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Nocturnal Blood Pressure Dipping Patterns and Orthostatic Hypotension as Markers of Vascular Ageing and Frailty in Community-Dwelling Older Adults

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Abstract

Background

Orthostatic hypotension (OH) and nocturnal blood pressure dipping patterns are common manifestations of impaired blood pressure regulation in older adults, but the interplay of these factors with frailty alongside measures of vascular ageing are understudied. This study examined associations between these blood pressure patterns, frailty, and arterial stiffness.

Methods

Community-dwelling adults aged ≥ 65 years with a Clinical Frailty Scale (CFS) score ≤ 6 were recruited. Frailty was assessed using PRISMA-7, Fried Frailty Scale, Short Physical Performance Battery (SPPB), and the Timed Up and Go (TUG) test. Arterial stiffness was measured using pulse wave velocity. Clinic blood pressure and 24-hour ambulatory blood pressure monitoring (ABPM) were recorded. OH was defined as a ≥ 20mmHg systolic or ≥ 10mmHg diastolic fall from sitting to standing. Nocturnal blood pressure patterns were categorised as dippers (> 10% fall), non-dippers (0–10% fall), and reverse dippers (any rise) during the night.

Results

One hundred participants were recruited (50 female; 92 Caucasian; mean age 74.6 years, range 65–101). Valid ABPM readings were available for 92 participants, classified as dippers (n = 40), non-dippers (n = 36), and reverse dippers (n = 16). Reverse dippers had significantly higher frailty and arterial stiffness measures than both other groups (Fried Frailty Scale, TUGT, cf-PWV) and higher PRISMA-7 scores than dippers. Across all participants, the magnitude of nocturnal BP dipping correlated with TUGT (r=-0.3, p = 0.02), PRISMA-7 (r=-0.2, p = 0.03), and Fried Frailty Scale (r=-0.2, p = 0.02). Clinic OH was present in 35% of participants (n = 35). While binary OH classification showed no significant differences in frailty, analysis of the magnitude of OH revealed correlations between systolic OH with PRISMA-7, and between diastolic OH with SPPB, PRISMA-7, and Fried Frailty Scale.

Conclusions

Nocturnal dipping patterns, particularly reverse dipping, and orthostatic blood pressure changes, especially the magnitude of diastolic OH, are associated with frailty and vascular ageing. Incorporating these objective, non-invasive measures into frailty assessments may enhance early detection and risk stratification in older adults.

BACKGROUND

Frailty is a complex health state characterised by a decline in multiple body systems, leading to reduced ability to cope with stressors (1). The ageing population means that there is an increasing prevalence of frailty, however frailty is not an inevitable consequence of ageing (2). Research to understand and recognise frailty in older adults is therefore crucial in order to support and target care to promote healthy ageing.

Vascular ageing involves the structural and functional changes of the arteries over a person's lifetime, and it is an important component of cardiovascular risk (3, 4). There is increasing evidence on the relationship between vascular ageing and frailty, particularly with the measures of arterial stiffness (5). Vascular ageing is also associated strongly with hypertension, which affects nearly three quarters of people over the age of 70. Yet the relationship between blood pressure and frailty remains poorly understood. Evidence suggests that blood pressure may decline in the decade preceding death, and clinical guidelines differ significantly in their recommendations for managing hypertension in frail individuals (6). This is often due to the complex balance of risks and benefits associated with antihypertensive treatment in this population. Further investigation is required to clarify how blood pressure patterns and vascular ageing interact and relate to the prevalence of frailty.

Orthostatic hypotension (OH) is a common manifestation of impaired blood pressure regulation in older adults, characterised by a significant drop in blood pressure on standing (7). It is linked to adverse outcomes, including falls, cardiovascular events, and increased mortality (8). The increase in OH seen in older adults is thought to be due to factors such as impaired autonomic function of blood pressure homeostasis, deconditioning, medications, and co-morbidities; all of which are interconnected with frailty (9). Orthostatic hypotension has been widely linked to frailty; however, the association between the magnitude of orthostatic blood pressure change and frailty is less well explored (10, 11). Emerging studies have indicated that increased frailty is associated with a greater drop in orthostatic blood pressure (12).

In addition to orthostatic blood pressure responses, nocturnal blood pressure patterns represent another important dimension of blood pressure regulation. Most individuals undergo a gradual reduction in systolic blood pressure while sleeping at night of 10–20%, which is known as 'nocturnal dipping'. Individuals who do not experience this reduction in blood pressure (BP) during the night are known as 'non-dippers' and those who experience paradoxical blood pressure increases during sleep as 'reverse dippers'. Both non-dippers and reverse dippers have also been shown to be at higher cardiovascular risk, and preliminary studies show this may be particularly true of reverse dippers (13, 14, 15). Non-dipping is known to be associated with markers of physical decline, for instance a slower walking speed, with both non-dipping and reverse dipping more prevalent in the older people(16, 17). However, direct evidence on the relationship between reverse dipping and frailty in older adults is an understudied area.

This study aimed to investigate the associations between frailty and arterial stiffness with blood pressure dynamics in older adults. Particularly, nocturnal blood pressure dipping patterns and orthostatic hypotension (OH) were explored to determine their associations with vascular ageing

parameters (arterial stiffness) and systemic physiological decline in community dwelling older adults. Furthermore, we examined how these be useful tools in the prediction and assessment of frailty.

METHODS

Community-dwelling adults were recruited in the cardiovascular frailty (c-FRAIL) study between November 2024 and July 2025 in Brighton, UK. Participants were eligible for inclusion if they were ≥ 65 years of age with a Clinical Frailty Scale of ≤ 6 with capacity to consent. Participants were excluded if they had a malignancy with current active treatment, or if it was documented in their medical records that mortality was expected within three months. People with severe frailty, with a Clinical Frailty Scale of > 6, were excluded. A cross-sectional analysis was undertaken using the baseline data from the study cohort.

Frailty was assessed using the Clinical Frailty Scale (CFS), PRISMA-7 and Fried Frailty phenotype. Physical frailty assessments such as Timed Up and Go Test (TUGT), Short Physical Performance Battery (SPPB) test and Charlson Comorbidity Index (CCI) were conducted.

Clinic blood pressure (CBP) was obtained with Omron 705 CP II® and 24-hour ambulatory blood pressure monitoring (ABPM) with Diasys Integra II (Novacor®, France) machine. A valid ABPM was defined as ≥ 14 daytime and ≥ 4 nighttime readings. Nocturnal blood pressure patterns were categorised as dippers (> 10% fall in BP overnight), non-dippers (0–10% fall in BP overnight), and reverse dippers (any rise in BP overnight). Orthostatic hypotension was calculated from clinic blood pressure readings using the UK National Institute for Health and Care Excellence (NICE) clinical criteria: a sustained reduction of systolic blood pressure of at least 20 mmHg or diastolic blood pressure of 10 mmHg within 3 minutes of standing (18). Study participants had their blood pressure measured whilst sitting and at 1 minute after standing. Orthostatic blood pressure changes were also calculated for all study participants, defined as: the difference in systolic and in diastolic blood pressure between sitting and standing (‘systolic orthostatic BP change’ and ‘diastolic orthostatic BP change’).

Arterial stiffness, an index of vascular ageing was assessed using carotid-femoral pulse wave velocity (cf-PWV) and carotid-radial pulse wave velocity (cr-PWV) from the Complior® device (Alam Medical, France).

Statistical analysis

A cross-sectional analysis of baseline data for all participants in the c-FRAIL study was performed. Analyses were conducted in Statistical Package for Social Sciences – SPSS (version 30). The baseline characteristics (e.g., demographics) for the three nocturnal BP change groups (non-dipper, dipper, reverse dipper) are presented as means ± SD for continuous normally distributed variables, median and interquartile range for skewed variables, and n (%) for categorical variables. Differences between dipping groups were assessed using one-way ANOVA for normally distributed continuous variables, Kruskal–Wallis test for skewed variables, and Chi-squared test for categorical variables.

Dipping groups were analysed using Univariate General Linear Models (ANCOVA style) to compare continuous frailty and arterial stiffness measurements between the categorical groups of dipper, non-dipper and reverse dipper. Reverse dipping was used as the reference group. This analysis was adjusted for age, antihypertensive use, sex, and average 24-hour systolic blood pressure. TUGT and cf-PWV were log transformed due to non-parametric distribution. Fried Frailty Scale was grouped into frail (3+), pre-frail (1–2) and non-frail (0), and ordinal logistic regression was applied with the same covariates. Dipping was then further analysed using the nocturnal change in BP ('magnitude of dipping', %) for all participants. The correlation of the magnitude of dipping with frailty and arterial stiffness measurements were analysed using Pearson's correlation. Partial correlation was also carried out to adjust for age, gender, antihypertensive use, and mean 24-hour systolic blood pressure.

Orthostatic Hypotension was analysed in two separate ways. Firstly, the participants with OH were compared to those without OH in a binary analysis; independent T-test, Mann-Whitney U test, or Chi-squared were used to compare binary OH status with demographic and frailty data. Binary logistic regression was then used to adjust for possible confounders for the characteristics found to be significant. The second method utilised the orthostatic change in BP for all participants in the sample, as a continuous variable. The associations of this orthostatic change in BP with frailty and arterial stiffness measurements were explored using Pearson's correlation and a Partial correlation was utilised to adjust for age, gender, antihypertensive use, and clinic mean arterial pressure (MAP).

RESULTS

One hundred participants were recruited (50 female; 92 White British; mean age 74.6 years, range 65–101), 94 participants completed ABPM.

Dipping status

92 of the 94 participants had valid ABPM readings for the dipping analysis, 2 participants were excluded for not meeting the minimum readings requirement (≥ 14 daytime and ≥ 4 nighttime readings). They were categorised as Non-dipper (n = 36), Dipper (n = 40), and Reverse Dipper (n = 16). Baseline characteristics of the study participants by dipping status group are shown in Table 1. Unadjusted analysis showed the reverse dipper group had participants who were older, had higher co-morbidities, and increased level of frailty compared to the. No significant differences were found between the dipper and non-dipper groups.

Table 1
Baseline characteristics by dipping group

Variables	Non-dipper (n = 36)	Dipper (n = 40)	Reverse dipper (n = 16)	p value
Age, years	73.97 ± 5.7	73.15 ± 6.4	78.88 ± 9.4	**0.02[b]**
Sex, % male	17 (47%)	19 (48%)	9 (56%)	*0.81*
Ethnicity, % White British	33 (92%)	35 (95%)	16 (100%)	*0.77*
BMI kg/m^2	27.4 ± 4.4	27.2 ± 3.7	27.1 ± 4.3	*0.96*
Antihypertensive use %	17(47%)	17(43%)	11(69%)	*0.20*
24-hour Sitting SBP	115.97 ± 14.1	120.23 ± 12.9	121.25 ± 15.1	*0.30*
24-hour Sitting DBP	71.36 ± 10.2	72.05 ± 7.7	72.00 ± 11.3	*0.95*
24-hour Standing SBP	120.61 ± 16.0	121.80 ± 14.2	124.69 ± 19.0	*0.69*
24-hour Standing DBP	73.17 ± 10.6	72.92 ± 9.0	76.06 ± 12.7	*0.57*
CFS	3.28 ± 0.8	3.33 ± 0.9	3.75 ± 1.4	*0.30*
CCI	3.89 ± 1.5	3.55 ± 1.2	4.56 ± 1.5	*0.06*
PRISMA-7	2.22 ± 1.1	1.98 ± 1.0	3.00 ± 1.5	**0.02[b]**
TUGT s	10.30 (9.3-12.42)	10.78 (8.81–12.59)	17.85 (12.25–23.66)	**0.002[a]**
SPPB	7.11 ± 2.05	7.43 ± 2.44	5.75 ± 2.67	*0.06*
Fried	1.64 ± 1.0	1.55 ± 0.9	2.38 ± 1.3	**0.02[b]**
cf-PWV m/s	11.48 (9.45–13.35) (n = 34)	11.85 (9.65–13.15) (n = 38)	12.95 (11.45–15.23) (n = 16)	*0.07*
cr-PWV m/s	12.55 ± 1.5 (n = 36)	12.57 ± 1.6 (n = 38)	12.98 ± 1.5 (n = 15)	*0.62*

X^2 for categorical variables, ANOVA for continuous, Kruskal-Wallis for non-parametric. Values are mean ± SD or median (IQR) unless

a *= significant difference found between reverse dippers and both other groups*

Variables	Non-dipper (n = 36)	Dipper (n = 40)	Reverse dipper (n = 16)	p value
stated otherwise. If 'n=' not specified: all study participants had measurements taken.			**b** *= significant difference found only between reverse dipper and dipper groups*	

Adjusted associations between dipping groups

An adjusted analysis of the frailty and arterial stiffness measurements was carried out (Table 2). The analysis was adjusted for age, antihypertensive use, sex, and average 24-hour systolic blood pressure. Significant differences between the reverse dipping group and other groups were seen for TUGT and cf-PWV, and between reverse dipping and non-dipping groups for Fried Frailty Scale.

Table 2
Adjusted associations between dipping status with frailty and arterial stiffness

Dependent variable	Comparison	Effect: B/OR (95% CI)	*p value*
Fried Frailty Scale	Non-Dipper vs Reverse Dipper	-1.45 (-2.81 to -0.08)	**0.04**
	Dipper vs Reverse Dipper	-1.36 (-2.71 to -0.004)	*0.05*
SPPB	Non-Dipper vs Reverse Dipper	0.47 (-0.79 to 1.73)	*0.46*
	Dipper vs Reverse Dipper	0.61 (-0.65 to 1.86)	*0.34*
TUGT	Non-Dipper vs Reverse Dipper	-0.39 (-0.61 to -0.16)	**< 0.001**
(log-transformed s)	Dipper vs Reverse Dipper	-0.37 (-0.59 to -0.15)	**0.001**
PRSIMA-7	Non-Dipper vs Reverse Dipper	-0.48 (-1.17 to 0.20)	*0.17*
	Dipper vs Reverse Dipper	-0.68 (-1.36 to -0.004)	*0.05*
cf-PWV	Non-Dipper vs Reverse Dipper	-0.14 (-0.25 to -0.03)	**0.02**
(log transformed m/s)	Dipper vs Reverse Dipper	-0.12 (-0.23 to -0.01)	**0.03**

Regression coefficients (β) are shown for continuous outcomes and odds ratios (OR) for ordinal outcomes. Models adjusted for age, gender, antihypertensive use, and mean 24-hour systolic blood pressure (cf-PWV was adjusted for clinic MAP rather than 24-hour systolic BP). Reverse-dipper is the reference category.

Correlation of nocturnal blood pressure dipping:

The nocturnal change in each participant's blood pressure ('magnitude of dipping', %) was correlated with the measurements of frailty and arterial stiffness. The unadjusted magnitude of dipping

significantly correlated with CFS (r = − 0.2, p = 0.02), CCI (r = -0.2, p = 0.03), PRISMA (r = − 0.3, p = 0.01), SPPB (r = 0.2, p = 0.02), log-transformed TUGT (r = − 0.3, p < 0.001), Fried Frailty Scale (r = − 0.3, p = 0.002), and log-transformed cf-PWV (r = − 0.2, p = 0.02).

Correlations were then adjusted for age, gender, antihypertensive use, and 24-hour systolic blood pressure (cf-PWV was adjusted for clinic MAP, not 24-hour SBP). A significant correlation with log-transformed TUGT remained (r = -0.3, p = 0.02), with weaker but still statistically significant correlations observed for PRISMA (r = -0.2, p = 0.03) and Fried Frailty Scale (r = -0.2, p = 0.02). No other statistically significant correlations remained following adjustments.

Orthostatic hypotension

Binary OH analysis

Orthostatic hypotension was found in 35% of participants when measured in clinic as part of the baseline assessment. A significantly higher proportion of the binary OH group were male (66% OH group vs 42% Non-OH group). No other statistically significant differences were found. The full table of baseline characteristics (including frailty measurements and antihypertensive use) for participants with OH compared to those without OH (Non-OH) is provided within the supplementary material (**Table S1**). Binary logistic regression was used to examine the association between sex and orthostatic hypotension, adjusting for CCI, smoking status and antihypertensive use. The odds ratio was 0.41 (95% CI: 0.17-1.0), B − .882 (p = 0.05).

Systolic orthostatic BP change

Orthostatic blood pressure changes were further analysed using the difference in systolic clinic blood pressure between sitting and standing for all participants in the sample. The systolic orthostatic BP change ranged from − 21 to + 33mmHg for the whole sample. The systolic orthostatic BP change in all participants was correlated with measures of frailty. Small but statistically significant correlations were observed between systolic orthostatic BP change and indices of clinical frailty including SPPB, PRISMA-7, and Fried Frailty Scale, as well as cf-PWV. An adjusted analysis was carried out using age, gender, antihypertensive use, and clinic mean arterial pressure (MAP) as control variables. In the adjusted analysis only PRISMA-7 remained significantly correlated with systolic orthostatic BP change (Table 3). Stepwise multivariate regression with degree of systolic OH as the dependent variable and age, clinic mean arterial pressure, PRISMA-7, SPPB and cf-PWV as independent variables, showed the strongest association with PRISMA-7 (B 3.43, p = 0.004).

Diastolic orthostatic BP change

The diastolic orthostatic BP change in clinic blood pressure readings was also calculated for all participants, with a difference in diastolic BP from sitting to standing ranging from − 20 to + 25mmHg.

Moderate statistically significant correlations were shown between diastolic orthostatic BP change and indices of clinical frailty of SPPB, PRISMA-7, and Fried Frailty Scale as well as cf-PWV. Small but statistically significant correlations were shown between TUGT and CFS. An adjusted analysis was carried out using age, gender, antihypertensive use and clinic mean arterial pressure (MAP) as control variables. SPPB, PRISMA-7 and Fried Frailty Scale remained significantly correlated with diastolic OH (Table 3). Stepwise multivariate regression with degree of diastolic OH as the dependent variable and age, clinic mean arterial pressure, PRISMA-7, SPPB, Fried Frailty Scale, and cf-PWV as independent variables, showed the strongest association with SPPB (B -1.57, $p < 0.001$).

Table 3
Orthostatic BP Change and Frailty Measurement Correlations

	Variables	Number	Unadjusted (Bivariate r)	p value	Adjusted (Partial r)	p value
Systolic Orthostatic BP Change	**SPPB**	100	**-0.3**	**0.01**	-0.2	*0.08*
	TUGT (log)	100	0.1	*0.17*	0.03	*0.80*
	PRISMA	100	**0.3**	**0.004**	0.2	**0.04**
	Fried	100	0.2	**0.03**	0.2	*0.18*
	CFS	100	0.2	*0.06*	0.1	*0.28*
	Cf PWV (log)	95	0.2	**0.02**	0.1	*0.29*
	Cr PWV	96	0.1	*0.29*	0.1	*0.66*
Diastolic Orthostatic BP Change	**SPPB**	100	**-0.4**	**< 0.001**	**-0.4**	**< 0.001**
	TUGT (log)	100	**0.3**	**0.01**	0.2	*0.16*
	PRISMA	100	**0.4**	**< 0.001**	**0.3**	**0.01**
	Fried	100	**0.3**	**< 0.001**	**0.4**	**0.002**
	CFS	100	**0.3**	**0.004**	0.2	*0.05*
	Cf PWV (log)	95	**0.3**	**0.001**	0.1	*0.24*
	Cr PWV	96	0.1	*0.22*	0.02	*0.83*

The magnitude of orthostatic BP change is associated with frailty (SPPB, TUGT, PRISMA, CFS and Fried) and measures of arterial stiffness (cf-PWV). However, the magnitude of diastolic orthostatic change has a stronger association with frailty than systolic orthostatic change, with associations for arterial

stiffness being attenuated after adjusting for age, gender, antihypertensive use and clinic mean arterial pressure (MAP).

DISCUSSION

This cross-sectional study of 100 community-dwelling older adults in the UK provides novel insights into vascular ageing and clinical frailty assessment. The key findings include the significant association between the reverse dipping phenotype and frailty assessments such as TUGT and Fried Frailty Scale. Non-dipping and reduced nocturnal dipping have previously been identified as markers of frailty (16, 19). Despite this, the reverse dipping phenotype has been less well characterised. When further exploring the relationship using the magnitude of nocturnal blood pressure dipping; the frailty measures of TUGT, PRISMA-7 and Fried Frailty Scale all showed a negative correlation with the magnitude of nocturnal dipping. This demonstrated that the less a participant's blood pressure dipped overnight, the more frail they were. Identifying dipping patterns as a marker of frailty holds clinical importance and relevance, as nocturnal blood pressure patterns can be assessed non-invasively and may offer an objective indicator to enhance future frailty assessments. This study also provides further evidence of the necessity of using ABPM, particularly to capture recognised nocturnal blood pressure patterns (20).

There is existing evidence demonstrating the association between orthostatic hypotension and frailty, thought to be due to a combination of factors including impaired autonomic regulation, reduced physiological reserve, co-morbidities and polypharmacy (9). However, utilising the magnitude of orthostatic difference rather than binary diagnostic thresholds (≥ 20 mmHg systolic or ≥ 10 mmHg diastolic decline) has been largely unexplored. The findings from this study showed significant correlations between the magnitude of orthostatic changes in blood pressure and frailty measurements, particularly highlighting the relevance of diastolic orthostatic changes, which are often overlooked. This association was not observed when frailty scores were compared between individuals classified through binary means as having orthostatic hypotension and those without. This suggests that the reliance on binary diagnostic thresholds of orthostatic hypotension may obscure clinically relevant markers of frailty and that looking at the orthostatic changes in blood pressure could be incorporated into frailty assessments to provide greater insight into frailty status.

When examining the association of arterial stiffness measurements with blood pressure patterns, the findings also demonstrated the association of carotid femoral PWV (cf-PWV) and reverse dipping status, which remained when adjusting for age, antihypertensive use, gender and clinic mean arterial pressure. This association was not seen when utilising carotid radial PWV (cr-PWV), however it is widely evidenced that cf-PWV is a more accurate indicator of atherosclerosis and cardiovascular risk than cr-PWV (21). Carotid femoral PWV was also shown to be correlated with orthostatic hypotension; however this correlation was lost when adjusting for age, gender, antihypertensive use and clinic mean arterial pressure (MAP). This shows the importance of considering confounding factors when investigating OH as a marker of vascular ageing and highlights the complexity in the relationships of factors impacting on vascular ageing, frailty and blood pressure regulation.

The results demonstrate that both nocturnal dipping and the magnitude of orthostatic hypotension hold the potential to be used in categorising and predicting a person's risk of frailty. Current frailty assessments rely mainly on subjective questionnaires or physical performance measures, which may be limited in individuals with cognitive impairment or comorbidities affecting mobility. Incorporating objective cardiovascular markers could therefore enhance frailty assessments.

This study had multiple limitations. The participants had to be able to attend a study visit at the hospital, and so those with a Clinical Frailty Score > 6 were therefore excluded. This means it did not study the most frail subset of the population. Due to the population of the study setting, the participants were largely White British, reducing the external validity to other ethnicities. The older population that were studied are more likely to be affected by conditions such as sleep apnoea and disrupted sleep patterns which can impact on nocturnal BP (15). The reverse-dipping group was relatively small; however, this pattern is known to be less prevalent, and significant differences persisted after adjustment, suggesting a robust and plausible association with frailty. Further longitudinal studies with larger cohorts are needed to investigate the associations between dipping status, particularly reverse dipping, and the magnitude of orthostatic hypotension, particularly diastolic blood pressure, with adverse clinical outcomes and the progression of frailty.

CONCLUSIONS

In this cohort study of community dwelling older people with detailed frailty phenotyping and ABPM, we found that both nocturnal blood pressure dipping patterns and orthostatic hypotension were associated with measures of frailty and vascular ageing and have potential to be useful markers of frailty. Incorporating these objective and non-invasive measurements into frailty assessments could improve frailty recognition and risk stratification, a growing clinical priority in the context of the ageing population.

Declarations

COMPETING INTERESTS:

On behalf of all authors, the corresponding author states that there is no conflict of interest.

ADDITIONAL INFORMATION

Correspondence and requests for materials and data should be addressed to Chakravarthi Rajkumar (corresponding author)

CONSENT TO PARTICIPATE

AND ETHICAL APPROVAL:

Informed consent

was obtained from all individual participants included in the study for both participation and for publication. This study was conducted in accordance with the Declaration of Helsinki and ethical approval was obtained from the Wales Research Ethics Committee (REC) on the 2nd October 2024, with REC reference number: 24/WA/0240.

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Author Contribution

All authors MW, EM, JM, CD, MO, SS and CR contributed to the concept design, literature search, data analysis, and manuscript writing

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Data Availability

Correspondence and requests for materials and data should be addressed to Chakravarthi Rajkumar (corresponding author)

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