Ozone Alerts and Respiratory Emergencies: The Environmental Protection Agency's Potential Biological Pathways for Respiratory Effects

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The purpose of this editorial is to review the broad relevance of environmental health in contemporary emergency nursing, introduce the Environmental Protection Agency's (EPA) 2020 Integrated Science Assessment (ISA) potential biological pathways for respiratory effects following ozone exposure,[1] and provide an introduction to select manuscripts that appear in this issue of the *Journal of Emergency Nursing* (*JEN*). To function as an expert in the emergency nursing specialty, we need to acquire a substantial breadth and depth of knowledge in environmental health. Our specialty knowledge includes the emergency management of exposure to thermal extremes, environmental and occupational poisoning, venomous bites and stings, vector-borne disease, animal bites, diving decompression, drowning, altitude sickness, wilderness emergencies, and all-hazard disaster preparedness and response.[2,3] Emergency nursing interventions include therapeutic environmental controls from maintaining body temperature through warmed intravenous fluids to reducing edema and pain in musculoskeletal injury through cryotherapy.[4] Emergency nurse leaders also influence the broader environment by making decisions on hospital architecture, sustainable health care purchasing, water and air quality policies, medical waste disposal, and global climate change mitigation efforts.[5,6]

The coronavirus disease pandemic has opened and accelerated new frontiers for environmental health and environmentally sustainable practices in emergency nursing. Pandemic telehealth opportunities have been exponentially fueled by public health officials discouraging patients from seeking emergency care for nonurgent reasons, while innovative telecommuting environmental controls to reduce infectious hazards are implemented. Teletriage and poison control consultation are well established telenursing interventions, but there is a substantial gap in the literature on the concept, intervention development, and efficiency or effectiveness testing of disaster or general emergency telenursing.[7] Telenursing aligns with United States national goals to improve outdoor air quality; one of the federal government's Healthy People 2020 objectives is to "increase the proportion of persons who telecommute."[8] Unexpectedly, emergency nurses are in a key position to redefine and expand their roles in remote patient monitoring through telehealth in urgent and emergent conditions, patient self-management education, and ensuring the interdisciplinary quality and safety of emergency telemedicine care delivery. We, at *JEN,* welcome manuscripts to accelerate the dissemination and reach of novel emergency telenursing ideas, interventions, and service lines in the US and globally.

"Why Should We Adrenaline Junkie Emergency Clinicians Care About This?"

Environmental health was a crucial component of each stage of my own nursing career. For me, environmental influences of individual emergency cases and clusters became my burning questions to motivate quality improvement and research projects. As a nursing assistant in Milwaukee, Wisconsin, I cared for patients who suffered from cryptosporidium contamination of the public water supply. This was also when I first learned about air quality measures. At that

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time, an estimated 43% of the US population was exposed to harmful amounts of ground-level ozone, with a higher proportion in children under 9 years and those who self-identified their race as black, African American, or Latinx.[9] As a home health nurse, I witnessed substantial racial disparities in both housing quality and outdoor environmental exposure sources next to residential housing. Heat stroke and heat illnesses became routine diagnoses in the summer months in my emergency nursing practice in Las Vegas, Nevada. Extra fluoride in the water supply in rural New Mexico resulted in brown and brittle teeth and bones in a condition called fluorosis, where I cared for larger numbers of younger people presenting with fractures than I had seen in my practice in other geographic locations. In a small-town hospital downwind of a large industrial sector in the Midwest, we had seemingly unrelated and unexplained clusters of patients with cardiac arrhythmias in 1 night, and then we did not see the same diagnosis again for months. On the basis of my experiences when I practiced in emergency departments in several industrial urban environments, I would drive into the start of my shift on hot, humid, air quality alert days anticipating crowded ED hallways packed with patients struggling to breath as their chronic obstructive pulmonary disease or asthma exacerbated beyond their control. In all emergency care settings, we prepared for environmental disasters and routinely responded to a wide variety of occupational exposure and inhalation toxicology emergencies.

By the time I was actively engaged in research projects on the emergency health effects of outdoor air quality levels, the proportion of the US population exposed to harmful amounts of ground-level ozone had fallen to 36%.[9] Although this was an overall improvement from previous years, it was still a harmful exposure that affected more than 1 in 3 people living in the US. One of my well-respected, senior emergency nurse clinical colleagues would bluntly question me, "Look, we have 6 patients hanging in on the verge of death right here, right now in this department. How are you not bored with your air quality work? Why should we adrenaline junkie emergency clinicians care about this?" Undoubtedly, there is a tremendous thrill in solving clinical problems to rescue the massively bleeding trauma patient or bring the cardiac arrest patient back to life. However, my scientific curiosity and passion was drawn to tackling the emergency care sector problems of patient volume spikes and crowding with environmentally-associated, and potentially preventable, dyspnea. I was also moved by the profound suffering I witnessed in my patients with severe dyspnea, especially when the pathology was linked to occupational and environmental causes outside of their control. In addition to the profound individual suffering, the national scope and scale of harmful air pollutant exposures compelled me to action. This journey to integrate an environmental health research focus with emergency nursing has led to tremendous interdisciplinary collaboration and leadership opportunities to inform national and international policy.[1,10–13]

Ozone

Health care providers and patients tend to hear more about ozone during periods of hot, sunny weather in the spring and summer, with some exceptions at high altitude in the winter months. We experience this seasonal timing because ground-level ozone is formed by a chemical reaction of nitrogen oxides, volatile organic compounds, methane and/or carbon monoxide precursors in the presence of solar radiation, with temperature- and sunlight-dependent conditions.[1] Whereas ozone and these precursors can be naturally occurring, the most common human-activity–related sources include petroleum and related industry, fuel combustion, and highway vehicle traffic. In the US, the most susceptible regions to high levels of health-harming ozone include the Southwest US, Texas, the Midwestern Lake Michigan region, and in the densely populated area of Washington DC to Boston, Massachusetts.[1] Over time, the regulatory standard has been strengthened from 80 parts per billion (ppb) to 75 ppb in 2008, and again to 70 ppb in 2015. In Canada, this standard is currently set at 62 ppb and scheduled to decrease to 60 ppb in 2025.[14] The concentration of ground-level ozone has improved over the last few decades.[1] However, there can still be detrimental health effects at exposure levels below the regulatory standard, especially for vulnerable populations. In the long term, climate change threatens to introduce new dynamics to elevate future ozone levels and harmful health effects.

Ozone demonstrates inconsistent germicidal properties, with a mechanism of action similar to chlorine and peroxide disinfectants.[15-17] The same reactions that harm germs and microbes also harm the human cell, and there is no established level at which ozone exposure is considered harmless to human health.

At the cellular level, harmful oxidants are created when ozone interacts with the fluid-bathed epithelial cells that line mucus membranes, including those of the respiratory tract.[1,18] Patients may experience symptoms related to the direct irritant action of ozone, including cough, pain on deep inspiration, and acute tissue soreness.[1] Subsequently, tissues and organs may be affected by ozone- and oxidant-induced inflammatory, immune, autonomic, and endocrine signaling. Research evidence on the health effects of ozone is periodically and comprehensively reviewed by the US EPA. The most recent review, published in April 2020 includes human, animal, and molecular mechanistic research studies across the bench-to-bedside-to-population continuum. Whereas there are varying levels of evidence that ozone exerts health-harming cardiovascular, metabolic, central nervous system, reproductive, and oncologic effects, and that ozone exposure is linked to increased total mortality, the strongest evidence supports that short-term exposure to ozone results in detrimental respiratory effects.

Potential Biologic Pathways for Respiratory Effects After Ozone Exposure

The Figure and Supplementary Figure 1 present the original and corrected EPA potential biological pathway for respiratory effects after short-term ozone exposure from the 2020 ISA for ozone and related photochemical oxidants (Barbara Buckley, PhD and Tom Luben, PhD, Center for Public Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, personal communication, June 1, 2020).[1] This depicts the pathways supported by well-designed research evidence that link ozone exposure to health-harming respiratory effects. Note that the outcomes in the figures include airway obstruction, increased respiratory symptoms, decreased lung function, and ED visits and hospital admissions for asthma exacerbation. Emergency nurses have in-depth understanding of how these relationships manifest in human health and translate to clinical practice.

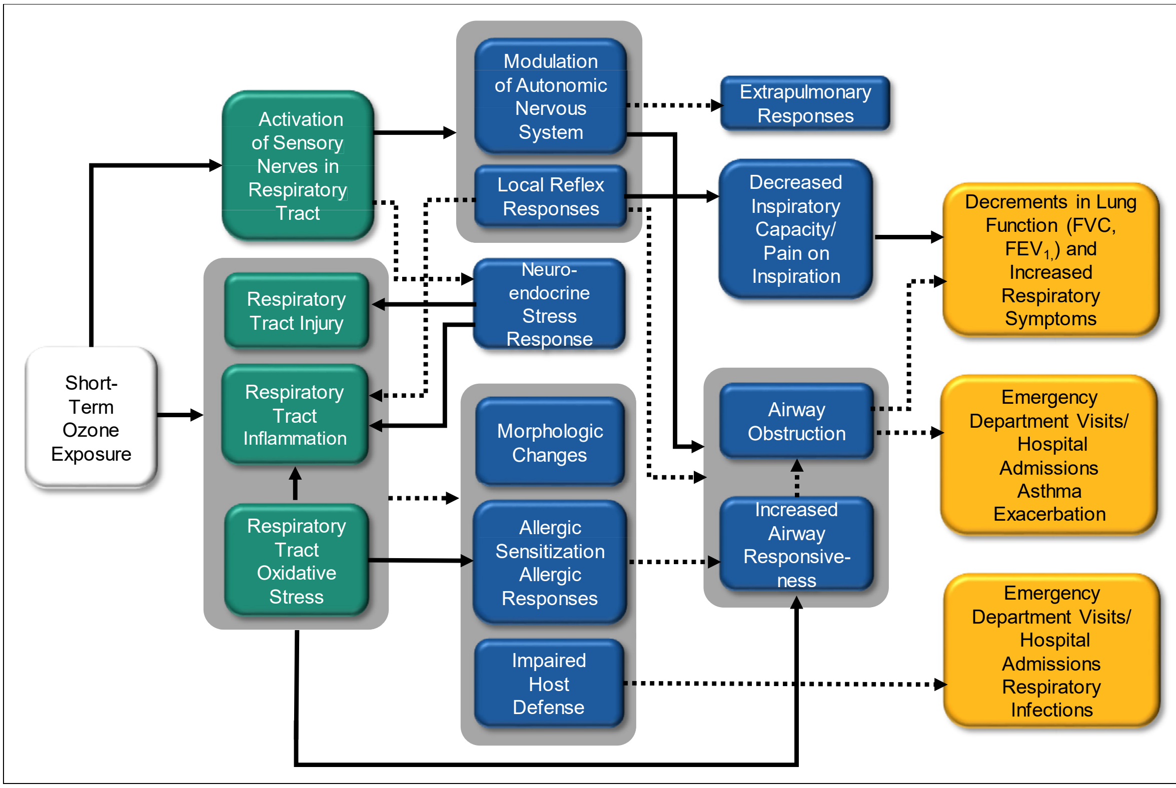
Briefly, the figures synthesize the evidence in the EPA ISA.[1] The airway obstruction in asthma pathophysiology is caused by increased mucus production, increased bronchoconstriction, and/or airway inflammation. Short-term increases in ozone exposure trigger this pathophysiology through autonomic nervous system activation, direct respiratory tract injury, inflammation, and oxidant formation. This triad of respiratory tract injury, inflammation, and oxidative stress is also associated with increased allergic response, impaired immune system defenses, and observable pathological changes in lung tissue histology (microscopic anatomy). Research demonstrates that oxidative stress enhances allergic responses, which is also a potential pathway to increased airway mucus production, inflammation, and bronchoconstriction. At the population level, there are associations between short-term increases in ozone and ED visits and hospitalizations for respiratory infections. Because ozone alters the host defense through immune system effects, this is a plausible relationship.

More research is needed at low levels of ozone exposure (≤40 ppb) in which there is little evidence on the health effects and there is more uncertainty inherent in the current research evidence. At low levels, the shape of ozone's dose-response curve with population health effects such as hospitalizations can appear more like a skewed arc or tipped "J" shape where health-harming risks associated with increasing ozone might actually decrease at very low levels of exposure (0-20 ppb). Owing to the uncertainty about health effects at these low levels, there is little direct application yet to clinical practice until more high-quality research evidence is available. Hypothetically, a decreasing dose-response shape at very low levels of exposure may be due to ozone's germicidal properties.[17,19] Of course, any of ozone's germicidal potential to decrease the transmission of infection must be carefully balanced with any direct impairment in human host defenses and direct human tissue damage when planning or interpreting ozone exposure research.

The EPA ISA determined that there were more uncertainties in the strength and consistency of the evidence linking long-term ozone exposure to respiratory health effects, compared with short-term ozone exposure.[1] Even with the greater uncertainty, the potential biological pathway (Supplementary Figure 2) can serve as an important critical thinking tool to inform emergency nursing practice. In addition to many of the same underlying mechanisms by which short-term ozone exposure exerts harmful respiratory health effects, there is evidence that long-term exposure may increase the severity of influenza, interfere with optimal lung development in children, and increase the risk of permanent alveolar damage, airway remodeling, and fibrosis that manifests in chronic lung disease development and exacerbation. It is still largely unknown if short- or long-term ozone exposure increases the severity of severe acute respiratory syndrome coronavirus 2 infection, which appears to be a biologically plausible hypothesis, given the current evidence on influenza infections.

What Do These Ozone Exposure Biologically Plausible Pathways Mean for Emergency Nursing Care?

Knowledge about the potential biological pathways for respiratory effects after ozone exposure can inform emergency nursing practice in patient education, referral, policy, and advocacy.[6,20,21] The nurse can assess if the patient with asthma uses public air quality alerts or ozone action day warnings to modify behavior and reduce potential triggers. Integrating critical thinking and pathophysiology of hazardous pollution exposure enrich patient education on lung disease development and education. In addition to providing behavior modification resources, such as those for smoking cessation, practical individualized patient counseling can include avoiding outdoor activities on air quality alert days or late afternoon high-risk times when conditions favor



FIGURE

Potential biological pathways for respiratory effects following short-term ozone exposure, corrected. Note: The boxes above represent the effects for which there is experimental or epidemiologic evidence related to ozone exposure, and the arrows indicate a proposed relationship between those effects. Solid arrows denote evidence of essentiality as provided, for example, by an inhibitor of the pathway or a genetic knockout model used in an experimental study involving ozone exposure. Shading around multiple boxes is used to denote a grouping of these effects. Arrows may connect individual boxes, groupings of boxes, and individual boxes within groupings of boxes. Progressing of effects is generally depicted from left to right and color-coded (gray, exposure; green, initial effect [2nd column of boxes from the left]; blue, intermediate effect [3rd and 4th column of boxes from the left]; orange, effect at the population level or a key clinical effect [right-most column of boxes]). Here, population level effects generally reflect results of epidemiologic studies. When there are gaps in the evidence, there are complementary gaps in the figure and the accompanying text. The structure of the biological plausibility sections and the role of biological plausibility in contributing to the weight-of-evidence analysis used in the 2020 Ozone ISA are discussed in Section IS.4.2. 1 Corrected figure provided by, and reprinted with permission from the EPA ISA and personal communications (Barbara Buckley, PhD, Tom Luben, PhD, Center for Public Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, June 1, 2020).

outdoor ozone formation. The Table (following the Figure) provides links to patient education material and handouts that can be used in individual patient education or as part of facility libraries or education kiosks. Interdisciplinary team leadership to integrate social and public health services promises to improve patient outcomes as well. For example, the emergency nurse practicing in a high-poverty area with poor outdoor air quality can facilitate connections to social or public health programs that support patient access to cooling centers or financial vouchers or provision of air filters or home air conditioners.

On the departmental level, emergency leaders can measure and anticipate patient volume changes and seasonal clusters of patient presentations linked to environmental conditions to plan accordingly. Unit level planning would include sensitivity to adequate staffing and ensuring adequate supplies of chronic respiratory disease treatments, rescue medications, and equipment. Quality improvement or continuing education for staff can address opportunities to integrate environmental health and asthma education into the unit culture. For example, interdisciplinary professional development courses and certification as an asthma educator, which include content on reducing environmental triggers, is open to emergency nurses by the National Asthma Educator Certification Board. If available, emergency leaders can establish referrals and collaborations with local respiratory disease–focused coalitions or support groups to connect patients with community resources and ongoing self-management education. Last, emergency care expertise is needed to inform policymakers or advocate for

TABLE
Clinical links for patient education on ozone

Patient education on ozone	Links
EPA Patient Education Tools	https://www.epa.gov/ozone-pollution-and-your-patients-health/patient-education-tools-ozone-pollution-and-your-patients
American Lung Association Clean Air	https://www.lung.org/clean-air

environmental or climate change policies that affect emergency health outcomes from the local to international level.

Manuscripts in the *Journal of Emergency Nursing*

The remaining issues in 2020 will include collections of manuscripts addressing disaster, environmental health, and infectious disease topics in emergency nursing. We have several high-quality manuscripts in this current issue that address a wide breadth of emergency care topics. Here, I'd like to take the opportunity to highlight a selection of our current issue manuscripts addressing fluid and electrolyte management, respiratory assessment, and 2 environment topics.

FLUID AND ELECTROLYTE MANAGEMENT

Dr Metheny is the nursing discipline's expert on fluid and electrolyte balance.[22] In this issue of *JEN*, Metheny and Krieger[23] provide a systematic review of salt toxicity from case reports of ingestion through accidental overdose poisoning, suicide, prank, religious ritual, and child maltreatment. A rarely seen emergency, it is important for emergency nurses to recognize hypernatremia from salt toxicity because it can be fatal. Fluid and electrolyte imbalance may be one of the causes for migraine, weakness, and dizziness presentations to the emergency department. Two of our sections provide evidence-based updates to enhance clinical reasoning and critical thinking about these presentations. Oliver's Advanced Practice Clinician's Corner manuscript[24] provides an update on migraine management whereas Somes' Geriatric Update section[25] provides an overview of dehydration and poor nutrition in the older adult who presents with weakness or dizziness. Further, end stage renal disease is a comorbidity with fluid and electrolyte derangement aftermath that is frequently treated in the emergency setting, particularly when the required dialysis treatments are missed or delayed. The case review by Adams and Osman[26] presents the signs and symptoms of a rare complication of dialysis access, dialysis access steel syndrome. Contextualized with environmental health, hypernatremia, headache and migraine, older adult dehydration, and management of patients with end stage renal disease can all be complicated and worsened in conditions with extreme heat or severe weather.

BASIC TO ADVANCED RESPIRATORY ASSESSMENT

Harry et al[27] bring us back to applying clinical excellence in the most basic of nursing skills by testing the accuracy of respiratory rate assessments in 78 emergency nurses. Although the nurses consistently assessed normal respiratory rate using a formal or spot-checking method, the accuracy of correctly identifying bradypnea fell to an unsafe 60% to 75% accuracy. The potential to miss important changes of conditions by short-cutting respiratory rate and vital assessment are concerning, and the article is an excellent reminder of the need to adhere to best practices in our fundamental skills, even as we acquire and apply complex, advanced clinical procedural abilities.

Shortness of breath is one of the most common presenting symptoms that brings patients to the emergency department.[28] Although triage is often pragmatically used as the point of hospital intake where health care leaders are often tempted to require mandatory and population health screening activities, priority must be placed on clinical vigilance and attention to nuanced presentations that might be immediately life threatening. Pulmonary embolism (PE) is one of these potentially rapidly fatal but subtle and easy to miss patient presentations. In this issue of *JEN*, Tomkiewicz and Kline[29] provide clinical decision rules to an evidence-based guide to assessing, diagnosing, and prognosing PE in the emergency setting. Continued updated knowledge in this area is needed to integrate the emergency nursing implications on how severe acute respiratory syndrome coronavirus 2 infection leads to deadly PE complications. Finally, our newest section, Images, debuts with X-ray and computed tomography images accompanied by a brief case description of a patient with coronavirus disease from Gleyzer and Milman.[30]

ENVIRONMENT

Tindle et al[31] provide fascinating insights using a novel application of geospatial analysis methods to study the ED unit architecture's associations with clinician communication. This research points to a tremendous gap in the science about how unit architecture and built environment decisions could be enhanced with a stronger evidence-based and better understanding of built environment impact on clinician and patient outcomes.

Mutlu and Yilmaz[4] studied a classic cold-pack cryotherapy emergency nursing intervention for soft tissue injury. Their randomized clinical trial to test 10-, 20-, or 30-minute cold-pack application duration with 105 participants reinforces the continuation of the common best practice of a 20-minute duration with sound clinical evidence and rationale.

Conclusion and Next Issue

The September 2020 issue of *JEN* will include a collection of papers focused on disaster nursing around the globe. We've foreshadowed this theme with our 50th anniversary celebration reprint in this current issue of the 1990 manuscript, "A disaster that can happen anywhere—The Palm Bay massacre."[32] We look forward to continued dissemination of environmental health and disaster nursing topics relevant to emergency nursing care.

Supplementary Data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jen.2020.05.008.

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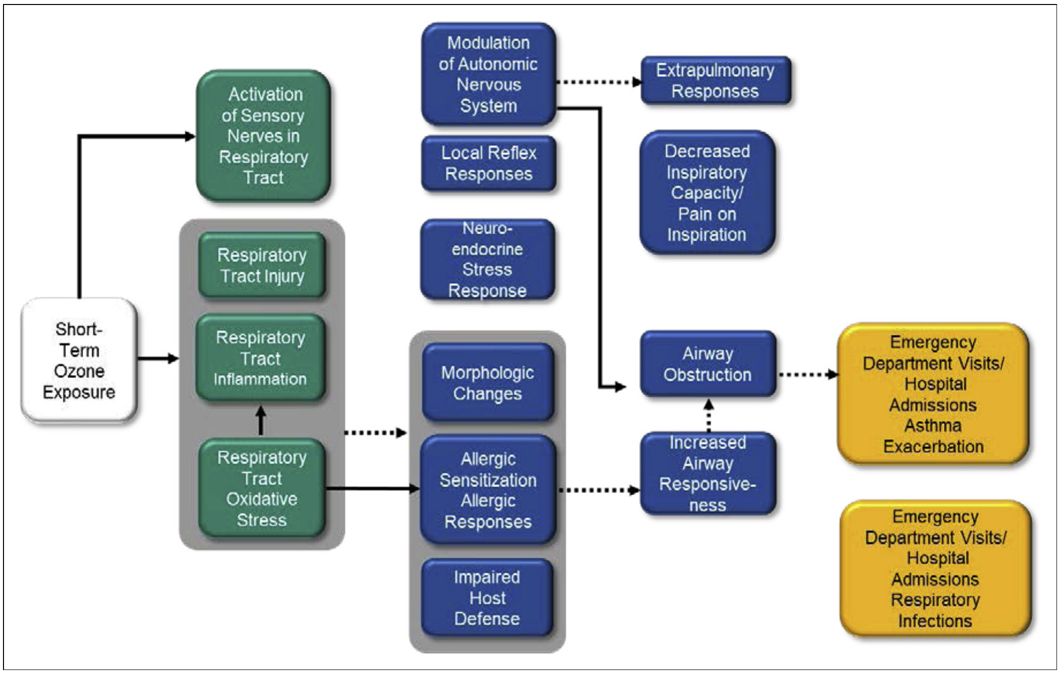
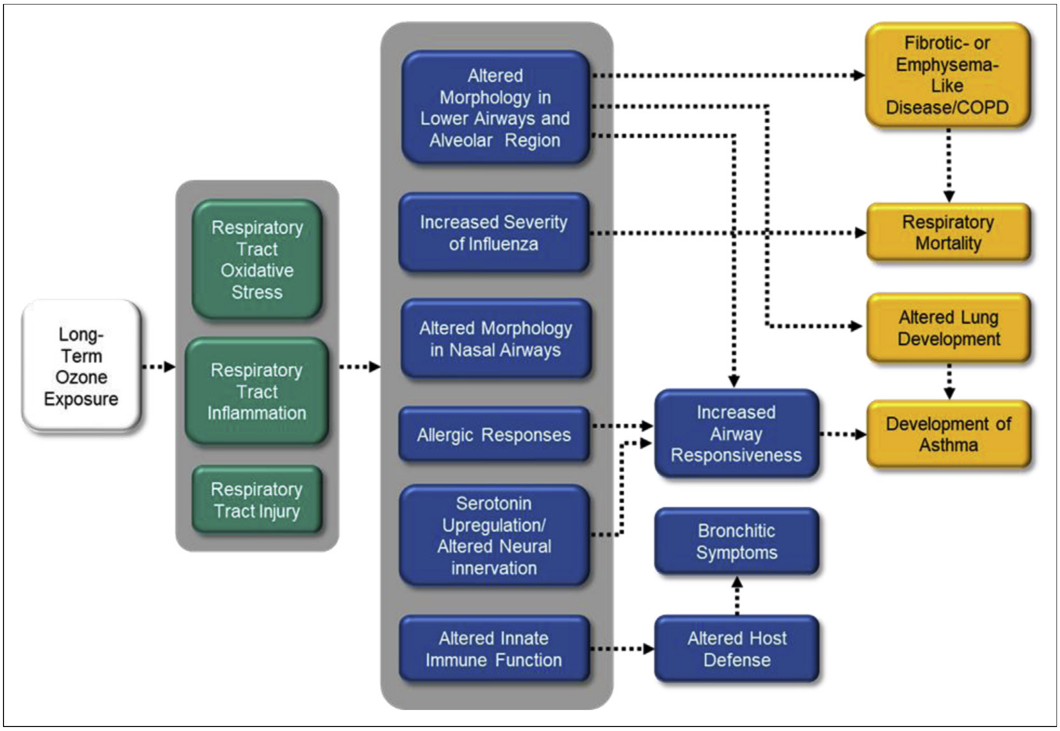
Supplemental Material



SUPPLEMENTARY FIGURE 1

Potential biological pathways for respiratory effects following short-term ozone exposure (original, uncorrected). The boxes above represent the effects for which there is experimental or epidemiologic evidence related to ozone exposure, and the arrows indicate a proposed relationship between those effects. Solid arrows denote evidence of essentiality as provided, for example, by an inhibitor of the pathway or a genetic knockout model used in an experimental study involving ozone exposure. Shading around multiple boxes is used to denote a grouping of these effects. Arrows may connect individual boxes, groupings of boxes, and individual boxes within groupings of boxes. Progression of effects is generally depicted from left to right and color-coded (gray, exposure; green, initial effect; blue, intermediate effect; orange, effect at the population level or a key clinical effect). Here, population level effects generally reflect results of epidemiologic studies. When there are gaps in the evidence, there are complementary gaps in the figure and the accompanying text. The structure of the biological plausibility sections and the role of biological plausibility in contributing to the weight-of-evidence analysis used in the 2020 Ozone ISA are discussed in Section IS.4.2. Figure reprinted with permission from the EPA ISA.



SUPPLEMENTARY FIGURE 2

Potential biological pathways for respiratory effects following long-term ozone exposure. Note: The boxes above represent the effects for which there is experimental or epidemiologic evidence related to ozone exposure, and the arrows indicate a proposed relationship between those effects. Solid arrows denote evidence of essentiality as provided, for example, by an inhibitor of the pathway or a genetic knockout model used in an experimental study involving ozone exposure. Shading around multiple boxes is used to denote a grouping of these effects. Arrows may connect individual boxes, groupings of boxes, and individual boxes within groupings of boxes. Progression of effects is generally depicted from left to right and color-coded (gray, exposure; green, initial effect; blue, intermediated effect; orange, effect at the population level or a key clinical effect). Here, population level effects generally reflect results of epidemiologic studies. When there are gaps in the evidence, there are complementary gaps in the figure and the accompanying text. The structure of the biological plausibility sections and the role of biological plausibility in contributing to the weight-of-evidence analysis used in the 2020 Ozone ISA are discussed in Section IS.4.2. 1 Reprinted with permission from the EPA ISA.