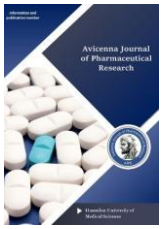
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Review Article

Global Warming Impacts on Drug Therapy, Pharmacodynamics, Pharmacokinetics of Drugs, and Treatment Failures

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Abstract

Global warming is increasingly affecting human health, with significant consequences for drug therapy. Rising temperatures and climate-related changes alter the pharmacokinetics and pharmacodynamics of medications, affecting their efficacy and safety. These changes may contribute to treatment failures, and may necessitate dose adjustments, especially in patients with chronic conditions such as heart failure and diabetes. Additionally, drug stability is compromised by higher ambient temperatures, increasing the risks of degradation and reduced therapeutic effectiveness. Vulnerable populations, including pediatric and elderly patients, face heightened risks due to impaired thermoregulation and heat intolerance. This article reviews the effects of climate change on drug therapy, emphasizing the need for healthcare systems to adapt their pharmaceutical care strategies in response to environmental changes. Understanding these shifts is critical to managing both emerging diseases and chronic health conditions in a warming world.

Keywords: Adverse Effects; Drug Therapy; Global Warming; Pharmacodynamics; Pharmacokinetics; Treatment Failure

Introduction

Global warming has far-reaching effects on human health, with significant implications for drug therapy and patient outcomes [1]. Rising environmental temperatures and climate-related changes are known to affect drug pharmacokinetics and pharmacodynamics, altering their efficacy and safety [2, 3]. This environmental shift challenges human acclimatization, further complicating drug administration and effectiveness [4].

Global warming may also compromise the stability and efficacy of drugs due to increased risks of degradation during storage under higher ambient temperatures [5]. Additionally, the increase in extreme weather events and environmental changes can lead to drug therapy complications by influencing the incidence of infectious diseases, for which pharmacological treatment may be less effective under these new climatic conditions [6].

Furthermore, shifts in temperature can disrupt normal pharmacokinetics, altering drug absorption, distribution, metabolism, and excretion, leading to unpredictable therapeutic outcomes and increased treatment failures [6, 7]. Medications may also become less effective or require dose adjustments in

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patients exposed to extreme heat due to the potential alteration of drug metabolism enzymes and transport proteins [8]. For instance, hyperthermia can cause enzyme inactivation, further complicating the pharmacodynamic responses of medications [6]. This necessitates a reevaluation of drug dosing regimens in light of changing environmental conditions to mitigate potential adverse effects [9].

The global rise in temperatures poses additional challenges to managing chronic diseases, such as heart failure and kidney diseases, where drugs that are already sensitive to temperature changes become even more prone to causing adverse outcomes under the strain of heat [10, 11]. These changes underscore the need for healthcare systems to adapt their approaches to pharmaceutical care and develop sustainable strategies to mitigate the risks posed by climate change [2].

This study aimed to synthesize clinically relevant findings from existing studies and drug monograph to alert healthcare professionals to the emerging risks that climate change poses to safe and effective drug therapy.

Methods

Searches were conducted in Google Scholar, PubMed, and Scopus databases for studies published up to October 10, 2024.

The search strategy included the following terms: “global warming” and “drug therapy” and all MeSH terms in the PubMed database. In Scopus, “global warming” and “drug therapy” were searched separately in the Keyword field, and the resulting records were combined. Google Scholar was searched for “global warming” and “drug therapy”; the total was then added to the records.

Review

Global warming and climate change are increasingly recognized for their significant effects on medication efficacy, treatment protocols, and drug demand. These impacts arise from various mechanisms, including changes in pharmacokinetics, medication storage challenges, and the emergence of new health conditions necessitating different therapeutic approaches.

Heat Shock Proteins and Thermoregulation

Heat shock proteins (HSPs) are arguably the most vital superfamily of proteins involved in maintaining protein homeostasis and preventing protein damage during acute or prolonged stress. They play a crucial role in cellular protection when exposed to severe stress. Increased HSP expression is an important physiological response that safeguards key cellular structures from harmful factors. Certain HSPs are particularly important for thermotolerance, serving as a critical factor for survival at elevated temperatures. The process of acclimatization, chronic exposure to tropical climates, or a gradual increase in temperature activates HSP gene transcription and subsequent protein synthesis to a lesser extent than sudden hyperthermia [12].

Certain drugs may impair HSP-related responses, such as calcium channel blockers and other antihypertensive agents. These agents block calcium influx, which may negatively affect HSP gene transcription. Alpha-1 receptor antagonists, which also block HSP production and are used as add-on drugs for refractory or complicated high blood pressure, should be used cautiously in this setting [13].

Dermatological and Cutaneous Considerations

A review exploring how rising global temperatures impact dermatological conditions and drug therapies used in their treatment highlights how heat-related illnesses can exacerbate skin conditions, influencing the effectiveness of treatments. When the body loses internal heat through direct heat exchange with the surroundings, assisted by increased blood flow to the skin and sweating from the eccrine glands, sweat evaporation helps cool the body even when the external temperature is higher than the skin’s surface. Several factors influence the skin’s ability to regulate temperature, including environmental conditions, physiological factors such as age and gender, and pathological factors such as existing health conditions, disorders affecting sweat glands, and the use of certain medications [14].

Medications used to treat heart failure can affect skin blood flow, especially beta-blockers, which may limit the heart’s ability to increase cardiac output in response to cutaneous vasodilatation. Diuretics can also influence skin blood flow by

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reducing blood volume. Additionally, dehydration due to sweating may further diminish cutaneous vasodilation in patients taking diuretics [9].

Drugs Impairing Thermoregulation

Some drugs impair thermoregulation, including serotonergic, antipsychotic, and anticholinergic agents, as well as amphetamines and anti-Parkinsonian drugs. Dose adjustment of antipsychotics is recommended to prevent suppression of hypothalamic thermoregulatory mechanisms, which can otherwise precipitate neuroleptic malignant syndrome [15, 16]. Selective serotonin reuptake inhibitors (SSRIs) may be used to treat anxiety disorders; however, their use during extreme heat may increase the risk of heat-related adverse effects. The use of stimulant drugs, including amphetamines, may further impair thermoregulation and increase the risk of hyperthermia.

Parasympathetic components of the autonomic system are protective in hot climates by contributing centrally to thermoregulation, stimulating hidrosis, and promoting vasodilation of peripheral blood vessels [17]. Using anticholinergics, which interfere with sweat glands, places patients at higher risk of hyperthermia and heat stroke.

The pediatric population is particularly sensitive to heat intolerance and hypohidrosis from antiepileptic drugs, especially zonisamide and topiramate [18]. Consumption of these drugs may result in a lower threshold for heat exhaustion or heat stroke.

Heat waves have been linked to more severe drug reactions, especially from diuretics, SSRIs, angiotensin-converting enzyme inhibitors, and proton pump inhibitors [4].

Diabetes, Obesity, and Metabolic Considerations

Individuals with diabetes are at higher risk of death or hospitalization during heat waves due to multiple factors. Common comorbidities such as obesity, cardiac dysfunction, and hyperlipidemia can impair thermoregulation. Climate change may necessitate new therapeutic approaches, particularly for chronic diseases like obesity and diabetes, where drug metabolism is affected by environmental factors [6]. Patients with diabetes may exhibit delayed cutaneous vasodilation, elevated core temperature thresholds, and impaired sweat responses, particularly those with poor glycemic control or neuropathy. This often results in reduced sweating on the lower body (hypohidrosis) and sometimes excessive sweating on the upper body (hyperhidrosis). Medications used to treat diabetes-related comorbidities can further worsen thermoregulation, increasing vulnerability to heat-related illnesses. HSPs both influence and are influenced by leptin and glucagon-like peptide-1 (GLP-1), which regulate appetite and weight [19].

Veterinary Medicines, Drug Residues, and Sustainability

Climate change, particularly global warming, may affects residues of veterinary medicines in livestock products. Higher temperatures may alter the pharmacokinetics and metabolism of drugs in animals, leading to increased treatment failures or the need for new drug regimens. Environmental implications of drug residues are also significant, as climate-induced changes in ecosystems may alter drug degradation, impacting food safety and the efficacy of veterinary interventions [20].

Broader implications of climate change on the sustainability of pharmaceuticals include how air and water pollution, exacerbated by global warming, may degrade the efficacy of medications and challenge the production of sustainable drugs. There is a growing need for environmentally friendly medications, adaptation of drug production to changing environmental conditions, and consideration of the effects of pollutants on drug stability and patient outcomes [2].

Drug Stability, Storage, and Degradation

Many commonly prescribed drugs, such as amlodipine and lansoprazole, degrade when exposed to high temperatures, potentially reducing their effectiveness [15]. Low humidity can degrade drugs such as levothyroxine, even if they remain stable at high temperatures [15]. Heatwaves can exacerbate side effects, such as increased hypotension from nitroglycerin or severe hypoglycemia from insulin [15]. High temperature also accelerates metabolism of human coagulation factors, raising the possibility that patients on warfarin will experience more bleeding incidents.

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Chronic exposure to high temperatures and pollution can worsen conditions such as asthma and chronic obstructive pulmonary disease (COPD), leading to increased treatment failures [6]. The degradation of drugs due to improper storage conditions during heatwaves can lead to reduced efficacy and treatment failures [5, 15].

Climate change has led to higher levels of UV radiation due to ozone layer depletion. Certain medications can increase photosensitivity, making patients more susceptible to UV-related skin damage [1].

Treatment Failures and Clinical Complications

Patients may experience treatment failures due to altered drug efficacy under extreme temperatures or humidity. For example, diuretics may cause dehydration during heatwaves, complicating the management of chronic conditions [13], as also observed during fasting in Ramadan. Cases of thrombosis in women receiving combined oral contraceptives also rise in hot seasons, as dehydration is a risk factor for this adverse effect. Dehydration further raises vulnerability to the nephrotoxicity of drugs such as nonsteroidal anti-inflammatory drugs (NSAIDs) and antibiotics.

Patients receiving chronic combination therapy of antihypertensives such as thiazides and angiotensin-converting enzyme inhibitors or angiotensin receptor blockers (ARBs) may experience elevated serum creatinine levels, predisposing them to acute kidney injury due to volume depletion, decreased renal perfusion, and diminished responsiveness of the renin-angiotensin system, especially in elderly patients with pre-existing kidney damage [15].

Climate change is associated with a rise in vector-borne diseases (e.g., malaria), respiratory issues due to poor air quality, and other health complications that require new therapeutic strategies [3]. Pharmaceutical demand is expected to shift as new diseases emerge and existing conditions worsen due to climate-related factors, necessitating a reevaluation of treatment protocols and drug indications [21].

Articles exploring drug resistance in tropical diseases such as leishmaniasis highlight how global warming impacts disease epidemiology and drug resistance; similar concerns apply to malaria and other insect-borne diseases [22]. In Iran, both leishmaniasis and malaria remain endemic. Liposomal amphotericin B, originally an antifungal agent, is used in managing leishmaniasis. Following the COVID-19 pandemic, there was an outbreak of mucormycosis that has not returned to pre-pandemic levels; corticosteroid overuse increased the risk among vulnerable patients (immunocompromised and diabetic), and shortages of liposomal amphotericin B became a healthcare concern. Further increases in leishmaniasis incidence may place additional pressure on the availability of liposomal amphotericin B for other indications..

Pharmacokinetic Alterations

Global warming may influence drug absorption, distribution, metabolism, and excretion, leading to potential drug failures or altered therapeutic windows. Data from a sample of 10 participants on a phenytoin derivative demonstrated a decrease in serum levels in summer due to increased sweating. In another observational study comparing spring to autumn, serum levels of valproate and carbamazepine were considerably lower. Storing carbamazepine and phenytoin formulations under high-temperature and high-humidity conditions compromised the stability of the pharmaceutical forms and decreased bioavailability by as much as 50%. In humid and hot settings, valproate should be stored in a refrigerator. Manufacturers recommend that phenobarbital be stored below 25˚C; similar explicit recommendations are not stated for other antiepileptics [18].

Studies investigating the impact of external heat on the absorption and elimination of certain orally administered drugs have shown minor changes in plasma drug concentrations. In contrast, systemic absorption of drugs taken transdermally or subcutaneously is more significantly affected [23].

Transdermal fentanyl patches are used as analgesics for chronic pain, including palliative therapy for cancer pain. Higher external temperatures (e.g., over 40 ˚C) may increase drug release and elevate blood concentrations, thereby increasing the risk of adverse effects such as apnea and respiratory depression can appear at lower doses, or the “end-of-dose pain” phenomenon can occur more frequently.

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Drug distribution can also be slightly influenced by changes in blood volume due to excessive dehydration, which reduces the volume of distribution (Vd) of drugs that are not highly lipid-soluble [23]. Hepatic enzyme activity plays a role in the metabolism of high-extraction drugs; increased environmental temperatures can enhance enzyme-catalyzed reactions, thereby reducing the hepatic clearance of these drugs. Additionally, high temperatures reduce renal blood flow, which, along with dehydration and hormonal changes, decreases urine output and limits drug elimination [23].

Summary of Interference Pathways is depicted in Figure 1.

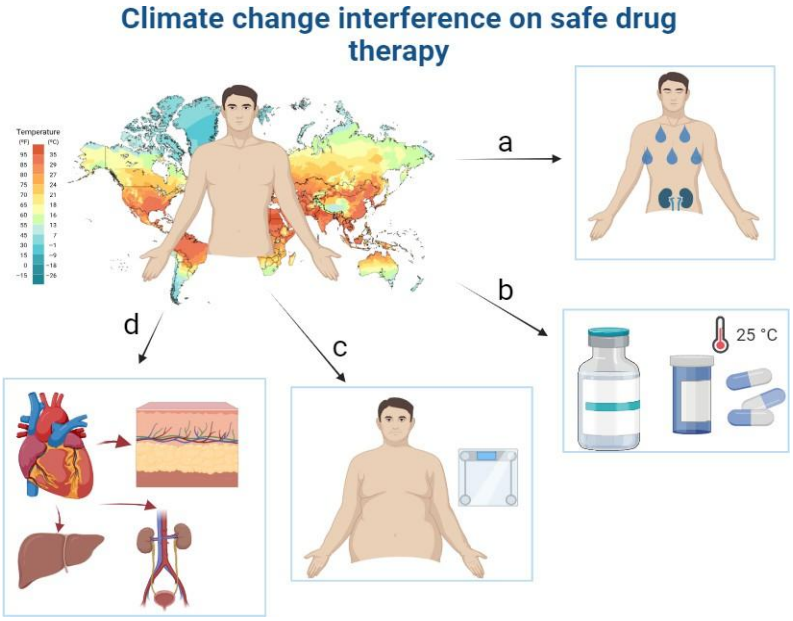


Figure 1. Climate change interference on Safe Drug Therapy. a) Excessive hidrosis leads to impairment of drug excretion and higher incidence of adverse effects. b) Drug storage and distribution face some challenges, leading to lower efficacy and safety. c) As rates of obesity and metabolic syndrome rise, drug delivery, drug pharmacokinetics, pharmacodynamics, and safety will be altered. d) With the temperature rise and vasodilation of dermal vessels, visceral blood flow is impaired, thus chronic diseases worsen, and drug metabolism and elimination change drastically.

Discussion

The present review synthesizes evidence that rising ambient temperatures and related climate stressors systematically alter both the pharmacological behavior of medicines and the physiological capacity of patients to tolerate them. While earlier commentaries have flagged the general importance of climate for health-system resilience [2, 3], the present work consolidates concrete pharmacokinetic, pharmacodynamic, and practical observations on drug storage into a single clinically oriented narrative. This integration constitutes the principal novelty of the paper: it moves beyond descriptive warnings to map specific drug classes, vulnerable populations, and mechanistic pathways that clinicians can address in current practice.

Comparison with recent literature reveals both convergence and remaining gaps. Wee et al. [8] provided a comprehensive pharmacological review of medications that impair heat-loss capacity; the present synthesis extends that work by linking those physiological effects to documented changes in serum drug levels (e.g., antiepileptics) and to real-world storage failures under heat and humidity [15, 18]. Likewise, the dermatological perspective of Williams [14] and the heart-failure observations of Aimo et al. [10] are placed here within a broader absorption, distribution, metabolism, and excretion (ADME) framework, showing that cutaneous vasodilation, reduced renal perfusion, and accelerated transdermal absorption are not isolated phenomena but concurrent threats to therapeutic windows. The 2024 RAND analysis of shifting pharmaceutical demand [21] further supports the prediction that climate-driven changes in disease epidemiology will necessitate proactive formulary

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and supply-chain adjustments—an implication only sparsely addressed in earlier clinical reviews.

Critical interpretation of the available data, however, must acknowledge important limitations. Most pharmacokinetic observations under heat stress remain observational or derived from small cohorts (e.g., the 10-patient phenytoin series). Controlled clinical trials that quantify temperature-dependent changes in area under the concentration–time curve (AUC), maximum plasma concentration (Cmax), or clearance for commonly used drugs are still scarce. Consequently, the magnitude of required dose adjustments is largely extrapolated rather than empirically established. In addition, the interaction between heat, pollution, and polypharmacy in older adults—precisely the population most vulnerable to both climate extremes and medication-related adverse events—has received insufficient systematic study.

Practical implications for healthcare systems and individual practitioners are nevertheless clear. First, drug-storage protocols may need to be revised for heatwave conditions; temperature-sensitive agents (insulin, levothyroxine, certain antiepileptics, transdermal opioids) require continuous monitoring and, where feasible, refrigerated alternatives. Second, high-risk drug classes—diuretics, anticholinergics, antipsychotics, beta-blockers, and ACE inhibitors/ARBs—could be flagged in electronic prescribing systems during extreme-heat alerts so that temporary dose adjustment, increased laboratory surveillance, or substitution may be considered. Third, patient counseling must expand to include heat-related risks: patients on SSRIs or anticholinergics need explicit advice on hydration and activity restriction; those using transdermal fentanyl must be warned against external heat sources that accelerate drug release. Fourth, national essential-medicine lists and hospital formularies in endemic regions should anticipate climate-driven shifts in vector-borne disease burden and the consequent pressure on agents such as liposomal amphotericin B.

From a research perspective, the findings underscore the need for temperature-controlled pharmacokinetic studies, development of heat-stable formulations, and prospective registries that capture medication-related heat illness. Regulatory agencies may eventually need to incorporate climate-resilience criteria into drug approval and labeling requirements. Until such data mature, the precautionary principle warrants proactive clinical adaptation rather than reactive management of treatment failures.

In summary, the novelty of this work lies in its clinical synthesis of disparate observations into actionable pathways of interference, while its practical value resides in the concrete recommendations it offers for storage, prescribing, counseling, and health-system preparedness. As global temperatures continue to rise, these adaptations will become integral to the safe and effective use of medicines.

Conclusion

The intersection between global warming and drug therapy presents complex challenges that healthcare professionals must navigate. Awareness of how climate influences medication efficacy, storage requirements, and the emergence of new health issues is essential for optimizing patient care. As climate-related health risks continue to evolve, so too will the landscape of pharmaceutical needs and therapeutic approaches. Strengthened surveillance, revised storage and dosing guidance, and proactive system-level planning may help maintain treatment safety and effectiveness in a warming world.

Ethical Considerations

Not applicable.

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