


BMJ Open Pathways between neighbourhood factors, stress and glycaemic control in individuals with type 2 diabetes in Southeastern United States: a cross-sectional pathway analysis

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ABSTRACT

Objectives Understanding the pathway by which neighbourhood factors influence glycaemic control may be crucial to addressing health disparities in diabetes. This study aimed to examine if the pathway between neighbourhood factors and glycaemic control is mediated by stress.

Design Structured equation modelling (SEM) was used to investigate direct and indirect effects in the relationship between neighbourhood factors, stress and glycaemic control, with standardised estimates to allow comparison of paths.

Participants Data was obtained from 615 adults with type 2 diabetes in the Southeastern United States.

Primary and secondary outcome measures The primary outcome variable was glycaemic control determined by glycated haemoglobin (HbA1c) within the prior 6 months. Neighbourhood factors included neighbourhood violence, aesthetic quality of the neighbourhood, access to healthy food, and social cohesion. Stress was measured using the perceived stress scale.

Results In the final model ($\chi^2(158)=406.97, p<0.001$, root mean square error of approximation=0.05, p-close 0.38, Comparative Fit Index=0.97, Tucker-Lewis index=0.96, the coefficient of determination=1.0), violence ($r=0.79, p=0.006$), neighbourhood aesthetics ($r=0.74, p=0.02$) and social cohesion ($r=0.57, p=0.04$) were significantly associated with higher perceived stress. Stress ($r=0.06, p=0.004$) was directly associated with higher glycaemic control. Significant indirect effects existed between violence and higher HbA1c ($r=0.05, p=0.04$). After controlling for other neighbourhood factors, there was no significant relationship between access to healthy food and either stress or glycaemic control.

Conclusions While a number of neighbourhood factors were directly associated with stress, only neighbourhood violence had a significant indirect effect on glycaemic control via stress within the tested pathway. Future studies should examine individual-level stress management interventions and should consider community-level interventions targeting neighbourhood violence as strategies for addressing disparities in diabetes.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ Structured equation modelling (SEM) was used to investigate direct and indirect effects.
- ⇒ SEM allows multiple independent and multiple dependent variables to be incorporated into a hypothesised model and allows estimation of effects using both measured and observed variables.
- ⇒ Cross-sectional data can be used when conducting SEM, however, due to the nature of the data causation cannot be assumed.

INTRODUCTION

Diabetes is the seventh leading cause of death in the USA and approximately 34.2 million Americans have diabetes.¹ Racial and ethnic minorities experience disproportionate diabetes risk, rates of complications and mortality compared with their white counterparts. The prevalence of diabetes in the USA has increased among adults 18 years or older from an estimated 9.5% in 1999–2002 to 12.0% in 2013–2016.¹ Persistent disparities for Hispanic and non-Hispanic black individuals in achieving diabetes care targets, including glycaemic control, and access to care remain despite interventions targeting these populations.^{2–4} Such health disparities are indicative of pervasive structural barriers in the USA, one of which is racial residential segregation.⁴ The consequences of racial residential segregation are borne disproportionately by communities of colour and may expose them to neighbourhood and environmental factors that may affect residents with diabetes and their ability to achieve the glycaemic control necessary to prevent complications with their diabetes.^{5–10} Therefore, understanding the pathway by which neighbourhood factors

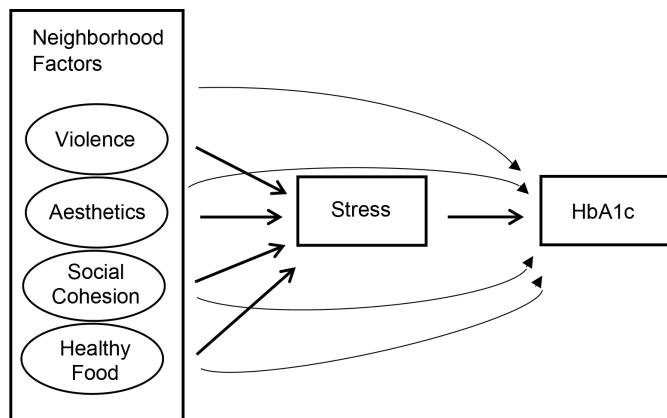


Figure 1 Hypothesised model showing direct and indirect pathways between neighbourhood factors and glycaemic control via perceived stress. HbA1c, glycated haemoglobin.

influence glycaemic control may be a crucial component to addressing health disparities.

Neighbourhood factors, including neighbourhood violence, access to healthy foods, social cohesion, social support, neighbourhood aesthetics, quality of environment and walking/exercise environment have been identified as potential influences on individual and community level health outcomes.^{4–17} Prior literature supports the hypothesis that neighbourhood factors may undermine self-care behaviour, thereby preventing individuals from achieving glycaemic control. For example, Smalls *et al* examined the pathways through which neighbourhood factors influence self-care behaviours and glycaemic control and found that neighbourhood characteristics have direct and indirect effects on glycaemic control via self-care behaviours.¹³ A second path analysis found that walking environment, social support, neighbourhood safety and neighbourhood problems had indirect effects on glycaemic control via food insecurity and medication adherence, while social cohesion had a direct effect on glycaemic control.¹⁷ It is likely that additional pathways further explain the association between neighbourhood factors and glycaemic control, but more research is necessary to elucidate these areas for future focus.^{13 17}

Chronic environmental stressors have been associated with poor diabetes outcomes.¹⁸ Physiologically, acute and chronic psychosocial stress are known to activate peripheral inflammatory pathways and systemic low-grade inflammation.¹⁹ Low-grade inflammation has been identified as key player in the development of chronic disease and increases in systemic inflammatory activity has been implicated as a mechanism leading to metabolic syndrome, insulin resistance and type 2 diabetes.²⁰ Preliminary evidence suggests that once an individual has diabetes, stress may serve as an important mediator of the relationship between neighbourhood factors and health outcomes.^{21–24} For example, increased neighbourhood violence has been linked to both perceived stress and low density lipoprotein cholesterol.^{11 12 21} Recent qualitative research has also found that people living with diabetes

in an inner-city environment indicate that their general experience of stress is largely influenced by the environment they live in and that neighbourhood factors, such as violence, take away from their sense of safety and security which is disruptive to caring for their diabetes and overall health.²⁵ However, most research has focused on either the relationship between neighbourhood factors and stress or the relationship between neighbourhood factors and health outcomes, and less information exists to understand if the pathway from neighbourhood factors to diabetes outcomes are mediated by stress.^{5 18}

To address this gap in knowledge, we sought to study the hypothesised pathway in which the relationship between neighbourhood factors and glycaemic control is mediated by stress. While there are many types of stressors, including diabetes-related stressors, and multiple ways stress plays out in an individual's life, we specifically chose general psychological stress as the focus of our model based on prior literature and qualitative findings from our team.²⁵ Using path analysis, we analysed cross-sectional survey and health record data from patients with diabetes in two Southeastern primary care clinics, hypothesising that neighbourhood factors would influence glycaemic control indirectly via stress.

METHODS

Sample

This study was conducted using data from a cross-sectional study of 615 adults with type 2 diabetes recruited from two primary care clinics in the Southeastern United States. Eligible individuals were ages 18 or older, diagnosed with type 2 diabetes based on their medical record and had the ability to communicate in English. If patients were determined to be cognitively impaired and unable to complete the questionnaire due to dementia or active psychosis based on interaction or chart documentation, they were ineligible for participation.

Recruitment included directly approaching patients in clinic waiting rooms and mailing letters of invitation to patient homes using the address in their medical records. A detailed explanation of the study was given prior to consent, after which participants completed a series of validated questionnaires that captured social determinants of health factors, sociodemographics and diabetes self-care information. Health status was assessed from participant response to the question 'in general, would you say that your health is excellent, very good, good, fair or poor?'

Patient and public involvement

Patients or the public were not involved in the design, reporting or dissemination plans of our research.

Outcome—glycaemic control

The most recent glycated haemoglobin (HbA1c) within the prior 6 months was abstracted from the medical record for each participant. Glycaemic control was used

Table 1 Sample demographics (n=615)

	Mean±SD or %
Age	61.3±10.9
Diabetes duration	12.3±9.1
Education (years of school)	13.4±2.8
Employment (hours per week)	12.5±19.0
Race	
White	33.0
Black	64.9
Other	2.1
Gender	
Women	38.4
Men	61.6
Marital status	
Never married	11.2
Married	49.7
Separated/divorced/widow	39.1
Income	
<US\$19 000	41.6
US\$20 000–US\$34 999	25.1
US\$35 000–US\$49 999	13.8
US\$50 000 or more	19.5
Insurance	
None	9.3
Private	20.2
Medicare/Medicaid	34.9
VA	23.9
Other	11.7
Health status	
Excellent/very good	13.3
Good	38.2
Fair/poor	48.5

as a continuous measured variable in the structured equation model.

Neighbourhood factors

Neighbourhood factors were measured using four scales developed by Echeverria *et al* to capture neighbourhood violence, aesthetic quality of the neighbourhood, access to healthy food and social cohesion.²⁶ In the questionnaire, neighbourhood violence consisted of 4 items, neighbourhood aesthetics consisted of 7 items, access to healthy food consisted of 11 items and social cohesion consisted of 5 items. The scales included items with response categories ranging from 1 to 5, for which 1 indicated strongly agree; 2 agree; 3 neutral (neither agree or disagree); 4 disagree; and 5 strongly disagree. The violence scale response options ranged from 1 to 4 for which 1 indicated often; 2 sometimes; 3 rarely; and

4 never. Thus, the higher the score the more perceived problems in the neighbourhood.

Latent factors were created for each scale with the questions that had the strongest loading and that held together as one factor being maintained for the final analysis. In the final latent structures neighbourhood violence had four items, neighbourhood aesthetics had three items, access to healthy foods had six items and social cohesion had five items. The questions that were maintained in each of the final latent structures are listed below:

- ▶ Neighbourhood violence—frequency in the last 6 months that the participant knew of fights in which a weapon was used, gang fights, sexual assault or rape, robbery or mugging in the neighbourhood.
- ▶ Neighbourhood aesthetics—my neighbourhood is attractive, there are interesting things to do in my neighbourhood, there is enjoyable scenery in my neighbourhood.
- ▶ Access to healthy foods—it is easy to purchase fresh fruits and vegetables, there is a large selection of fresh fruits and vegetables, fresh produce is of high quality, it is easy to purchase low-fat products, there is a large selection of low-fat products, low-fat products are of high quality
- ▶ Social cohesion—this is a close-knit community, people here are willing to help their neighbours, people generally get along, people can be trusted, people share the same values.

Stress

To capture the concept of general stress, we measured stress using the perceived stress scale, a 4-item scale that assesses generalised perceptions of stress from external situations and internal triggers that cause stress for an individual.²⁷ Questions ask about how often respondents felt they were unable to control important things in their life, how often they felt confident about the ability to handle personal problems, how often they felt things were going their way and how often they felt difficulties were piling up so high they could not overcome them. Responses for each of the four questions range from ‘0’ (never) to ‘4’ (very often) and questions ask about the frequency of feelings related to events in the previous month.²⁷ The Cronbach alpha value is 0.69 and scores are highly correlated with stress, depression and anxiety.²⁸

Statistical analysis

Structured equation modelling (SEM) was used to investigate direct and indirect effects in the relationship between neighbourhood factors, stress and glycaemic control. This methodology was chosen as it allows multiple independent and multiple dependent variables to be incorporated into a hypothesised model and allows estimation of effects using both measured and observed variables.²⁹ SEM tests hypothesised models by combining a measurement model, identified through factor analysis, and structural model, developed through regression and path analysis.³⁰ Figure 1 shows the hypothesised model we

Table 2 Descriptive statistics for measures included in the path model

	Mean values±SD	Range for scale
Glycaemic control (HbA1c)	7.9±1.8	
Perceived stress	5.3±3.3	0–15
Neighbourhood violence		
Item 1	1.4±0.7	1–4
Item 2	1.2±0.5	1–4
Item 3	1.1±0.4	1–4
Item 4	1.4±0.7	1–4
Neighbourhood aesthetics		
Item 1	2.2±1.0	1–5
Item 2	2.8±1.1	1–5
Item 3	2.4±1.1	1–5
Access to healthy foods		
Item 1	2.7±1.3	1–5
Item 2	2.7±1.3	1–5
Item 3	2.7±1.3	1–5
Item 4	2.6±1.3	1–5
Item 5	2.6±1.3	1–5
Item 6	2.7±1.3	1–5
Social cohesion		
Item 1	2.6±1.0	1–5
Item 2	2.3±0.9	1–5
Item 3	2.3±1.0	1–5
Item 4	2.5±0.9	1–5
Item 5	2.8±1.0	1–5
HbA1c, glycated haemoglobin.		

tested. Cross-sectional data can be used when conducting SEM, however, due to the nature of the data causation cannot be assumed.²⁹ Following recommended guidelines for conducting SEM, an a priori hypothesised model was developed and then tested using Stata V.14 software (StataCorp, College Station, Texas, USA) to identify if the model was supported by the data. A sample size of 615 provided the recommended 20:1 ratio of subjects to variables needed to maintain 80% power while estimating stable parameters and SEs for each hypothesised pathway, while minimising the risk of oversaturating the model.^{30 31}

First, we investigated the variables within each of the hypothesised latent constructs and glycaemic control as the primary outcome. Descriptive statistics were used to ensure data were multivariate normal, linearly related and at least interval scaled to meet SEM assumptions for data analysis. Correlations between all variables were also run to investigate risk for multicollinearity. Second, we conducted confirmatory factor analysis to identify single factors for each latent structure (neighbourhood violence, neighbourhood aesthetics, access to healthy food, social

cohesion and stress). The alpha statistic and factor loading were used to examine each factor and ensure goodness of fit for each hypothesised latent variable after using principal component factor analysis. Finally, SEM was used to investigate the relationship between neighbourhood factors, stress and glycaemic control. Stress was hypothesised to partially mediate the relationship between neighbourhood factors and glycaemic control. Direct and indirect effects were assessed for each hypothesised path, all analyses were conducted using standardised estimates, and the ‘mlmv option’ in Stata was used to retain variables rather than using listwise deletion. Each path was investigated based on magnitude and direction of the coefficient. The overall model was investigated based on a series of fit statistics, as recommended by SEM best practices.³² Since the χ^2 statistic is sensitive to large sample sizes, root mean square error of approximation (RMSEA), Tucker-Lewis Index (TLI) and Comparative Fit Index (CFI) were used. The model was considered to have a good fit if RMSEA<0.08, TLI<0.95 and CFI<0.95.^{32 33} Throughout all analyses $p<0.05$ was considered statistically significant.

RESULTS

Table 1 provides sample demographics for the 615 adults with diabetes included in this analysis. The mean age was 61.3 years, mean length of diabetes diagnosis was 12.3 years and mean number of years of school was 13.4 years. The majority of the sample were non-Hispanic black (64.9%), approximately half were married (49.7%) and less than 10% had no insurance.

Table 2 provides descriptive statistics for all variables incorporated into the model.

Table 3 provides correlations between all variables. The mean HbA1c was 7.9%.

Table 4 presents the standardised direct, indirect and total effects for the relationship between neighbourhood factors, stress and glycaemic control, and **figure 2** shows the final model with significant direct paths indicated. Standardised estimates in **table 4** and **figure 2** can be interpreted as the change in SD of the outcome resulting from a change of 1 SD in the predictor. Therefore, estimates can be compared with higher numbers indicating a stronger relationship. In the final model ($\chi^2(158)=406.97$, $p<0.001$, RMSEA=0.05, p -close 0.38, CFI=0.97, TLI 0.96, CD (the coefficient of determination)=1.0), violence ($r=0.79$, $p=0.006$), neighbourhood aesthetics ($r=0.74$, $p=0.02$) and social cohesion ($r=0.57$, $p=0.04$) were significantly associated with higher perceived stress. Stress ($r=0.06$, $p=0.004$) was directly associated with higher glycaemic control. Significant indirect effects existed between violence and higher HbA1c ($r=0.05$, $p=0.04$).

DISCUSSION

Within the tested pathway in this sample of adults with diabetes, neighbourhood violence had a significant

Table 3 Pairwise correlations of all measures included in path model

	1	2	3	4	5	6	7	8	9	10
1. Glycaemic control	-	-	-	-	-	-	-	-	-	-
2. General diet	-0.12*	-	-	-	-	-	-	-	-	-
3. Specific diet	-0.07	0.36*	-	-	-	-	-	-	-	-
4. Exercise	-0.10*	0.29*	0.15*	-	-	-	-	-	-	-
5. Blood sugar testing	0.09*	0.21*	0.19*	0.11*	-	-	-	-	-	-
6. Foot care	0.03	0.22*	0.22*	0.12*	0.28*	-	-	-	-	-
7. Self-efficacy	-0.34*	0.37*	0.22*	0.21*	0.09*	0.08	-	-	-	-
8. Stress	0.12*	-0.22*	-0.22*	-0.13*	-0.11*	-0.07	-0.35*	-	-	-
9. Violence	0.12*	-0.09*	-0.08	0.02	-0.04	0.03	-0.15*	0.19*	-	-
10. Crime	0.13*	-0.12*	-0.10*	-0.05	-0.02	0.02	-0.23*	0.18*	0.46*	-
11. Discrimination	0.06	-0.10*	-0.13*	0.01	-0.002	-0.01	-0.17*	0.27*	0.25*	0.20*

*p<0.05.

indirect effect on glycaemic control via stress, while neighbourhood aesthetics and social cohesion had a significant direct relationship with stress, but no indirect association with glycaemic control. After controlling for other neighbourhood factors within the tested pathway, there was no significant relationship between access to healthy food and either stress or glycaemic control. Based on the results, this study suggests that stress is a possible pathway between neighbourhood violence and diabetes outcomes

and should be investigated in the future as a target for interventions.

Our findings are consistent with other studies which have linked neighbourhood violence with individual stress levels,¹¹ though to our knowledge this is the first to evaluate the stress pathway as it relates to neighbourhood factors and clinical outcomes. One population-based study examining the association of stress biomarkers with neighbourhood characteristics found that neighbourhood violence was associated with alterations in the circadian rhythm of cortisol even after adjusting for individual socioeconomic status (SES).²¹ In subjects affected by chronic stress, alterations to the hypothalamus pituitary adrenal axis, and its main end hormone cortisol, have been associated with altered basal activity, characterised

Table 4 Standardised direct, indirect and total effects for the relationship between neighbourhood factors, glycaemic control and perceived stress

	Direct effects	Indirect effects	Total effects
Glycaemic control			
Perceived stress	0.06**	-	0.64**
Violence	-	0.05*	0.05*
Aesthetics	-	0.05	0.05
Healthy food	-	-0.002	-0.03
Social cohesion	-	0.04	0.04
Perceived stress			
Violence	0.79**	-	0.79**
Aesthetics	0.74*	-	0.74*
Healthy food	-0.04	-	-0.04
Social cohesion	0.57*	-	0.57*

Significant direct effects indicate direct association between variables. For example, higher levels of perceived stress are associated with higher glycaemic control. Significant indirect effects indicate pathways through which variables influence outcomes. For example, increased levels of violence is associated with glycaemic control through perceived stress.

*p<0.05.
**p<0.01.
***p<0.001.

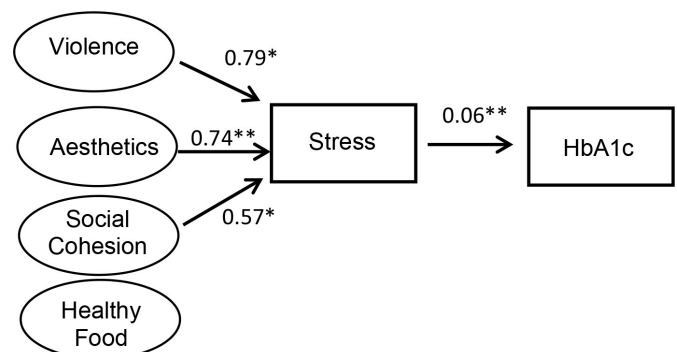


Figure 2 Final model showing significant pathways between neighbourhood factors and glycaemic control. Neighbourhood factors were directly associated with stress, while only neighbourhood violence had a significant indirect effect on glycaemic control via stress. Note: Standardized estimates indicated. Overall model fit: $\chi^2(158)=406.97$, $p<0.001$, RMSEA=0.05, p -close 0.38, CFI=0.97, TLI 0.96, CD=1.0. *= $p<0.05$, **= $p<0.01$, ***= $p<0.001$. CD, the coefficient of determination; CFI, Comparative Fit Index; HbA1c, glycated haemoglobin; RMSEA, root mean square error of approximation; TLI, Tucker-Lewis index.

by loss of circadian rhythm and lower overall cortisol output throughout the day.³⁴

Based on these findings, individual-level interventions that target stress management by focusing on social support and/or family support to increase self-efficacy may be effective in improving glycaemic control and achieving blood glucose, however, very few studies have examined the role of stress management in improving glycaemic control.^{35 36} In a prospective study by Surwit *et al*, patients with type 2 diabetes were randomised to undergo group diabetes education sessions with or without stress management training. After 1 year, stress management training was associated with a 0.5% significant reduction in HbA1c, suggesting that group stress management programmes can result in clinically significant benefits for patients with type 2 diabetes.³⁷ While these studies suggest that individual-level interventions may lower HbA1c levels for individuals living in neighbourhoods with high levels of environmental stress, they are unlikely to be sufficient in the absence of simultaneous community-wide efforts to reduce environmental stress.

By delineating a likely pathway by which neighbourhood factors may influence diabetes outcomes, our findings shed light into promising areas for future research. Prior literature has shown that diabetes self-management requires carrying out important self-care behaviours (eg, healthy diet, exercise and medication adherence) and this is likely a part of the relationship between stress and A1c. Neighbourhood factors interrupt self-care behaviours and are often related to other social risk factors and competing basic needs such as food and housing.^{15 17} Individuals with diabetes living in environments characterised by violence, discrimination, crime and segregation have reported that they are stressed by a perceived fundamental lack of safety and security and that this makes it hard to envision an ideal life for themselves or focus on their health.²⁵ One community-level intervention, neighbourhood greening of vacant land, has been shown to reduce individual-level stress levels.³⁸ This type of intervention generally involves low-cost remediation measures to improve the aesthetics of blighted and vacant land. Neighbourhood greening and blight remediation has consistently been shown to reduce neighbourhood violence, including shootings, evidence which further supports the pathway indicated by our findings.^{39 40} In addition to greening and blight remediation interventions, another community-level intervention uses the violence interruption model, also known as CureViolence, which employs trusted community members to change individual and community attitudes toward gun violence and intervene on escalating conflicts. In multiple randomised control trials, the intervention resulted in reductions in violent crime.⁴¹ Taken in sum with prior work suggesting high rates of diabetes in areas with more violence, our findings suggest such community-focused interventions could lead to improved diabetes outcomes, though further research is needed.⁴²

Limitations

Despite methodological strengths of this study, there are study limitations to note. First, because cross-sectional data was used we cannot determine a causal relationship between violence, stress or glycaemic control. Second, the study sample is specific to two primary care clinics in a particular region of the USA and therefore our findings may not be generalisable to the general population of adults with type 2 diabetes. Third, the sample was primarily comprised of black (65%) and non-Hispanic white (33%) respondents so results may not be generalisable to other racial/ethnic groups. Neighbourhoods across the USA that are under-resourced due to historical residential segregation by SES, race and ethnicity share similar neighbourhood characteristics described in this paper and patterns that maintain health disparities among their residents, and therefore this analysis may be relevant across multiple sociodemographic subpopulations.⁴ Fourth, diabetes-specific behaviours, such as treatment type, and psychosocial factors, such as diabetes distress, were not captured in this study but have been shown to influence both stress and glycaemic control in adults with diabetes. Similarly, the length of time an individual has been diagnosed may influence both their level of stress and their glycaemic control. Further studies should consider the relative importance of a variety of pathways indicated through the literature to exist between neighbourhood factors and glycaemic control, and if these pathways differ by factors such as length of time an individual has been diagnosed with diabetes.

CONCLUSION

Despite decades of research dedicated to reducing unequal diabetes outcomes between Hispanic, non-Hispanic black and white individuals with diabetes, dramatic disparities remain.^{3 4} This study found within the tested pathway that neighbourhood violence had a significant indirect effect on glycaemic control via stress, and therefore, future studies should identify the relative importance of different pathways between neighbourhood factors and glycaemic control, examine individual-level stress management interventions based on the type of stress an individual is experiencing and test community-level interventions targeting neighbourhood violence as strategies for addressing disparities in diabetes care targets.

Contributors EM-J, RW and LEE designed the study. LEE acquired and analysed the data. RW developed the analyses and interpreted the data and results. EM-J, RW, LH, SLW, CM and JAC drafted the initial manuscript. LEE is responsible for the overall content as the guarantor. All authors critically revised the manuscript for important intellectual content and approved the final manuscript.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Approvals were obtained from the Medical University of South Carolina institutional review board and the Ralph H. Johnson Veterans Affairs Medical Center Research and Development Program prior to study enrolment (PR000017676). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

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