, 180 and 365 day estimates and perhaps enhances the differences between them, producing spurious changes in direction of the estimates. However, the probability random error explains the difference between the 0-90, 0-180, and the 0-365 day intent-to-treat estimates entirely (i.e., in the absence of residual confounding or genuine medication effects during treatment or upon discontinuation), or to the differences between the 0-90, 0-180 and 0-365 day former user risks entirely, would be considerably less than 50%.

Thus, the simplest consistent interpretation of the outcome-focused results is that some level of residual baseline confounding biasing against valproate persists in the 0-365 day analyses, although it is not the only contributor to the risk estimates. When dissociation-associated risks and/or (less likely) effects from confounding arising during treatment weaken from 0-180 days to 0-365 days, any residual baseline confounding might then serve to “pull” the former user risk much closer to the null over a relatively short period, and contribute an overestimation in the intent-to-treat estimates of the amount of decreased mortality risk associated with lithium initiation.

Online Supplement DS11  Value of Lithium Treatment Persistence

If, as discussed above, the possibility of substantial confounding cannot be fully excluded, then an important implication results: it becomes difficult to assess whether patients initiating lithium are at greater or lesser overall mortality risk when the combined impact of both the possibility of possibility of reduced mortality risks during active treatment and increased mortality risks after discontinuation are considered. This is especially true because the margin of beneficial intent-to-treat association observed at 0-180 and 0-365 days is generally small (and statistically nonsignificant). That is, as pointed out in online supplement DS8, even relatively small amounts of residual confounding (for the 0-180 day and 0-365 day analyses, respectively) would be sufficient to conceal any overall hazardous treatment effects associated with lithium compared to valproate. For this reason, we note in the manuscript that further research is clearly needed and caution should be exercised regarding any judgments of whether greater or lesser lithium use would be desirable.

However, despite this uncertainty, at least one conclusion can be made with greater confidence: unless sufficient confounding exists to conceal an actually hazardous relationship between lithium and mortality during active treatment, then a clear benefit would exist for maximizing persistence with lithium treatment once initiated. Our data, being nonrandomized, cannot exclude this possibility, although such founding would have to be quite substantial (i.e., considerably more substantial than the confounding sufficient to conceal a net overall, intent-to-treat hazard for lithium). However, if lithium is associated with reduced mortality risks or at worse a neutral effect on mortality (relative to valproate) during active treatment, then our data would support benefits to increasing persistence with lithium treatment, once initiated. Put another way, regardless of whether the overall impact of lithium over the entire follow-up period leads to lesser or greater mortality risks than initiation of valproate, as long
as active treatment with lithium is not associated with an increased, rather than decreased, mortality risk, then our data supports the benefits of improved persistence with lithium once initiated. Emphasizing treatment persistence would have the effect of increasing any benefits experienced during active treatment and reducing any risks resulting from discontinuation. Regardless of which risk predominates, once a decision is made to initiate lithium, efforts to boost treatment persistence when feasible appear likely to benefit the patient.

**Online Supplement DS12  Challenges in Completely Modeling Important Risk Factors**

It is important to recognize there is inherent difficulty in capturing a fully desirable amount of information concerning some types of variables. Hospitalizations prior to medication initiation are an example. We chose to model these hospitalizations in three ways: multiple indicators for the overall number of recent nonmental health hospitalizations, whether any hospitalization of a particular type (e.g. ICU, cardiac, etc.) had occurred in the past 2 years, and what type of hospitalization had occurred most recently prior to medication initiation. However, it can be easily conceptualized that near-complete modeling of hospitalizations experienced by the patient in the last two years might have included the timing and number of days preceding medication initiation for every hospitalization type, and potentially length of stay as well. Furthermore, indicators concerning whether multiple hospitalizations of the same type had occurred and how separated in time the repeat admissions were might be desirable. And of course, as pointed out in the manuscript, we did not have information about hospitalizations that occurred outside the VHA system. For many variables, such as those denoting recent hospitalizations, at some point practical decisions must be made concerning what detail in modeling is appropriate and feasible.

**Online Supplement DS13  The Importance of Identifying Incident Users**

Including prevalent and/or past users of a medication in a study cohort can induce a number of potential undesirable biases. For instance, including prevalent users can introduce “survivor bias” and/or “adherence bias” (sometimes identified by the overarching term “healthy users” or “healthy adherers”, complicate the control of confounding (since “baseline” covariate values may be affected by the treatment itself), and select for patients who find the medication either unusually tolerable or effective. Including past users can also introduce bias since patients who have had a past trial of a medication are likely to select it again if they (or their provider) believe it to have been effective, and are likely to choose an alternative if they (or their provider) believe it to have likely been ineffective.

However, a design choice is forced in nonrandomized research concerning how long of a “clean period” to implement as an exclusion criteria for cohort membership. What is usually done is to impose some uniform requirement, such as 12 months with no evidence of a prescription of either study medication. Obviously, such a requirement creates the possibility that “past users” with use more remote than 12 months will be included in the study cohort. Despite such a drawback, such a uniform period is usually chosen for nonrandomized studies comparing medications, because the alternative approach, prohibiting any past use, risks creating a variably-determined “clean period” between patients. If any past use is prohibited, then longtime users of a system are forced to not be exposed to the study medication for 3 years, 5 years, 7 years, etc. (depending on the length of their electronic medical record), whereas patients more recently entering the cohort by default do not have such a restriction, since their medical record does not extend back as far.

In this study, because we had some concern that we might have inadequate sample size to examine a uniform follow-up period (i.e., 365 days from initiation), we deliberately chose a less restrictive “clean period” of 6 months. However, for the small number of patients for which we had evidence of past use of either medication, a covariate was included in the high-dimensional propensity score denoting past use of either medication. (This approach is the approach recommended when the “incident user” design was described). This approach led to an extremely similar proportion of patients in both treatment groups having prior exposure to one of the two medications (11.9% of the hdPS-patients initiating valproate and 12.0% of the hdPS-matched patients initiating lithium). While these procedures do not eliminate entirely the possibility for bias, especially in VHA studies in which outside medication use is a possibility, they likely reduce substantially the impacts of any bias relating to prevalent or past users.
**Additional references**


