# Associations between neighbourhood characteristics and depression: a twin study

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## ABSTRACT

**Background** Depression is an important contributor to the global burden of disease. Besides several known individual-level factors that contribute to depression, there is a growing recognition that neighbourhood environment can also profoundly affect mental health. This study assessed associations between three neighbourhood constructs—socioeconomic deprivation, residential instability and income inequality—and depression among adult twin pairs. The twin design is used to examine the association between neighbourhood constructs and depression, controlling for selection factors (ie, genetic and shared environmental factors) that have confounded purported associations.

**Methods** We used multilevel random-intercept Poisson regression among 3738 same-sex twin pairs from a community-based twin registry to examine the association between neighbourhood constructs and depression. The within-pair association controls for confounding by genetic and environmental factors shared between twins within a pair, and is the main parameter of interest. Models were adjusted for individual-level income, education and marital status, and further by neighbourhood-level population density.

**Results** When twins were analysed as individuals (phenotypic model), all neighbourhood constructs were significantly associated with depression. However, only neighbourhood socioeconomic deprivation showed a significant within-pair association with depression. A 10-unit within-pair difference in neighbourhood socioeconomic deprivation was associated with 6% greater depressive symptoms (1.06, 95% CI 1.01 to 1.11); the association did not substantially change in adjusted models.

**Conclusion** This study provides new evidence linking neighbourhood socioeconomic deprivation with greater depression. Future studies should employ longitudinal designs to better test social causation versus social selection.

## INTRODUCTION

Depression is a considerable public health problem. Among adults in the USA, the prevalence of diagnosed depression is approximately 8%, and antidepressants are the most frequently prescribed drugs.[1–4] Healthcare utilisation and loss of productivity due to depression cost society up to $97 billion annually.[1]

It is well accepted that individual-level factors such as socioeconomic status and social isolation influence depressive symptoms by affecting behaviours, moods and neuroendocrine stress responses, and by modifying gene expression through epigenetic processes.[5 6] There is, however, a growing recognition that neighbourhood-level characteristics also contribute to poor mental health risk, independent of individual-level characteristics.[7] Three neighbourhood constructs of particular interest are socioeconomic deprivation, residential instability and income inequality.

These constructs affect mental health through multiple pathways. Neighbourhood socioeconomic deprivation may lead to negative perceptions of neighbourhood quality and fear of crime and victimisation, preventing the creation of social ties,[8 9] and can impact the quality of neighbourhood infrastructure and local amenities including parks and recreation facilities and healthcare services.[10–12] Similar to neighbourhood deprivation, residential instability, or the extent to which residents remain in the neighbourhood over time, may impede the formation of social ties.[9 13] Income inequality, defined as an unequal distribution of income among a population, decreases the public services and amenities offered if those with higher incomes withdraw from participation in such services; decreases the sense of civic fairness and justice; and increases perceived loss of autonomy and helplessness in the face of obstacles, discrimination and victimisation.[14 15]

Despite positive findings in previous studies, support for the association between these neighbourhood factors and mental health outcomes is limited by concerns of bias due to individual self-selection into neighbourhoods. Traditional observational studies address this concern by explicitly measuring and adjusting for variables that are thought to drive self-selection; however, it is not possible to measure all variables associated with selection into neighbourhoods.[16] Because residential self-selection can be driven by genetic and childhood upbringing factors,[17] the twin study design partially addresses this bias.[18] Twins reared together share both their genes and their upbringing, but are frequently discordant in behaviour and location of residence in later life. It is therefore possible to investigate associations between neighbourhood characteristics and health outcomes while controlling for much of the confounding that would otherwise limit inference in an observational study among unrelated individuals.[18 19]

The aim of this study was to examine the associations between depression and neighbourhood deprivation, residential instability and income inequality, controlling for confounding by shared genetic and childhood environment factors. We hypothesised



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that more advantaged neighbourhood characteristics would be associated with less depressive symptoms.

## METHODS

### Participants

This study used a cross-sectional analysis of data from the Washington State Twin Registry (formerly the University of Washington Twin Registry), a community-based sample of adult twins who had been raised together. Construction of the registry has been described elsewhere.[20] Briefly, each twin completes a recruitment survey on enrolment, and a follow-up survey providing information on sociodemographic, lifestyle behaviour, and physical and mental health-related outcomes. Additionally, each twin's residential address is geocoded and linked to a variety of environmental factors. All procedures were reviewed and approved by the university's institutional review board.

All twins in the study were from same-sex pairs. Using standard questions about childhood similarity, twins were categorised as either identical (monozygotic, MZ) or fraternal (dizygotic, DZ). Compared with DNA-based methods, these questions have been shown to have greater than 90% accuracy at identifying zygosity.[21]

A total of 7476 twins (3738 pairs) were included in the study. The majority (70%) were MZ twins. Most lived in Washington State (74%); however, twins lived in the District of Columbia and all 50 states except Delaware. Approximately 78% of twins lived in a different census tract from their cotwin.

### Exposure measures

All neighbourhood exposures were measured at the census tract level. Neighbourhood socioeconomic deprivation was measured by the Singh Index, which used principal components analysis to combine 2010 census data on education, employment, income and income disparity, poverty, characteristics of the home and home, vehicle and telephone ownership.[22] Greater deprivation is represented by higher index scores.

Both residential instability and income inequality were derived from the 2010 American Community Survey 5-year estimates. Residential instability was operationalised as the percentage of the population in a given census tract who had moved into owner-occupied units within the previous 5 years. Income inequality was measured by the Gini Index. The Gini Index ranges from 0 to 1; higher values represent more unequal distributions where the majority of income is earned by a small proportion of the population.

Because of the considerable difference in scale between the outcome measure and neighbourhood deprivation and residential instability, the two neighbourhood exposures were rescaled for the analysis (divided by 10).

### Outcome measures

Depression was measured by the two-item Patient Health Questionnaire (PHQ-2).[23] The PHQ-2 is a shorter version of the nine-item scale (PHQ-9), and measures self-reported depressive symptoms through questions about the two cardinal symptoms from the PHQ-9: depressed mood and the inability to experience pleasure. Respondents were asked how often in the last 4 weeks they had been bothered by either symptom (0 not at all; 1 several days; 2 more than half the days; 3 nearly every day). Responses were then summed to create a scale of symptom severity. The measure has been validated in other populations using the Diagnostic and Statistical Manual of Mental Disorders, 4th Edition as the gold standard, and has shown substantial rater agreement when compared with a mental health professional interview ($\kappa$=0.62).[23] While the longer nine-item scale is more commonly used in research on neighbourhood effects,[24] the PHQ-2 has shown acceptable validity compared with the PHQ-9.[25]

### Covariates

Traditional confounders of age, sex and race/ethnicity are inherently controlled for in the twin model, and so not included as covariates in this analysis, except as potential effect modifiers in sensitivity analysis described below. At the individual level, we decided a priori to include annual household income, education and marital status. At the census tract level, we included population density (people/square mile).

### Statistical analysis

To evaluate associations between the neighbourhood exposures and depressive symptoms, we used a multilevel random intercept model with the outcome modelled as a Poisson distribution. This is a particular case of the non-linear mixed effects model. Random intercepts at the census tract and twin-pair level were included to account for the correlation between twins within a pair and between individuals within the same census tract.

We first estimated the phenotypic association by regressing depression on the neighbourhood exposures, treating each individual as a singleton instead of a member of a twin pair. This model assumes that the average difference in outcome associated with a given difference in exposure is the same for twins within a pair as for unrelated individuals. Thus, although the model accounts for the correlation in the data through the use of random intercepts for twin pair and Census tract, it does not provide the within-pair estimates that inherently adjust for shared genetic and environmental characteristics.

Second, to estimate the within-pair associations, we used the model shown in equation 1:[26]

$$\begin{aligned}\log(\lambda_{ij}) = \quad & \beta_0 + \beta_B * X_i + \beta_w * (X_{ij} - X_i) \\ & + \beta_3 * g_z + \beta_4 * g_z * (X_{ij} - X_i) \\ & + \mu_{k[ij]} + \mu_I \end{aligned} \qquad (1)$$

where $y_{ij}$ represents the risk of depression for twin $j$ in pair $i$ as a function of the mean neighbourhood exposure of twin-pair $i$, $x_i$ and each individual twin's deviation from their twin-pair mean, $(x_{ij} - x_i)$. Pair zygosity, $g_z$, is coded 0 for MZ twins and 1 for DZ twins, and $\mu_{k[ij]}$ and $\mu_i$ are random intercepts for census tract and twin pair, respectively.

Due to the nature of the twin model, the within-pair association for MZ twins ($\beta_W$) is not subject to confounding by genetic or shared childhood environment factors. When exponentiated, it can be interpreted as the ratio of depressive symptoms associated with a one-unit difference in neighbourhood exposure within a MZ twin pair, conditional on the mean neighbourhood exposure of the twin pair. The between-pair coefficient, $\beta_B$, represents the extra variation in depression due to differences between twin pairs.

The inclusion of an interaction term for zygosity can assist in making inferences about genetic confounders. The within-pair difference for MZ twins is $\beta_W$; for DZ twins, it is $\beta_W + \beta_4$. Because MZ twins share all their genes and DZ twins share only half their genes, if the within-pair association for MZ twins is significantly different from that for DZ twins ($\beta_4 \neq 0$), this is suggestive of genetic confounding in the observed association. If the two within-pair associations were not significantly

different, however, we removed zygosity from the model, simplifying the model to equation 2:[27]

$$\log(\lambda_{ij}) = \beta_0 + \beta_B * X_i + \beta_w * (X_{ij} - X_i) + \mu_{k[ij]} + \mu_i. \quad (2)$$

In this instance, however, we still present results stratified by zygosity in addition to the main results of equation 2.

We first regressed depression only on the neighbourhood exposure (model A). Each subsequent model included the potential confounders; first, the individual-level covariates of income, education and marital status (model B) and then these individual-level covariates as well as neighbourhood-level population density (model C). Models were fit using the lme4 package in R.[28]

We conducted two sensitivity analyses to further explore the association between these neighbourhood characteristics and depression. First, for any neighbourhood characteristics that showed a statistically significant within-pair association with depression, we used interaction terms to test age (years) and sex (male/female) as effect modifiers. There are substantial differences in the prevalence of depression by both age and sex, and so we wanted to explore the potential for the association between various neighbourhood characteristics and depression to vary based on these factors.

Second, we conducted the same analysis limited to twins who were discordant for depression. We defined this as twins who had a within-pair difference in PHQ-2 score of at least 3 (n=318 individuals, 159 pairs). A score of 3 or greater on the PHQ-2 is commonly used to indicate depression; limiting to twins with a within-pair difference of at least 3 results in a study sample where one twin would be categorised as depressed and the other would not.

## RESULTS

Table 1 gives select characteristics of the 7476 twins included in the study. The majority were female (66%), and the study sample was overwhelmingly non-Hispanic white (92%). Most respondents had greater than a high school education (82%) and were married or living with a partner (56%). Eight percent of the sample scored a 3 or greater on the PHQ-2, indicating the presence of diagnosable depression. Approximately 14% of the sample moved residential locations within the past 5 years.

**Table 1** Select characteristics of 7476 adult twins (3738 pairs) in the Washington State Twin Registry, 2009–2013

| | Mean | SD |
|---|---|---|
| Age | 41.0 | 17.1 |
| Gini Index | 0.40 | 0.07 |
| Population density | 4243.7 | 7772.9 |
| Singh Index | 89.1 | 20.6 |
| PHQ-2* | 0.81 | 1.24 |
| | **n** | **%** |
| Male | 2582 | 34.5 |
| White | 6910 | 92.4 |
| Hispanic | 303 | 4.1 |
| Income | | |
| <$60 000 | 3528 | 47.2 |
| ≥$60 000 | 3944 | 52.8 |
| Education | | |
| Less than HS | 195 | 2.6 |
| HS graduation | 1169 | 15.6 |
| Some college | 2663 | 35.6 |
| Bachelors or more | 3449 | 46.1 |
| Marital status | | |
| Single | 2395 | 32.0 |
| Living as married | 4169 | 55.8 |
| Previously married | 912 | 12.2 |
| PHQ-2* | | |
| 0 | 4427 | 59.2 |
| 1 | 1251 | 16.7 |
| 2 | 1197 | 16.0 |
| 3 | 246 | 3.3 |
| 4 | 190 | 2.5 |
| 5 | 67 | 0.9 |
| 6 | 98 | 1.3 |

*The two-item Patient Health Questionnaire used to measure depressive symptoms.
Continuous variables shown as mean ±SD and categorical variables as counts (n) and percentages.
HS, high school.

### Phenotypic models

All neighbourhood exposures were significantly associated with depressive symptoms in the phenotypic models (data not shown). The interaction terms with zygosity were not significant, and were removed from the models. A 10-unit difference in Singh Index was associated with approximately 6% greater depressive symptoms (1.06; 95% CI 1.03 to 1.13); a 10-unit difference in residential instability was associated with approximately 3% greater depressive symptoms (1.03; 95% CI 1.00 to 1.04); and a completely unequal income distribution (Gini Index value of 1) was associated with approximately 78% greater depressive symptoms compared with complete income equality (Gini Index value of 0) (1.78; 95% CI 1.01 to 3.13).

### Within-between twin models

Only neighbourhood deprivation showed significant within-pair associations in the within-between models. The interaction term with zygosity was not significant in the neighbourhood deprivation model; thus, we used equation 2 to assess the association with depression. In the unadjusted model, a 10-unit difference in neighbourhood deprivation was associated with nearly 6% greater depressive symptoms (1.06, 95% CI 1.01 to 1.11), conditional on the mean deprivation score for the twin pair; this association did not substantially change when adjusting for individual and neighbourhood-level covariates (table 2). Individuals in the 75th percentile of neighbourhood deprivation (Singh Index=101.9) had on average 12% greater depressive symptoms (1.12, 95% CI 1.02 to 1.23) than those residing in the 25th percentile of neighbourhood deprivation (Singh Index=81.6).

Although the interaction term with zygosity was not significant in the neighbourhood deprivation model, we present the fully-adjusted model, stratified by zygosity, in table 3. DZ twins had a larger within-pair association between neighbourhood deprivation and depression than did MZ twins (1.10, 95% CI 1.05 to 1.14; vs 1.03, 95% CI 1.00 to 1.06).

There were no significant within-pair associations for residential instability or income inequality.

### Sensitivity analyses

We did not find any significant interaction between neighbourhood deprivation and age or sex (data not shown).

**Table 2** Associations between neighbourhood deprivation and depressive symptoms* among 7476 adult twins (3738 pairs) in the Washington State Twin Registry, 2009–2013

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | exp(β) | 95% CI | exp(β) | 95% CI | exp(β) | 95% CI |
| Singh Index | | | | | | |
| Between pair | 1.06 | 1.03 to 1.20 | 1.02 | 0.99 to 1.06 | 1.02 | 0.99 to 1.06 |
| Within pair | 1.05 | 1.01 to 1.11 | 1.05 | 1.01 to 1.09 | 1.05 | 1.01 to 1.10 |
| Income | | | 0.92 | (0.90 to 0.94) | 0.93 | 0.91 to 0.94 |
| Education | | | 0.91 | (0.86 to 0.97) | 0.91 | 0.86 to 0.97 |
| Marital status | | | | | | |
| Single | | | 1.00 | | 1.00 | |
| Living as married | | | 0.78 | 0.70 to 0.88 | 0.78 | 0.69 to 0.87 |
| Previously married | | | 1.05 | 0.91 to 1.21 | 1.05 | 0.91 to 1.21 |
| Population density† | | | | | 1.01 | 0.94 to 1.10 |
| Random effects variance | | | | | | |
| Census tract | 0.12 | | 0.09 | | 0.09 | |
| Monozygotic twins | 0.74 | | 0.66 | | 0.67 | |
| Dizygotic twins | 0.00 | | 0.03 | | 0.02 | |

*Measured by the two-item Patient Health Questionnaire.
†Scaled to 10 000 people per square mile.
Model 1 unadjusted for covariates.
Model 2 adjusted for individual-level income, education and marital status.
Model 3 adjusted for individual-level income, education and marital status, and area-level population density.

Results for the fully adjusted neighbourhood deprivation model limited to twin pairs discordant for depression are given in table 4. The within-pair association between neighbourhood deprivation and depression symptoms is substantially greater in this model; adjusting for individual and neighbourhood-level covariates, a 10-unit difference in neighbourhood deprivation was associated with 20% greater depressive symptoms (1.20, 95% CI 1.14 to 1.26), conditional on the mean deprivation score for the twin pair.

## DISCUSSION

The results of this study support the hypothesis that greater neighbourhood socioeconomic deprivation is associated with greater depression, but do not provide evidence linking residential instability or income inequality to depression. The results of the sensitivity analysis limiting to twins discordant for depression further adds to our understanding of the complexity of the associations between neighbourhood deprivation and depression. Among twins where one member of the pair is depressed and the other is not, the magnitude of the association between neighbourhood deprivation and depression becomes much greater compared with the entire study population.

Results from previous studies of neighbourhood deprivation and depression are mixed.[7 29 30] A 2008 review of the literature found that 11 of 22 community-based studies showed a significant association between neighbourhood deprivation and depression among adults after controlling for individual-level characteristics,[29] while a subsequent review of the literature published between January 2009 and January 2010 found that two of five studies showed significant associations.[7] One potential explanation for the observed difference in study results is differences in operationalising neighbourhood deprivation.

**Table 3** Zygosity-specific associations between neighbourhood deprivation and depressive symptoms* among 7476 adult twins (3738 pairs) in the Washington State Twin Registry, 2009–2013

| | Monozygotic | | Dizygotic | |
|---|---|---|---|---|
| | exp(β) | 95% CI | exp(β) | 95% CI |
| Singh Index | | | | |
| Between pair | 1.02 | 1.00 to 1.05 | 1.02 | 0.98 to 1.05 |
| Within pair | 1.03 | 1.00 to 1.06 | 1.10 | 1.05 to 1.14 |
| Income | 0.92 | 0.91 to 0.93 | 0.93 | 0.91 to 0.95 |
| Education | 0.93 | 0.89 to 0.96 | 0.88 | 0.83 to 0.93 |
| Marital status | | | | |
| Single | 1.00 | | 1.00 | |
| Living as married | 0.78 | (0.73 to 0.84) | 0.79 | 0.71 to 0.88 |
| Previously married | 1.02 | (0.94 to 1.12) | 1.11 | 0.97 to 1.27 |
| Population density† | 1.03 | (0.97 to 1.10) | 0.99 | 0.94 to 1.05 |

*Measured by the two-item Patient Health Questionnaire.
†Scaled to 10 000 people per square mile.

**Table 4** Associations between neighbourhood deprivation and depressive symptoms* among 318 adult twins (159 pairs) in the Washington State Twin Registry with discordant depression scores, 2009–2013

| | exp(β) | 95% CI |
|---|---|---|
| Singh Index | | |
| Between pair | 0.99 | 0.95 to 1.03 |
| Within pair | 1.20 | 1.14 to 1.26 |
| Income | 0.94 | 0.92 to 0.96 |
| Education | 0.96 | 0.90 to 1.01 |
| Marital status | | |
| Single | 1.00 | |
| Living as married | 0.79 | 0.71 to 0.89 |
| Previously married | 1.04 | 0.91 to 1.18 |
| Population density† | 0.90 | 0.80 to 1.01 |

*Measured by the two-item Patient Health Questionnaire.
†Scaled to 10 000 people per square mile.

While measures of neighbourhood deprivation are commonly derived from administrative data, variables may be single indicators (eg, percentage of families living in poverty) or combinations of multiple indicators (eg, percentage of families living in poverty, percentage of female-headed households and percentage of individuals with a high school diploma/General Educational Diploma).[29] The inclusion of these different aspects of neighbourhood deprivation will affect results if they influence depression through different mechanisms. However, without testing specific theories or causal pathways, it is not possible to determine if contradictory conclusions are due to differences in study design and methodology or to the absence of important mechanisms from specific studies.[7]

Despite positive findings with neighbourhood deprivation, there was no association between depression and residential instability or income inequality. There has not been much previous research on mental health and residential instability; however, our results are inconsistent with other published studies.[9 31 32] One possible explanation is our use of a single indicator as a measure of instability. Previous studies have created more comprehensive measures by combining percentage of population moved in the last 5 years with factors such as percentage of residents with home ownership, percentage of those living in apartment buildings and percentage of vacant households.[9 31 32] Furthermore, we looked only at residential instability of the current neighbourhood, whereas residential instability may be more aetiologically relevant during childhood.[32]

Our finding of no association between income inequality and depression is also inconsistent with previous studies.[33 34] We conceptualised income inequality at the neighbourhood level, while other studies have used state-level or country-level measures. Depending on the proposed mechanism, the level of the measure chosen can obscure the association. If income inequality affects health primarily through decreased government services, inequality at the city level or state level may be the most relevant. Alternatively, if income inequality erodes social cohesion and contributes to social disorder, the neighbourhood (census tract) would be a more appropriate level.[34 35]

While the Gini Index is the most commonly used measure of income inequality, and previous research suggests that the choice of measure will not substantially change the results,[36] it is possible that a different measure would give different results.[35] Finally, our negative results related to income inequality may be explained by the threshold effect, where adverse health effects appear only after the neighbourhood reaches a certain threshold in income inequality.[34] Despite the lack of consistency with previous studies regarding depression and income inequality, the robust study design and methods employed provides strong evidence to support the lack of association found in this study.

### Strengths and limitations

An important strength of this study is the use of a large community-based sample of twins raised together, which controls for confounding due to shared genetic and childhood environment factors. Early-life socioeconomic status predicts socioeconomic status in adulthood, and the characteristics of the neighbourhood in which a child is born and raised are strongly correlated with those of the neighbourhood in which they will live as adults. By additionally adjusting for select individual-level sociodemographic characteristics, this study can overcome some of the concerns regarding residential self-selection that limit the ability to draw causal inference from observational studies. Because it is neither practical nor ethical to randomise individuals to different neighbourhood environments, a genetically informed twin model is the best approximation to an experimental design.[18 26]

The twin design, however, does not inherently account for other factors that can affect self-selection into neighbourhoods. For example, we were unable to adjust for general neighbourhood preference or selection factors such as wanting to live close to work or within a certain school's catchment area. A further limitation is the cross-sectional study design; while the underlying hypothesis in our study is that neighbourhood characteristics affect health (social causation), previous studies have shown that individual health can affect neighbourhood choice (social selection).[37] Despite this concern, prior research suggests that, while social selection may be an important factor for explaining the association between socioeconomic factors and some mental disorders like schizophrenia, social causation is the more relevant mechanism for depression.[38]

A further limitation is the use of census tracts to represent neighbourhoods. Selecting neighbourhood boundaries would ideally be driven by theoretical considerations instead of methodological ones. However, the availability and consistency of boundaries over time make census tracts a widely used operationalisation of neighbourhood in the USA. Additionally, census tracts are designed to be economically homogeneous, decreasing concerns that individual heterogeneity may obscure results.[39] Furthermore, state and local governments may allocate resources based on these administrative areas, and this can impact the experience of the individuals residing in them.[40]

Finally, the lack of racial diversity in the sample limits generalisability to other populations. There was, however, substantial diversity of income, and while the twins in the registry may not be representative of the US.population as a whole, they are generally representative of residents of Washington State.

## CONCLUSION

The results of this study suggest that greater neighbourhood socioeconomic deprivation is associated with more depressive symptoms. Future studies should employ longitudinal designs to better test social causation versus social selection. Longitudinal

### What is already known on this subject

Depression contributes to the global burden of disease. Several known individual-level factors, such as socioeconomic status, contribute to depression. However, neighbourhood-level factors are gaining appreciation for their contributions to mental health.

### What this study adds

This study assessed the associations between neighbourhood factors, including area-level socioeconomic deprivation, residential instability and income inequality, and depression among a large sample of adult twin pairs. The twin sample controls for confounding of the association between neighbourhood factors and depression by shared genetic and childhood environment factors. Using this model, the results provide evidence to support the concept that neighbourhood factors are associated with depression, even when controlling for known individual-level factors as well as shared genetic and childhood environment factors.

designs would also allow for assessing the trajectory of depression and empirically testing proposed pathways and theories.

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**Contributors** HC-C and GED formulated the original research questions and designed the study. HC-C and GED were responsible for and provided the data. Critical input from WEB, SAAB, JW and RLM refined the research questions, methods and analyses as part of HC-C's doctoral dissertation. HC-C analysed the data with guidance from JW and a consultant. HC-C drafted the manuscript with critical input and feedback on all aspects of data interpretation and subsequent manuscript versions from all authors.

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