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Stroke and Environmental Factors

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This issue of the NEHRI Report examines the current evidence on the links between environmental factors—notably air pollution and temperature extremes—and the risk of stroke. We begin with a global overview, summarizing key findings and proposed biological mechanisms from international literature. The report then turns to Israel, presenting a synthesis of all locally conducted studies to date, highlighting unique climatic and demographic contexts, and outlining their implications for future research and public health policy.

¹NEHRI, Negev Environmental Health Research Institute, <https://www.bgu.ac.il/en/u/research-centers/nehri/>

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Executive Summary

Stroke remains one of the leading causes of death and disability worldwide. A growing body of evidence links environmental exposures—notably *air pollution* and *temperature extremes*—to both the incidence and outcomes of stroke. These exposures act as acute triggers and, in some cases, contribute to long-term cerebrovascular risk.

Globally, fine particulate matter (PM_{2.5}) from traffic, industry, and other sources is associated with a higher risk of ischemic stroke, transient ischemic attack (TIA), and, to a lesser extent, intracerebral hemorrhage. Temperature extremes, especially heatwaves, can precipitate stroke through physiological stress, dehydration, and blood pressure variability. Vulnerable groups include older adults, individuals with cardiovascular comorbidities, and socioeconomically disadvantaged populations.

Israeli studies confirm and extend these findings, showing that:

- Short-term PM_{2.5} exposure raises ischemic stroke risk even at levels below Israeli air quality standards.
- Temperature effects are season- and age-dependent, with younger adults more affected in summer and older adults in winter.
- Socially vulnerable groups, including non-Jewish populations and those with pre-existing cardiovascular disease, face disproportionate risks.

Policy Implication: Environmental mitigation, reducing air pollution exposure and protecting populations during temperature extremes, is a risk-free intervention with potential for substantial stroke prevention impact. Strategies include:

- Integrated heat + air quality warning systems.
- Targeted outreach to at-risk populations.
- Urban planning for cooling and clean air access.
- Public and clinical education on minimizing exposure during high-risk periods.

Environmental health interventions have no adverse medical side effects and can be implemented at the population scale, offering a unique “*no-regrets*” strategy for reducing the burden of stroke.

סיכום מנהלים

שבץ מוחי הוא אחת הסיבות המובילות לתמותה ולנכות ברחבי העולם. מחקרים מצטברים מצביעים על קשר ברור בין חשיפה סביבתית – ובעיקר זיהום אוויר וטמפרטורות קיצוניות – לבין היארעות שבץ מוחי והחמרת תוצאותיו. חשיפות אלו עלולות לשמש כטריגרים מיידיים ובחלק מהמקרים אף לתרום לסיכון ארוך הטווח.

בעולם, זיהום חלקיקי ($PM_{2.5}$) ממקורות תחבורה, תעשייה ואחרים, נקשרים לעלייה בסיכון לשבץ איסכמי TIA, ובמידה פחותה – דימום תוך מוחי. טמפרטורות קיצוניות, ובעיקר גלי חום, עלולות לגרום לאירוע מוחי דרך עומס פיזיולוגי, התייבשות ושינויים בלחץ הדם. אוכלוסיות פגיעות כוללות קשישים, חולים עם מחלות לב וכלי דם, ואוכלוסיות מוחלשות מבחינה סוציו-אקונומית.

בישראל, מחקרים מאשרים ומרחיבים ממצאים אלה:

- חשיפה קצרה ל $PM_{2.5}$ -מעלה את הסיכון לשבץ איסכמי גם ברמות נמוכות מהתקן הישראלי.
- השפעות הטמפרטורה תלויות עונה וגיל – הצעירים מושפעים יותר בקיץ, והמבוגרים יותר בחורף.
- אוכלוסיות מוחלשות, לרבות לא-יהודים וחולים במחלות לב וכלי דם, נמצאות בסיכון מוגבר.

השלכות למדיניות: צמצום חשיפה סביבתית, הפחתת זיהום אוויר והגנה על האוכלוסייה בעת טמפרטורות קיצוניות, הוא התערבות בטוחה וללא תופעות לוואי רפואיות, עם פוטנציאל משמעותי למניעת שבץ. צעדים מומלצים כוללים:

- מערכות התרעה משולבות לחום וזיהום אוויר.
 - פנייה ממוקדת לאוכלוסיות בסיכון.
 - תכנון עירוני המאפשר קירור וגישה לאוויר נקי.
 - חינוך הציבור והצוותים הרפואיים על הפחתת חשיפה בימים בסיכון גבוה.
- צעדי התערבות סביבתית הם אסטרטגיה חסרת סיכון הניתנת ליישום בקנה מידה רחב, בעלות נמוכה, עם פוטנציאל להפחתת נטל השבץ באוכלוסייה.

Methodology

A systematic literature search was conducted to identify peer-reviewed studies examining the relationship between environmental factors—specifically air pollution, temperature, and other climatic variables—and stroke incidence or outcomes in Israel. Searches were performed in PubMed and Web of Science using combinations of keywords and MeSH terms, including *stroke*, *cerebrovascular disease*, *air pollution*, *temperature*, *climate*, *dust*, and *Israel*. No date restrictions were applied, and results were limited to articles published in English. Full-text articles meeting these criteria were reviewed in detail. Global context was established through a targeted review of recent systematic reviews and high-quality international studies on environmental determinants of stroke. Findings were synthesized narratively, with Israeli studies summarized chronologically to illustrate the evolution of local evidence and interpreted considering the broader international literature.

What is Known Globally: Stroke and Environmental Factors

Stroke is a leading cause of death and disability worldwide. While traditional risk factors such as hypertension, diabetes, smoking, and atrial fibrillation remain central to prevention efforts, there is growing recognition that environmental conditions play a significant role in shaping stroke risk. Among these, air pollution and temperature extremes have emerged as the most consistently implicated exposures. Extensive epidemiological studies from multiple continents have shown that fine *particulate matter*, particularly particles smaller than 2.5 microns in diameter (PM_{2.5}), is linked to an increased likelihood of both ischemic stroke and transient ischemic attack, with less consistent associations for intracerebral hemorrhage. These effects are observed not only during chronic exposure over years, which may accelerate atherosclerosis and vascular aging, but also in the hours and days following acute increases in pollution, when transient physiological changes can precipitate an event. Importantly, elevated risks have been documented even when pollutant concentrations fall below current national air quality standards, suggesting the absence of a clear safe threshold.

Temperature is another environmental driver of cerebrovascular events. Both extreme heat and extreme cold have been associated with higher stroke incidence, though the underlying pathways differ. Heatwaves can provoke dehydration, reduce plasma volume, concentrate the blood, and disrupt blood pressure regulation, all of which strain the cardiovascular system and may trigger clot formation or vessel rupture. In contrast, cold exposure tends to increase sympathetic nervous system activity, raise blood pressure,

and promote vasoconstriction, which may contribute to plaque rupture or thrombus formation. Seasonal fluctuations in stroke incidence have been reported across diverse climates, with variation by age, comorbidity, and stroke subtype.

The biological plausibility of these associations is supported by mechanistic evidence from both human and animal studies. Air pollution and thermal stress can cause endothelial dysfunction, oxidative stress, and systemic inflammation, leading to a pro-thrombotic state and destabilization of atherosclerotic plaques. They can also influence cardiac rhythm and autonomic balance, which may serve as triggers for embolic events. Because environmental exposures affect entire populations simultaneously, even modest relative increases in risk translate into large absolute numbers of additional strokes.

From a public health perspective, environmental determinants are particularly compelling targets for intervention. Reducing exposure to air pollution and mitigating the impact of temperature extremes can be achieved through policies in transportation, energy production, building design, and urban planning, and these measures carry no direct medical risk. Moreover, the benefits extend beyond cerebrovascular disease to other major health outcomes, including respiratory illness and cardiovascular morbidity. Addressing these exposures represents a “no-regrets” strategy—an opportunity to reduce the burden of stroke while improving overall population health and resilience in the face of climate change.

Israeli Findings: Stroke and Environmental Factors

Israel offers a unique setting for studying environmental triggers of stroke, combining extreme heat and marked climatic variability with nearly complete, population-wide medical data. This rare overlap allows patterns to be detected that are often impossible to study in countries where only one of these elements is available.

The earliest Israeli investigation into environmental triggers of stroke was conducted by **Berginer et al. (1989)** in the Negev Desert. This study examined the clustering of stroke events in relation to meteorological conditions over a two-year period. The authors reported a noticeable increase in stroke incidence on days with high ambient temperatures, suggesting that acute heat exposure could act as a precipitating factor in susceptible individuals. This work was among the first to draw attention to environmental conditions as immediate triggers for cerebrovascular events in a semi-arid climate.

More than two decades later, **Zeevi et al. (2012)** analyzed seasonal variation in spontaneous intracerebral hemorrhage in northern Israel. Using hospital records, they demonstrated a clear winter peak in hemorrhagic strokes, aligning with the hypothesis that cold temperatures may promote blood pressure elevation and vascular stress, thereby increasing the likelihood of vessel rupture. This study highlighted that temperature effects are not confined to ischemic stroke but may extend to hemorrhagic subtypes, with different seasonal patterns.

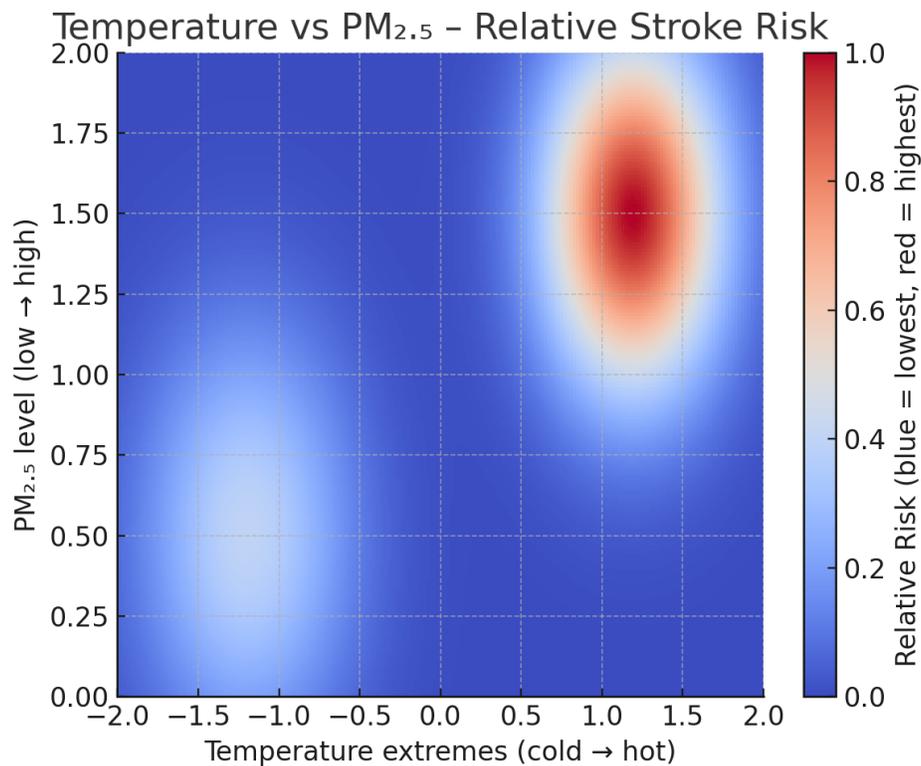
Yitshak-Sade et al. (2015) advanced the field by integrating high-resolution air pollution monitoring data with a case-crossover design to investigate ischemic stroke risk among young adults in the Negev. They found that short-term exposure to particulate matter, particularly PM_{2.5}, was associated with a significantly increased risk of ischemic stroke in individuals under 55 years of age. The effect was strongest for those living close to major roads, implicating traffic-related pollutants as a key source of risk. This was one of the first Israeli studies to quantify pollution–stroke associations using modern exposure assessment techniques.

Honig et al. (2016) investigated the relationship between meteorological changes and spontaneous intracerebral hemorrhage (SICH) subtypes in Jerusalem over five years. In 206 patients with primary supratentorial hemorrhage, they found that drops in barometric pressure 2–3 days before symptom onset were significantly associated with deep, but not lobar, hemorrhages, a pattern consistent with hypertensive vasculopathy. Deep ICH clustered in February, coinciding with larger pressure fluctuations, whereas lobar events, often related to probable cerebral amyloid angiopathy, showed no seasonal pattern. The authors propose that impaired vascular responses in hypertensive patients may make them susceptible to pressure-related blood pressure surges, precipitating hemorrhage

In **2017**, **Yitshak-Sade et al.** examined whether environmental exposures could improve long-term cardiovascular risk prediction. By incorporating air pollution and greenness metrics into predictive models for myocardial infarction, stroke, and cardiovascular mortality, they found minimal improvement in predictive accuracy, suggesting that these exposures are more relevant as acute triggers than as long-term individual risk modifiers. Nonetheless, the study confirmed that chronic exposure to low greenness and high pollution correlates with worse cardiovascular outcomes.

Vered et al. (2020) conducted a nationwide time-stratified case-crossover study to assess the relationship between high ambient temperatures and stroke or transient ischemic attack (TIA). They observed that increased mean daily temperature in summer was associated with a higher risk of ischemic events within one to six days, particularly among working-age adults. Interestingly, a greater diurnal temperature range (cooler nights) appeared to mitigate this risk, suggesting a protective role of nighttime cooling.

Also in 2020, **Yitshak-Sade et al.** published a large national analysis on air pollution and ischemic stroke. Using registry data and high-resolution PM_{2.5} exposure models, they reported a non-linear exposure–response curve, with stroke risk increasing even at levels well below the Israeli 24-hour PM_{2.5} standard. No association was observed for intracerebral hemorrhage, and the relationship with TIA was similar in magnitude but not statistically significant. Stratified analyses indicated stronger effects in women, older adults, non-Jewish populations, and those with diabetes, hypertension, or ischemic heart disease.



In **2023**, **Gaines et al.** revisited the air pollution–stroke relationship with an emphasis on high-risk subgroups. Their findings reinforced earlier observations that vulnerable populations experience greater absolute and relative risk from particulate matter exposure, and they argued for lowering Israeli air quality standards in light of evidence that harm occurs below current thresholds.

Most recently, **Librunder et al. (2024)** analyzed over two decades of national stroke registry data to explore age-dependent seasonality in stroke incidence. They found that ischemic stroke and TIA peaked in the summer among individuals younger than 70, whereas in older adults, the peak occurred in winter. Intracerebral hemorrhage incidence was highest in winter and autumn, independent of age. These results underscore the complexity of temperature–stroke relationships and suggest that prevention strategies in

Israel should be tailored not only to environmental conditions but also to patient age and stroke subtype.

Summary of the Israeli findings

Israeli research offers a distinctive view on environmental determinants of stroke, shaped by the country's varied climates, pollution sources (traffic, industry, desert dust), and high-resolution environmental monitoring. The main findings are:

- *Heat and temperature variability:* Short-term heat exposure increases stroke and TIA risk. Ischemic events peak in summer among adults <70 and in winter among older adults, while ICH peaks mainly in winter/autumn.
- *Barometric pressure:* Drops in atmospheric pressure 2–3 days before onset are linked to deep ICH but not lobar ICH, suggesting vulnerability in patients with hypertensive vasculopathy.
- *Air pollution:* PM_{2.5} exposure increases ischemic stroke risk even below current Israeli standards, with stronger effects in younger adults, women, non-Jewish populations, and those with cardiovascular comorbidities; no clear association is seen for ICH.
- *Greenness:* Residential greenness shows limited added value for long-term stroke risk prediction, supporting a role for environmental factors mainly as acute triggers.
- *Mechanisms:* Findings align with global evidence, implicating dehydration, blood pressure instability, inflammation, and hypercoagulability as key pathways.

Future Projections

Climate projections suggest that Israel will experience higher temperatures, more frequent and intense heatwaves, and increased Saharan dust events. Combined with ongoing urbanization, traffic-related air pollution, population aging, and rising cardiovascular comorbidity, these trends are expected to increase the number of environmentally triggered strokes, with risks varying by season, age, and stroke subtype.

Policy and Research Implications

Israeli evidence shows that stroke prevention must be climate-specific and population-targeted, reflecting hot summers, temperature variability, dust storms, and urban traffic. Because risks vary by age, stroke subtype, and environmental trigger, *prevention strategies* must be tailored accordingly. Below are a few clinically relevant suggestions.

Integrated Environmental Health Alerts:

Establish a national early-warning system combining air quality, weather, and barometric pressure data.

Include thresholds to protect high-risk hypertensive individuals.

Deliver targeted, potentially personalized alerts (using geolocation and health data) for:

- Older adults during winter cold spells and pressure drops
- Working-age adults during summer heatwaves and pollution events
- Residents of high-exposure areas, including traffic corridors and dust-prone regions

Urban planning: Reduce traffic-related PM_{2.5}, expand urban cooling/greening, and mitigate desert dust exposure.

Clinical care: Integrate environmental risk alerts into EMRs and prepare hospitals for surge periods.

Public education: Provide targeted guidance on heat, pollution, and pressure-related risks.

Data integration: Link national stroke registries with high-resolution environmental data.

Research & prevention: adopt a non-regrets environmental mitigation strategy by studying combined environmental stressors and implementing targeted interventions during high-risk periods, supported by barometric pressure–based early-warning systems for high-risk populations.

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