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SHORT REPORT

Ambient Cold and Mortality in Pan-Arterial Diseases: A Nationwide Ecological Analysis of CDC WONDER Data

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Introduction: Pan-arterial diseases, including atherosclerosis (AS), aortic aneurysm and dissection (AAD), and peripheral arterial disease (PAD), impose a substantial global health burden. Although ambient temperature has been implicated in individual arterial conditions, its association with mortality across the pan-arterial spectrum remains incompletely understood.

Objective: To evaluate the association between ambient temperature and mortality from pan-arterial diseases across the United States.

Methods: We analysed mortality data for adults aged ≥25 years with AS, AAD, or PAD in the United States CDC WONDER database from 1999 to 2023. Age-adjusted mortality rates (AAMR) and average annual percent change (AAPC) were estimated. Monthly air-temperature metrics (1999–2023) were linked at the United States Census region level. Seasonal variation was assessed using analysis of variance. Associations between temperature and mortality were examined using Spearman correlation, Poisson regression with lag structures, and distributed lag non-linear models (DLNM), with results expressed as relative risks (RR) per 10°F increase in temperature.

Results: Between 1999 and 2023, AAMRs declined for AS, AAD, and PAD, yet mortality burden remained substantial. Mortality from all three conditions was consistently higher in winter than in summer across Census regions. Monthly mean temperature was inversely correlated with crude mortality for pan-arterial diseases ($P < 0.05$). In the Northeast, cumulative RR per +10°F across lags 0–3 months was 0.919 for AS, 0.945 for AAD, and 0.953 for PAD, with similar patterns observed in other regions. DLNM analyses demonstrated a predominantly cold-related excess risk, with acute effects and regional heterogeneity at higher temperatures.

Conclusion: Lower ambient temperatures are associated with increased mortality from pan-arterial diseases in the United States. These findings highlight shared vulnerability to cold exposure across arterial diseases and support winter-focused preventive and healthcare preparedness strategies.

Keywords: pan-arterial diseases, atherosclerosis, aortic aneurysm and dissection, peripheral arterial disease, ambient temperature, mortality

Introduction

Pan-arterial diseases impose a substantial global disease burden and are characterized by acute or chronic injury across arteries of all calibers, principally encompassing atherosclerosis (AS), aortic aneurysm and dissection (AAD), and peripheral arterial disease (PAD).[1–3] These conditions share common pathological substrates, including vascular inflammation, endothelial dysfunction, extracellular matrix remodeling, and hemodynamic stress, which support their consideration within a unified pan-arterial disease framework.[4–6] Identifying shared, underlying risk factors for pan-arterial diseases is therefore essential to inform integrated prevention strategies and therapeutic decision-making.

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Emerging evidence suggests that ambient temperature may influence vascular pathophysiology. Cold exposure has been associated with increased sympathetic activation, vasoconstriction, elevated blood pressure, enhanced blood viscosity, and prothrombotic responses, all of which may increase the risk of vascular injury and acute cardiovascular events.[7–9] Previous studies have reported associations between low temperature and the incidence or mortality of specific vascular conditions, such as AAD.[10–15] However, the impact of temperature on mortality risk across the broader pan-arterial spectrum remains insufficiently studied.

This study aims to evaluate the association between ambient temperature and mortality rates from pan-arterial diseases (AS, AAD and PAD) using the United States Centers for Disease Control and Prevention Wide-ranging Online Data for Epidemiologic Research (CDC WONDER) database. By examining temperature-mortality relationships across multiple vascular territories, this study seeks to provide population-level evidence that may inform protective and preventive strategies for vascular health.

Methods

Data Sources and Statistical Analysis

The mortality and temperature indicators for pan-arterial diseases in this study were obtained from the United States CDC WONDER database (https://wonder.cdc.gov/). We included adults aged ≥25 years in the four United States Census regions (Northeast, Midwest, South, and West) from 1999–2023, for whom pan-arterial diseases were recorded as the underlying cause of death.[16] Causes of death were classified using the International Classification of Diseases, Tenth Revision (ICD-10) (Supplementary Methods): AS I70–I70.9, AAD I71–I71.9, and PAD I73–I73.9. We calculated age-adjusted mortality rates (AAMR) per 1,000,000 population to account for temporal changes in age structure and ensure comparability across years.[17] To summarize long-term trends in AAMR during 1999–2023, we also estimated the average annual percent change (AAPC) with 95% confidence intervals (CI).

Additionally, we assembled monthly air-temperature metrics for the four Census regions for 1999–2011, including monthly mean maximum temperature (Max Temp), monthly mean minimum temperature (Min Temp), monthly mean temperature (Mean Temp), monthly within-month temperature range (Monthly Range), and month-to-month temperature range (Month-to-Month Range). Temperatures were expressed in degrees Fahrenheit (°F). Temperature data corresponding to the study period (2012–2023) were obtained from the North American Land Data Assimilation System (NLDAS). Specifically, we used the NLDAS Primary Forcing Data L4 Monthly 0.125° × 0.125° Version 2.0 dataset (NLDAS_FORA0125_M).[18]

In analyses of the association between crude mortality from pan-arterial diseases and season, we stratified by United States Census region (Northeast, Midwest, South, West) and by season: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). Within each stratum, we calculated the mean monthly crude mortality rate (per 100,000 population) and its 95% CI using the t-distribution. Between-season differences within each region were assessed with one-way analysis of variance (ANOVA) followed by Tukey's honestly significant difference (HSD) post-hoc pairwise comparisons, and we report multiplicity-adjusted P values.

Correlations between crude mortality rates and temperature characteristics were evaluated using both Pearson correlation and Spearman's rank correlation coefficients (r), with two-sided P values reported. To provide robust visualisations of exposure–response patterns without excessive smoothing, we fitted generalised additive models (GAM) with a smooth term for temperature (mgcv, formula $y \sim s(x, k = 5)$) separately within each stratum.

In the temperature risk–lag analyses, we centred monthly mean temperature within each United States Census region and scaled it per +10°F. We constructed lag structures for lag 0 through lag 3 (within-region, not pooled across regions). For single-lag models, each lag (0–3) was entered separately into Poisson log-linear regressions with a log(population) offset; we report relative risks (RR) per 10°F increase with 95% CI. For multi-lag models, lags 0–3 were entered simultaneously; we report the partial effects for each lag and the cumulative effect over lags 0–3 months, obtained by summing the relevant coefficients and estimating its variance via the delta method, then exponentiating to yield the cumulative RR.

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We additionally fitted distributed lag non-linear models (DLNM) separately by Census region to estimate cumulative associations between temperature and mortality.[19] Monthly death counts were modelled using Poisson regression (log link) with an offset for log(population), a natural spline for calendar time to adjust for long-term and seasonal trends (approximately 3 degrees of freedom per year; minimum 3, constrained by sample size), and a 12-level month factor. The cross-basis spanned lags 0–3 months in monthly steps. Exposure–response curves present the cumulative RR over lags 0–3 across the observed exposure range (restricted to the 5th–95th percentiles), centred at the region-specific median temperature as the reference. Two-sided $P < 0.05$ was considered statistically significant. All analyses and visualisations were conducted in R version 4.4.0.

Ethical Statement

This study utilized publicly available, de-identified, and aggregated mortality data from the CDC WONDER database. As no individual-level or identifiable information was accessed and no attempts were made to re-identify individuals, institutional ethics approval was not required. According to the National Statement on Ethical Conduct in Human Research (Australia, 2023), Section 5.1.17 (a) and (d), research using publicly available, non-identifiable data is exempt from ethics review. The Ethics Committee of the Western Sydney Local Health District confirmed that no additional ethical approval was required.

Results

Temporal Trends in Mortality from Pan-Arterial Diseases

Among United States adults aged ≥25 years, there were 14,975 AS-related deaths in 1999, with an AAMR of 8.55 (8.41, 8.69); in 2023, AS deaths were 3,728 with an AAMR of 1.37 (1.32, 1.41), and the AAPC was −7.35% (−7.49, −7.20). For AAD, there were 15,771 deaths in 1999 (AAMR 8.89 [8.75, 9.03]) and 10,082 deaths in 2023 (AAMR 3.75 [3.68, 3.83]); AAPC −3.53% (−3.63, −3.43). For PAD, there were 6921 deaths in 1999 (AAMR 3.94 [3.85, 4.04]) and 7,949 deaths in 2023 (AAMR 2.85 [2.79, 2.92]); AAPC −1.34% (−1.48, −1.20). Taken together, mortality rates across pan-arterial diseases have declined overall, yet they continue to represent a substantial population burden.

Seasonal Variation in Mortality from Pan-Arterial Diseases

Visual inspection of time-series plots of monthly mean air temperature and monthly mortality from pan-arterial diseases (1999–2011) suggested a potential association (Figure 1A). We then grouped months into seasons and calculated the mean monthly crude mortality for each season (Figure 1B). In the United States Northeast, winter AS mortality averaged 0.46 (0.42, 0.51), significantly higher than in summer at 0.38 (0.35, 0.42). Winter AAD mortality averaged 0.65 (0.60, 0.70) versus 0.55 (0.51, 0.58) in summer, and PAD mortality averaged 0.34 (0.32, 0.36) versus 0.30 (0.29, 0.31) in summer; each increase was statistically significant. Similar seasonal patterns were observed across the other United States Census regions.

Cold Exposure is Associated with Increased Mortality Risk in Pan-Arterial Diseases

Using Spearman's rank correlation, we examined the association between monthly crude mortality from pan-arterial diseases and temperature metrics (Figure 2). Across all four United States Census regions, higher monthly mean temperature was associated with lower mortality, with a consistently negative correlation between monthly mean temperature and mortality ($P < 0.05$). These findings support a cold-related increase in mortality risk for pan-arterial diseases.

As a sensitivity analysis, we repeated the analyses using data from 2012–2023 (Supplementary Figure 1A–F). The seasonal patterns were consistent with the main findings, with higher mortality generally observed in winter and lower mortality in summer across regions. Pearson correlation analyses showed significant inverse associations between monthly mean temperature and monthly crude mortality rates for AS, AAD, and PAD in most regions, with the strongest correlations observed for AAD. These results support the robustness of the primary analyses.

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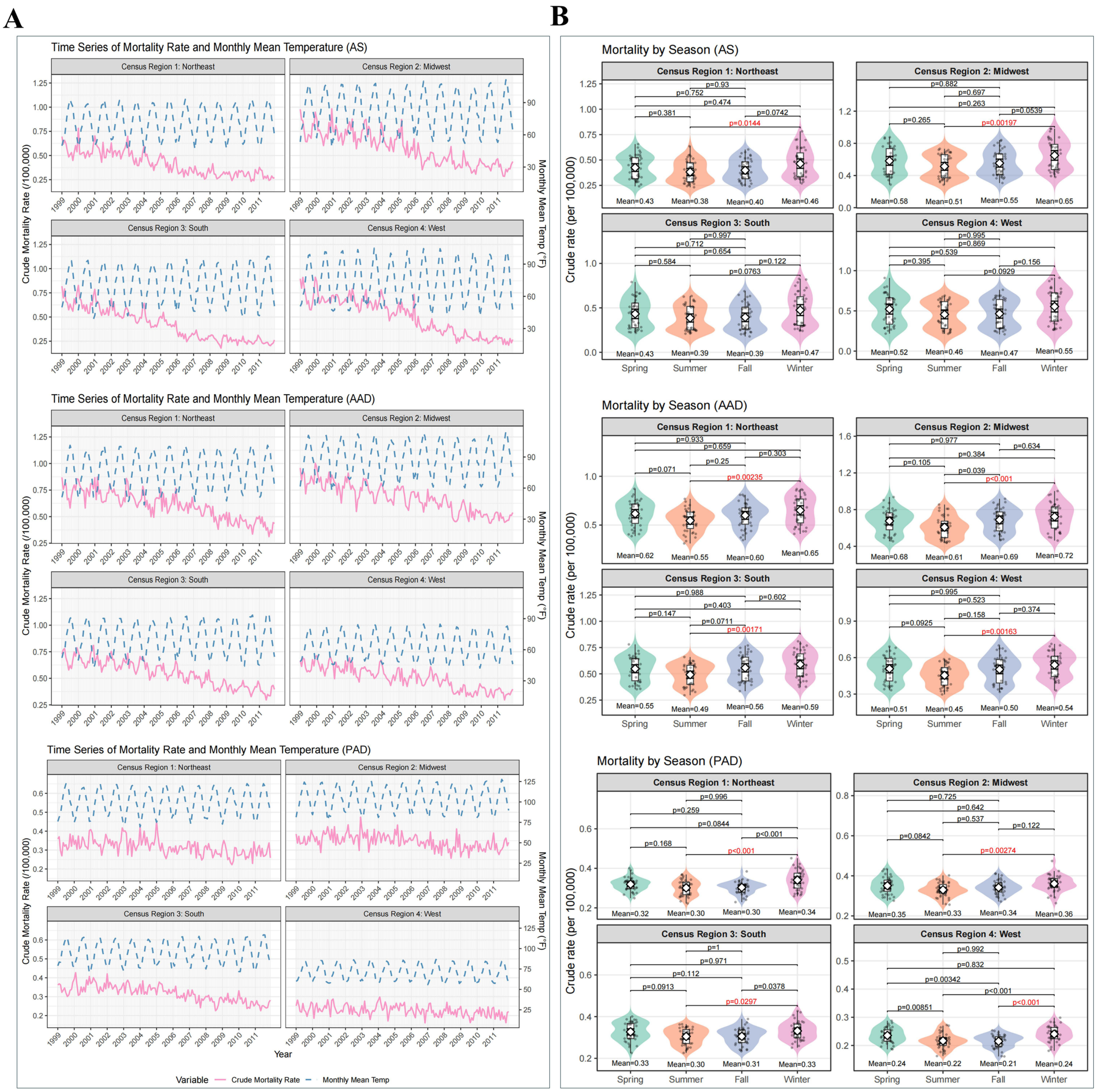

Figure 1 Seasonal association of monthly mean crude mortality rates in pan-arterial diseases. From top to bottom, each panel corresponds to AS, AAD and PAD. (**A**) Monthly time series of mean air temperature and crude mortality from pan-arterial diseases (adults aged ≥25 years), by the United States Census region (Northeast, Midwest, South, West). (**B**) Seasonal comparisons of mean monthly crude mortality (per 100,000) with 95% CI (t-distribution), stratified by region and disease: winter (Dec–Feb), spring (Mar–May), summer (Jun–Aug), autumn (Sep–Nov). Between-season differences were assessed by one-way ANOVA with Tukey HSD; adjusted P values are shown. P values shown in red indicate statistically significant differences ($P < 0.05$).

We further extended the sensitivity analysis to the broader ICD-10 category I70–I78 (Diseases of arteries, arterioles and capillaries) (Supplementary Figure 2A and B). Pearson correlation analyses similarly demonstrated significant inverse associations between monthly mean temperature and mortality across all United States Census regions ($r = -0.49$ to -0.62, all $P < 0.001$). Seasonal patterns were also consistent with the primary analysis, with mortality generally higher in winter and lower in summer. These findings further support the robustness of the observed cold-related increase in mortality risk.

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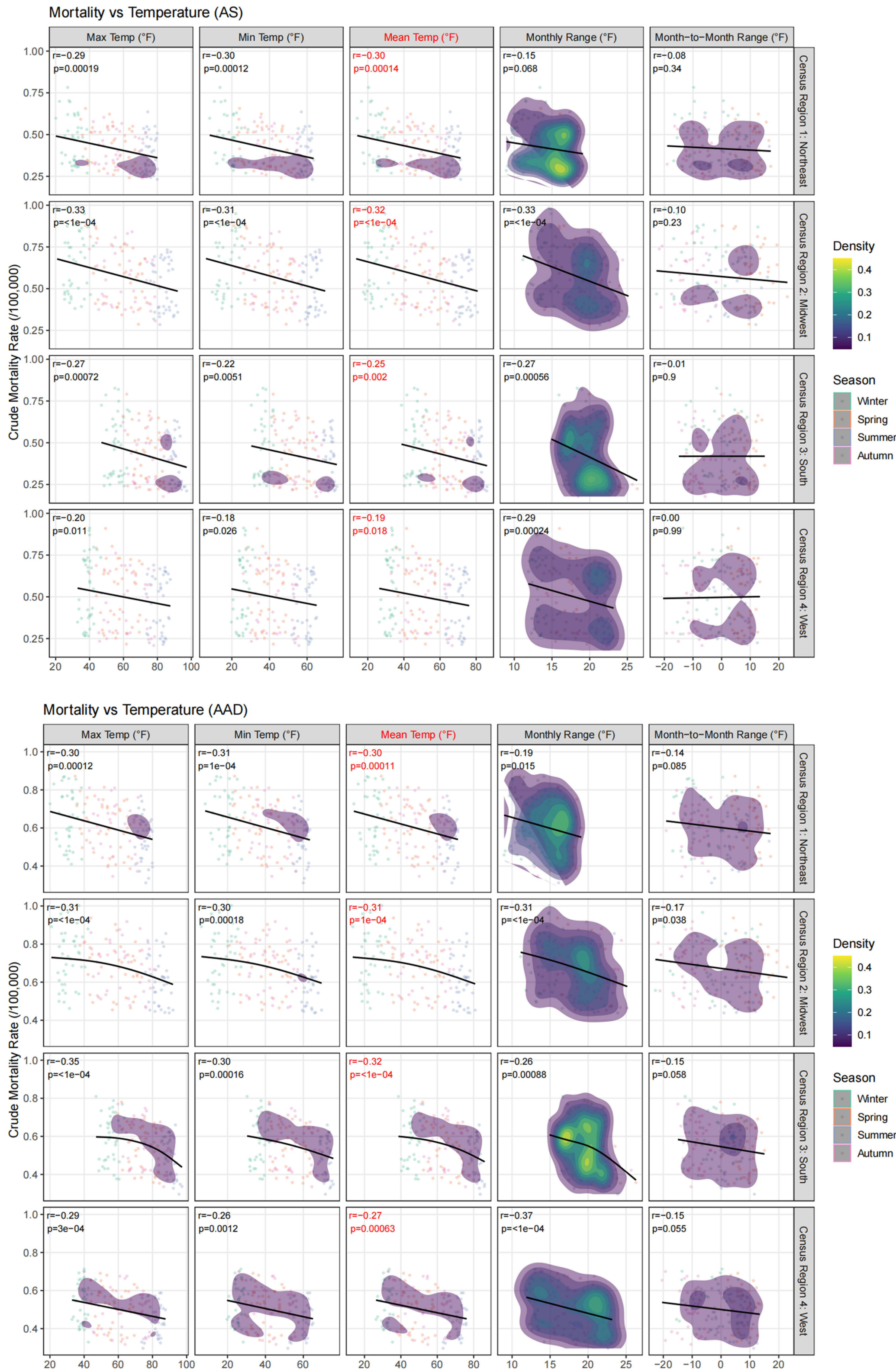

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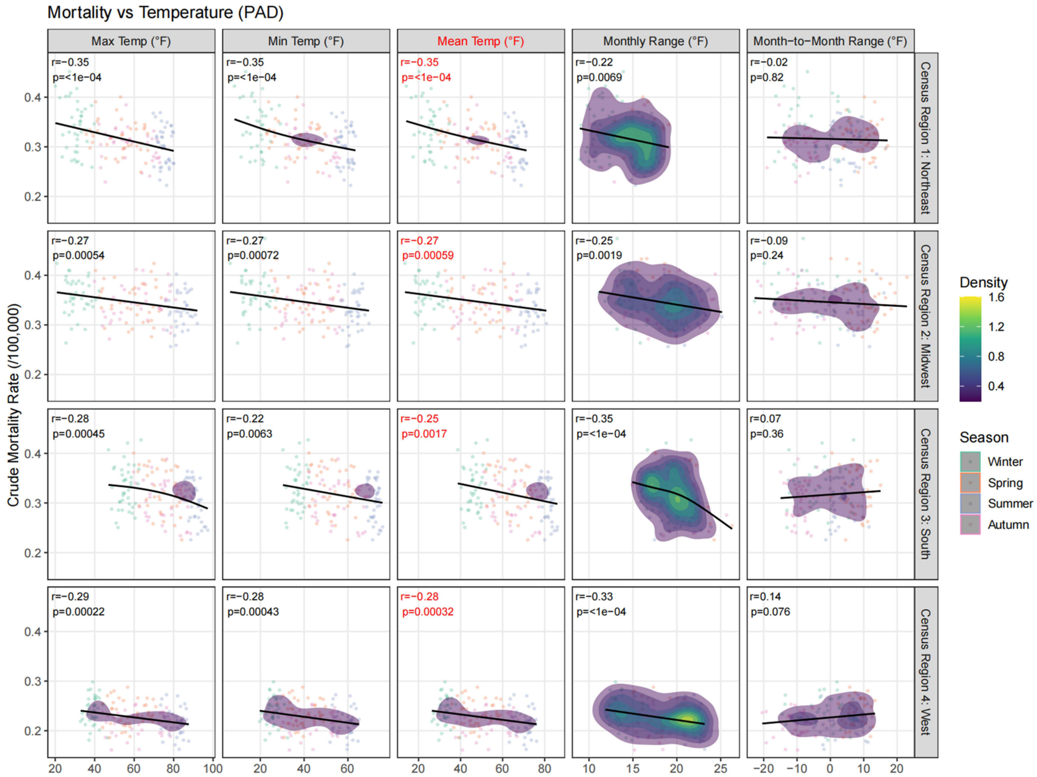


Figure 2 Correlation between monthly mean crude mortality rates and monthly temperature in pan-arterial diseases. Association between monthly crude mortality and temperature metrics—monthly mean maximum temperature (Max Temp), monthly mean minimum temperature (Min Temp), monthly mean temperature (Mean Temp), monthly within-month temperature range (Monthly Range), and month-to-month temperature range (Month-to-Month Range)—summarised by Spearman's r with two-sided P values; smoothed exposure–response overlays are from GAM fits (mgcv, formula y ~ s(x, k = 5)). Values shown in red indicate the correlation between monthly mean temperature and the monthly crude mortality rate of pan-arterial diseases.

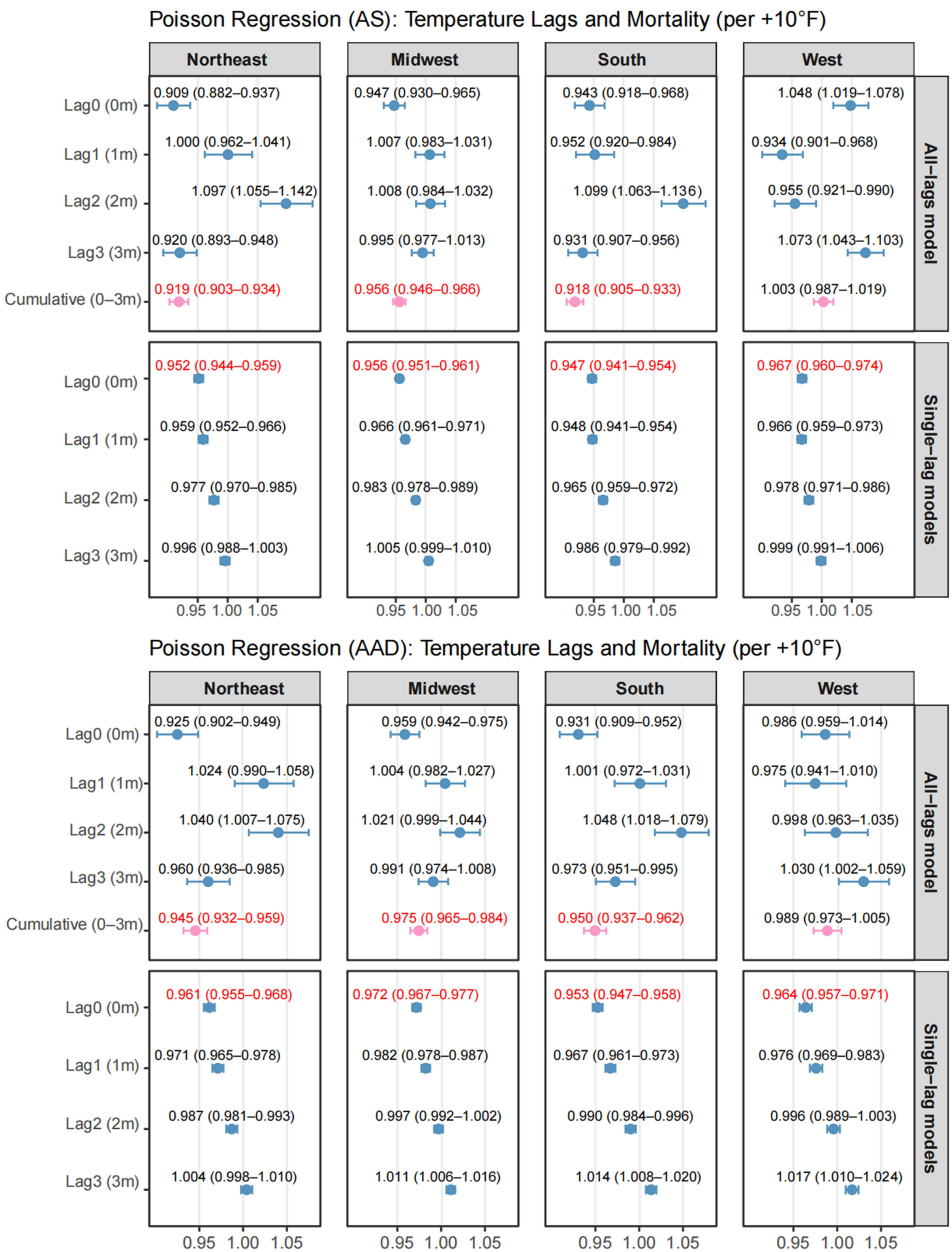
Lagged Effects of Temperature on Mortality from Pan-Arterial Diseases

In the Northeast region, the all-lags model showed cumulative RR per +10°F of 0.919 (0.903, 0.934) for AS, 0.945 (0.932, 0.959) for AAD, and 0.953 (0.934, 0.972) for PAD, indicating 9.1%, 5.5%, and 4.7% lower risk, respectively, for each 10°F increase in monthly mean temperature (Figure 3). Similar patterns were observed in the other Census regions. Notably, as the lag lengthened, RRs approached 1, suggesting that cold-related excess risk is predominantly acute.

In the Northeast, the cumulative exposure–response curve for AS was monotonically decreasing with temperature, centred at 47.7°F: at −15–20°F, RR was ~2.0–2.4, falling to ~0.50–0.90 at 50–60°F, consistent with harmful effects of cold and lower risk under warmer conditions (Supplementary Figure 3). Other pan-arterial diseases exhibited broadly similar trends, with regional heterogeneity: for example, in the West, high temperatures also increased AS mortality risk, whereas in the South, neither high nor low temperatures showed a significant effect on AAD mortality.

Discussion

To our knowledge, this is the first study to systematically examine the association between ambient temperature and mortality across the spectrum of pan-arterial diseases, including AS, AAD, and PAD, using nationwide mortality data from the United States CDC WONDER database. Across multiple analytical approaches, we consistently observed a cold-associated increase in mortality risk. Correlation analyses demonstrated significant inverse associations between monthly mean temperature and mortality across the United States Census regions, while Poisson regression models quantified increased mortality risk associated with lower temperatures. DLNMs further demonstrated temperature-dependent exposure–response patterns and lagged effects. Importantly, these findings were consistent across geographic regions and analytical frameworks, suggesting that cold exposure represents a shared environmental stressor affecting



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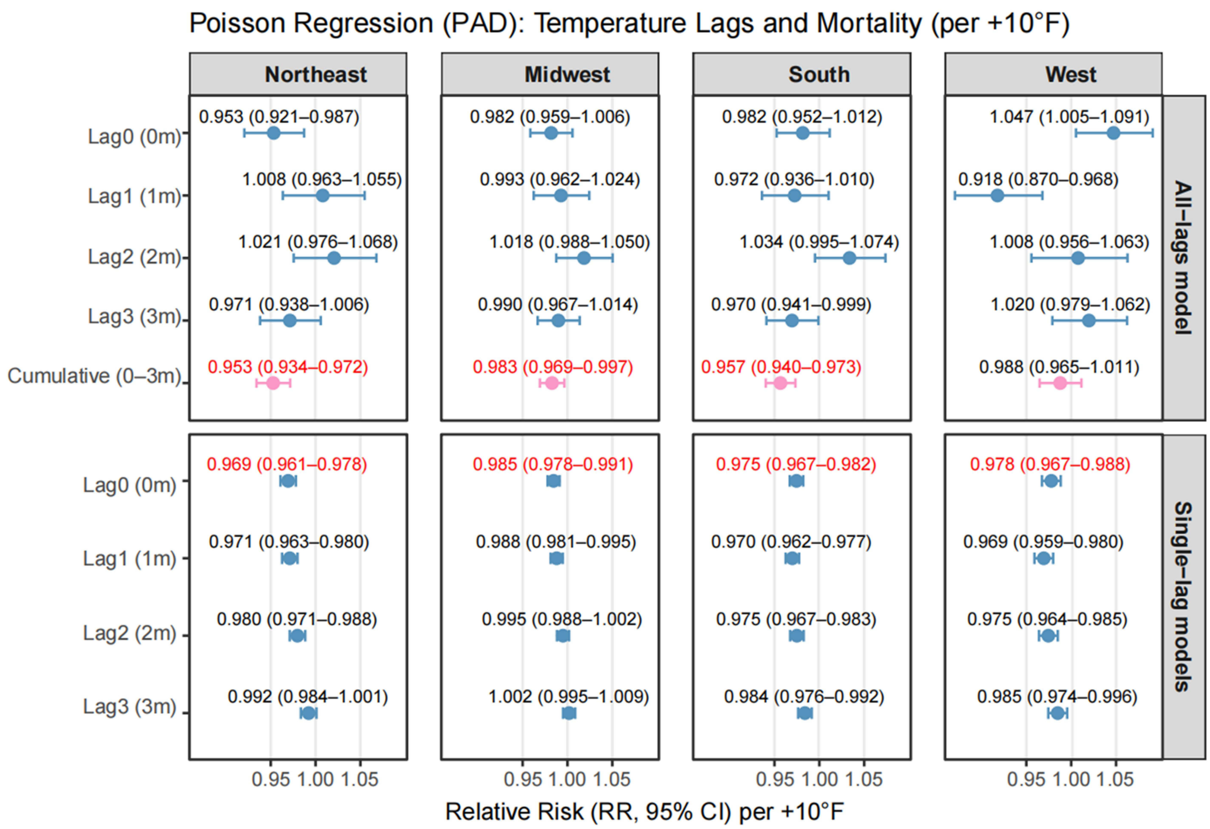

Figure 3 Lagged associations between regional temperature and mortality risk in pan-arterial diseases. Poisson log-linear models (offset log[population]) estimating cumulative RR per +10°F increase in region-centred monthly mean temperature across lags 0–3 months (all-lags model), by region and disease; points and bars denote RR and 95% CI. Estimates shown in red indicate statistically significant inverse associations, defined as rate ratios <1 with 95% CI excluding 1.

multiple arterial disease phenotypes. Together, these results provide population-level evidence supporting the concept that pan-arterial diseases exhibit common vulnerability to cold-related environmental exposure.

Current evidence indicates that the associations between ambient temperature and all-cause as well as cardiovascular mortality typically follow U-shaped or J-shaped patterns, suggesting that both low and high temperatures increase cardiovascular risk.[20] Several studies have further demonstrated that low temperatures and large temperature fluctuations are associated with a significantly increased risk of acute aortic dissection, accompanied by higher hospital admissions and surgical volumes.[10,21–23] In a nationwide case-crossover analysis conducted in Brazil, a predominantly tropical country, low temperature was shown to confer a substantial mortality risk and disease burden from AAD.[11] However, evidence regarding the associations between ambient temperature and the incidence or mortality risk of patients with PAD remains scarce.

In clinical practice, seasonal variation in presentations is commonly perceived.[24,25] For example, in the authors' vascular surgery service, winter presentations of PAD appear more frequent than in summer, although such observations are anecdotal. Based on national-level epidemiological data from the United States, our study identifies a heightened vulnerability of pan-arterial diseases to cold exposure, with important implications for targeted prevention strategies and clinical management in high-risk populations.

This study has several limitations. First, the ecological design precludes causal inference at the individual level, and the observed associations should therefore be interpreted with caution. Second, the use of monthly mean temperature may obscure short-term variability, such as diurnal fluctuations and abrupt temperature shifts, which may also influence vascular risk. Finally, the mortality database did not contain detailed clinical information, preventing adjustment for individual-level comorbidities, treatments, or complications.

Conclusion

By coupling nationwide mortality with temperature metrics, our findings provide population-level evidence to inform winter preparedness and rapid-response measures during cold snaps: reinforcing thermal protection for patients with pan-arterial diseases, seasonal capacity planning in vascular services, and intensified winter health education.

Abbreviations

AS, Atherosclerosis; AAD, Aortic aneurysm and dissection; PAD, Peripheral arterial disease; AAMR, Age-adjusted mortality rate; AAPC, Average annual percent change; DLNM, Distributed lag non-linear model; RR, Relative risk; CI, Confidence interval; CDC WONDER, Centers for Disease Control and Prevention Wide-ranging Online Data for Epidemiologic Research; ANOVA, One-way analysis of variance, HSD, Honestly significant difference; GAM, Generalised additive model.

Data Sharing Statement

The datasets analysed during the current study are available in the public database, https://wonder.cdc.gov/. The data used during the current study is available from the corresponding author on reasonable request.

Ethical Statement

This study utilized publicly available, de-identified, and aggregated mortality data from the CDC WONDER database. As no individual-level or identifiable information was accessed and no attempts were made to re-identify individuals, institutional ethics approval was not required. According to the National Statement on Ethical Conduct in Human Research (Australia, 2023), Section 5.1.17 (a) and (d), research using publicly available, non-identifiable data is exempt from ethics review. The Ethics Committee of the Western Sydney Local Health District confirmed that no additional ethical approval was required.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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