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SYMPOSIUM

Geoenvironmental Diabetology

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Abstract

Many reports have documented the negative health consequences that environmental stressors can have on patients with diabetes. Studies examining the interaction between the environment and a patient with diabetes can be unified under a single discipline termed "geoenvironmental diabetology." Geoenvironmental diabetology is defined more specifically as the study of how geophysical phenomena impact a patient with diabetes, to include effects on metabolic control, ancillary equipment (e.g., glucometers and insulin pumps), medications, supplies, access to care, and influences on the adaptive strategies employed by patients to care for their diabetes under extreme circumstances. Geological events such as natural disasters (e.g., earthquakes) or extreme weather (e.g., heat waves) are examples of stressors that can affect patients with diabetes and that can be included under the heading of geoenvironmental diabetology. As proposed here, geoenvironmental diabetology refers to how events in the physical world affect those with diagnosed diabetes, rather than how environmental factors might trigger development of disease. As the global prevalence of diabetes continues to increase, including in parts of the world that are especially vulnerable to disasters and climate change, further discussion is warranted on how to best prepare for management of diabetes under conditions of extreme geological and weather events and a changing climate. An overview is presented of various studies that have detailed how geoenvironmental phenomena can adversely affect patients with diabetes and concludes with a discussion of requirements for developing strategies for geoenvironmental diabetes management.

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Introduction

Multiple studies have documented negative health effects that environmental stressors can have on patients with diabetes. Studies examining the interaction between the environment and a patient with diabetes can be unified under a single discipline termed "geoenvironmental diabetology." Geoenvironmental diabetology is defined more specifically as the study of how geophysical phenomena impact a patient with diabetes, to include effects on metabolic control, ancillary equipment (e.g., glucometers and insulin pumps), medications, supplies, access to care, and influences on the adaptive strategies employed by patients to care for their diabetes under extreme circumstances. Geological events such as natural disasters (e.g., earthquakes) or extreme weather (e.g., heat waves) are examples of stressors that can be included under the heading of geoenvironmental diabetology. The proposed concept of geoenvironmental diabetology refers to how events in the physical world affect those with diagnosed

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Abbreviations: (HbA1c) hemoglobin A1c, (NGO) nongovernmental organization

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diabetes, rather than how environmental factors interact with genetic predisposition to trigger development of disease.[1,2]

An overview is provided on how various geoenvironmental phenomena affect patients with diabetes. Discussion could also incorporate scenarios where patients voluntarily insert themselves into physically stressful environments, such as traveling to high altitudes (e.g., recreational mountain climbing), or situations that involve increased atmospheric pressure (e.g., scuba diving). Much of diabetology is concerned with teaching patients how to interact with their environment. This article focuses on the unexpected (though in some cases foreseeable) geological disasters and environmental stresses that can impact patients with diabetes.

The global prevalence of diabetes is increasing, including in geographic regions where populations are especially vulnerable to disasters and climate change.[3] Developing plans to care for diabetes patients during times of anticipated and unanticipated events will take on greater priority. This review is concluded by discussing general requirements for constructing a strategy for geoenvironmental diabetes management.

Methods

A literature search was conducted using Ovid MEDLINE 1960 to present, EMBASE, CINAHL, PsychINFO, Healthstar, and SCOPUS databases. The first set included Medical Subject Heading terms "diabetes mellitus" and "diabetes complications," with both terms exploded for maximum retrieval. The text words "diabetes" or "diabetics" were searched, and one large set of diabetes terms was created by joining all terms with the Boolean "OR." In like manner, a second set was created by searching Medical Subject Heading terms "earthquakes," "cyclonic storms," "tsunamis," "tornadoes," "droughts," "starvation, "floods," "cold temperature," "hot temperature," "extreme heat," "extreme cold," "volcanoes," "air pollution," "environmental pollution," "humidity," "weather," "disasters," "disaster planning," and "disaster medicine." The same terms were searched as text words allowing for variant endings and also included "hurricanes," "famine," "seasonal variation," "seasonal fluctuation," "heat waves," "airborne particulate matter," "environmental factors," "disaster preparedness," and "natural disasters." The two major sets were combined using the Boolean "AND" and limited to English and human. The same search strategy was utilized in the other database allowing for variations in controlled vocabularies. Duplicates were removed. The bibliographies of articles were reviewed to identify resources not discovered in the database searches. As a result, 99 articles have been cited as references.

Natural Disasters and Patients with Diabetes

Earthquakes

Worsened metabolic control in diabetes patients has been documented following earthquakes. For example, following the Japanese Hanshin-Awaji earthquake in January 1995, hemoglobin A1c (HbA1c) levels significantly increased from 7.74% in December 1994 (pre-quake) to 8.34% by March 1995 then declined to pre-earthquake levels by September 1995; levels rose significantly after the quake regardless of mode of hyperglycemia therapy.[4] Other analyses of Hanshin-Awaji earthquake data, and of the Japanese Kobe (January 17, 1995) and Mid-Nagata (October 2004) earthquakes, also demonstrated significant worsening of HbA1c levels for up to 6 months following the disasters.[5–7] Patients were separated from their needed medications and supplies, and access to medical care was disrupted. Most patients lost insulin vials, needles, or pens because of the destruction.[7] Securing needed medications, dealing with stress, and obtaining an appropriate diet were identified as the greatest needs of patients with diabetes after the earthquakes.[8] As the earthquake in Haiti demonstrated, a heavy reliance on nongovernmental organizations (NGOs) to provide necessary diabetes relief efforts may be necessary during the period following a natural disaster.[9,10]

Analysis of the Marmara earthquake that struck Northwestern Turkey in August 1999 showed worsened glycemic control and quality of life among patients with type 1 diabetes following the disaster.[11] Hemoglobin A1c increased significantly 3 months after the earthquake and remained elevated up to 1 year after. Insulin requirements also statistically increased with respect to pre-quake doses. Patient quality of life was significantly lower 3 months after the earthquake and remained lower after 1 year in some subscales.[11]

Hurricanes

Hurricanes, like earthquakes, can have a detrimental effect on patients with diabetes through rapid depletion of needed medications and impaired access to medical care. Epidemiological studies indicate that diabetes is one of the most prevalent chronic conditions encountered in hurricane stricken areas in the United States.[12–17] Examination of cases seen in a field hospital set up outside of Homestead, Florida, following Hurricane

Andrew in 1992 showed that supplies of insulin were depleted within 24 h.[18] In a study on mortality following Hurricane Iniki that struck the island of Kauai, Hawaii, in 1992, deaths among patients with diabetes significantly increased relative to pre-hurricane data.[19] An analysis of surgical cases after Hurricane Ivan struck Grenada in 2004 found a statistically significant increase in patients seen with diabetic foot problems relative to admissions occurring the year prior to Ivan.[20]

Estimates of chronic disease prevalence in the New Orleans area after Hurricane Katrina, which struck the U.S. Gulf Coast in 2005, showed that 9% of the population affected by the disaster had diabetes, with nearly 25% being on insulin therapy.[21] The high prevalence of diabetes was unanticipated by relief agencies.[22] The impact of the storm was due far more to the levy breaches and represents a combined disaster of both a hurricane and flooding. Access to diabetes care was severely impaired with the collapse of the health care infrastructure, with heavy reliance on NGOs to provide needed diabetes supplies, medications, and glucometers.[22,23]

An assessment of HbA1c levels following Katrina indicated that underlying socioeconomic disparities in glucose control were exacerbated by the disaster. Fonseca and colleagues[24] examined metabolic control in 1795 diabetes patients and compared values 6 months before Katrina with values 6 to 16 months after in patients cared for by three different New Orleans health care systems: a private teaching hospital, a Veteran's Administration health system, and a state-funded indigent care delivery system. Hemoglobin A1c levels increased significantly only among patients cared for in the state-funded system. Katrina increased direct, indirect, and total health care costs for patients seen in all three systems, with the greatest impact occurring in the indigent population.

Temperature Extremes and Diabetes

Heat

The Intergovernmental Panel on Climate Change anticipates an increased frequency of extreme heat and heat waves as global temperatures rise.[25] Individuals in some regions of the world, such as the Middle East, Sub-Saharan Africa, and India—where great increases in the number of diabetes cases are expected[26,27]—may be better adjusted to the continuation of heat events. However, there may be more heat wave events in mid-latitude regions such as the United States and Europe, where patients are not as well prepared.

Patients with diabetes may have increased susceptibility to the heat because of impairment of thermoregulatory mechanisms and impaired orthostatic responses at elevated temperatures.[28,29] Whether these physiologic impairments are associated with increased heat-related illness is not known; however, patients with diabetes do have higher numbers of emergency department visits, hospitalizations, and mortality documented during heat waves and hot weather.[30–36]

Prolonged exposure to high temperatures can alter insulin kinetics and stability.[28] In general, unopened vials, cartridges, and prefilled insulin delivery systems should be stored at 2–8 °C (36–46 °F), and opened vials may be kept at <30 °C (86 °F) for 28 days. Keeping insulin cool can be a challenge in some regions of the world. For instance, refrigerator availability is variable in developing tropical countries. Consequently, in some parts of the world (e.g., Africa), patients have developed unique adaptive strategies to protect their insulin from heat, such as storing their medication in clay pots. The clay pots contain sand and water, and it is hypothesized that cooling occurs by water evaporating through the porous clay. The efficacy of this method at keeping insulin cool has not been critically assessed.[37]

Cold

Normal body temperature is maintained in a cool environment by increased heat production and peripheral vasoconstriction to reduce conductive heat losses.[38,39] Loss of efferent vasomotor control can occur with diabetic autonomic neuropathy and could have important thermoregulatory implications by placing the individual at increased risk for hypothermia. Impairment in the ability to raise core body temperature and to vasoconstrict in response to cold exposure has been demonstrated in diabetes patients with autonomic neuropathy.[38–42] A study in diabetes patients showed that immersion of fingers and forearms into cold water can affect the accuracy of glucometers, with measurements taken from cold extremities causing underestimation of glucose levels.[43]

These studies suggest that patients with diabetes could have a susceptibility to cold weather. Higher diabetes mortality has been reported during winter months.[44] Unpublished data have been cited, indicating that patients with diabetes report more cardiac symptoms in the cold.[45] In a study conducted in England, Neil and associates found that emergency room visits and hospitalizations due to hypothermia occurred more commonly in elderly women with diabetes than in the general population. Although the effects of heat waves have been well studied,[30,31,34] the interaction between cold weather and diabetes from an epidemiological standpoint has been less studied.

Seasonal Variation in Metabolic Control

Numerous studies have documented a relationship between changes in seasons and glycemic control in patients with both type 1 and type 2 diabetes. Studies typically report that the highest HbA1c levels occur during the colder months and the lowest levels during the warmer seasons.[47–55] Significant seasonal changes in glycemic control have been noted in both the northern and the southern hemispheres, with less variation occurring in an equatorial country (Singapore) characterized by very little seasonal variation.[56]

In a multicenter analysis, Tseng and coworkers[57] examined seasonal variations in HbA1c from 72 Veteran's Administration health centers by age, sex, race, and climate characteristics over a 2-year period (1998–2000), controlling for patient characteristics, insulin use, and regional climate. Hemoglobin A1c values rose during the winter months then declined during the spring/summer months regardless of age, race, sex, and insulin use; regions characterized by warmer winters had less of a winter–summer contrast. Liang[58] found that HbA1c levels, systolic blood pressure, diastolic blood pressure, low-density lipoprotein cholesterol, and preprandial glucose were all highest in the winter and lowest in the summer and varied inversely with monthly mean climate temperature.

One explanation for the observed cyclical variation in glycemic control is that changes in weather result in alterations in diet or exercise patterns. For example, HbA1c values in children with type 1 diabetes were highest in winter and lowest in summer, while physical activity was noted to be highest in summer and lowest in winter.[50] However, another analysis demonstrated that, while fasting glucose levels varied by season in community-dwelling adults even after controlling for seasonal changes in obesity, there were no significant coincident seasonal variations in exercise or nutritional composition of diet.[59]

Another possibility is that there are physiological adaptations in other metabolic factors entrained to the seasons that result in higher glucose levels. Sohmiya and colleagues[60] found that percentage body fat was highest in winter versus summer months in men with type 2 diabetes. In a study performed in a sample of healthy Japanese men and women, significant variations in glucagon levels occurred with the seasons and were highest in winter (December to January), declining thereafter and reaching their lowest levels in autumn months (September to November).[61]

The aforementioned data have at least two implications. First, it may be necessary to make seasonal changes in diabetes therapy to achieve consistency in glycemic control, intensifying therapy in the fall and winter and deintensifying during the transition from the winter to summer months to avoid hypoglycemia. Secondly, adjusting for season (or month) of measurement may be needed when using HbA1c to assess quality of diabetes care.[49,57] It is not known whether these cyclical increases in HbA1c are correlated with diabetes complication risk.

Environmental Factors and Point-of-Care Glucose Testing

An important component in diabetes care is the ability of the patient to perform self-assessment of blood glucose levels. However, glucometers are particularly prone to environmental effects. Factors affecting accuracy of glucose meters include air exposure, altitude, humidity, and temperature.[62–65] Glucose monitoring strips are particularly susceptible heat, humidity, and storage conditions.[64,65] Seasonal variations in humidity and temperature affect the accuracy of glucose readings within individual hospitals.[66]

The Indonesian tsunami of 2004 and Hurricane Katrina confirmed the importance of glucometers during times of natural disasters. Following these events, glucometers were often the only means by which operating health care facilities checked glucose levels. However, they were limited in number, and with the collapse of infrastructure and the inability to maintain recommended ambient operating conditions, the equipment had to be employed under extremes of humidity and temperature for which they were not intended. Glucometers should be developed to withstand extreme ranges of temperature and humidity, particularly if they are going to be used in suboptimal conditions such as occur after natural disasters.[67]

Air Pollution

Recent data suggest a relationship between air pollution and diabetes prevalence.[68,69] Air pollution is associated with pulmonary and cardiovascular events.[70] Multiple studies have demonstrated a link between particulate airborne particles and ozone and higher mortality, more emergency room visits, and more hospitalizations among diabetes patients.[71–77] This higher morbidity and mortality is generally attributed to cardiovascular disease, and studies indicate that diabetes increases the susceptibility of patients to the cardiovascular events that can be precipitated by air pollution.[71,72,75,78,79] The effects appear to be linearly associated with the concentration of airborne particles. For instance, in an analysis of Medicare hospital admissions from 2000 to 2003 involving 26 communities, for every 10 $\mu g/m^3$ increase in 2.5 μm size airborne particles, diabetes admissions due to cardiovascular disease significantly increased by 2.74%.[77]

Air pollution and heat events often occur together and may reinforce each other. The effect of air pollution on mortality on patients with cardiovascular disease and coexisting diabetes has been shown to be greatest in warm seasons.[80] However, the relationship between concentrations of airborne particulate matter and susceptibility to cardiovascular events in patients with diabetes persists even after adjusting for ambient temperature, humidity, and season.[73,77,78]

The potential mechanisms of how diabetes modifies and increases the negative cardiovascular effects of air pollution are now being elucidated.[79] Increasing concentrations of airborne sulfates, black carbon, and particles <2.5 μm in size have been associated with decreased-flow-mediated and nitroglycerine-mediated vascular reactivity among those with diabetes.[81] Besides changes in vascular reactivity, the relationship between adverse cardiovascular effects of air pollution has been postulated to be mediated by increased inflammation caused by air pollution. Higher concentrations of inflammatory markers (e.g., intercellular adhesion molecule 1, vascular adhesion molecule 1, C-reactive protein) have been found to be increased in diabetes patients with increasing levels of air pollution.[82,83] Platelet activation increases with greater exposure to particulate matter in patients with both type 1 and type 2 diabetes.[84]

Geoenvironmental Diabetes Management

A multitiered approach will be needed when developing a strategy for geoenvironmental diabetes management. Coordinated efforts of the government, NGOs, and clinical institutions will be necessary to develop, implement, and disseminate preparedness plans for diabetes patients during times of extreme geological or environmental events. Emergency transport of patients—which can be severely impaired following any natural disaster or severe weather event—is also an issue that requires a collaborative solution. For geographic areas that are particularly prone to natural disasters or extreme weather, better understanding of local diabetes prevalence would help relief agencies anticipate the quantity of supplies and medications that would be needed for these patients in the event of major geological or weather events.[85]

Individuals with diabetes must also take personal steps to be prepared. Guidelines for disaster preparedness are available for patients with diabetes.[86–93] It is not known how familiar patients are with these recommendations, however. Disparities in diabetes disaster preparedness exist, with lower socioeconomic groups less well prepared than higher socioeconomic groups.[94] Although diabetes patients themselves can take the initiative in personal disaster preparedness, clinical diabetes programs operating in regions at risk for geological or extreme weather events should incorporate information into their routine diabetes educational programs.

As with natural disasters, response to extreme weather phenomena will require a multilevel approach to mitigate health consequences for patients with diabetes. When it comes to hot weather, municipalities are not well prepared to deal with its health consequences.[95] Using hot weather further as an example, employing personal air conditioning can reduce the risk of hospitalizations due to diabetes,[96] and cities should facilitate access to cooled facilities during heat waves for vulnerable patients. A survey of patients with diabetes revealed deficits in knowledge about diabetes self-management in relation to hot weather.[29] Many patients did not understand the significance of the heat index and did not associate hot weather forecasts with their diabetes management.[29] Public awareness campaigns, educational materials, and programs advising patients how to cope during weather extremes are important, and diabetes education programs should include information on managing or combating the effects of weather extremes such as heat waves.

Certain technologies could serve as important adjuncts in geoenvironmental diabetes management. For instance, geographic information systems can be employed to map urban areas where increased patient vulnerability to heat might exist.[97] Wireless transmission of personal blood glucose data by patients to a centralized electronic health record system has been suggested as a means of early detection for epidemic disease outbreaks.[98] A similar concept could be adopted for centrally monitoring individual glucose control during extreme weather events that might allow early intervention (e.g., a phone call to the patient to provide advice on whether to seek medical attention). Real-time methods such as transmission of text messages to cell phones by local area weather services could be better promoted as a means to communicate weather advisories to patients with diabetes.

While the impact of natural disasters and weather extremes on the diabetes patient can potentially be tempered with enhanced national planning, educational programs on preparedness, and individual readiness, effects of other environmental stressors on the diabetes patient, such as air pollution and climate change, are not as easily mitigated, and the reversal of these forces require major shifts in national and global policy. However, in a report outlining the research needs on climate change and health, diabetes—one of the most prevalent and rapidly increasing diseases—was not one of the priority disease areas listed.[99]

Conclusions

Geological and other environmental variables and stressors can negatively affect patients with diabetes, having impact on such important variables as metabolic control, equipment performance, quality of life, access to medical care, mortality, and health care utilization. The term geoenvironmental diabetology is proposed as a discipline to unify the studies on the interaction of the environment with diabetes. Given the national and global rise in diabetes prevalence, further discussion on how to best prepare for management of diabetes under situations of extreme geological and weather events and a changing climate is warranted.

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