EC PULMONOLOGY AND RESPIRATORY MEDICINE
Review Article

Supply Chain Logistics Innovations for Respiratory Therapeutics: Post-COVID-19 Advances and Future Directions

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Received: October 06, 2025; **Published:** November 11, 2025

Abstract

The COVID-19 pandemic exposed critical vulnerabilities in global supply chains for respiratory therapeutics, creating unprecedented shortages of ventilators, oxygen, and medications. This literature review analyzes the transformation of respiratory therapeutics supply chains from 2020-2025, examining technological innovations, structural reforms, and persistent challenges. Through analysis of 22 peer-reviewed studies, we identify three key developments: rapid technological adoption including blockchain and AI systems, regional manufacturing shifts away from global dependencies, and ongoing equity challenges particularly in oxygen access. While significant progress has been achieved in supply chain resilience, persistent gaps remain in low-resource settings where infrastructure limitations continue to affect over 800,000 preventable deaths annually. Future directions point toward integrated digital ecosystems and patient-centric delivery models that could enhance both efficiency and equity in respiratory care access globally.

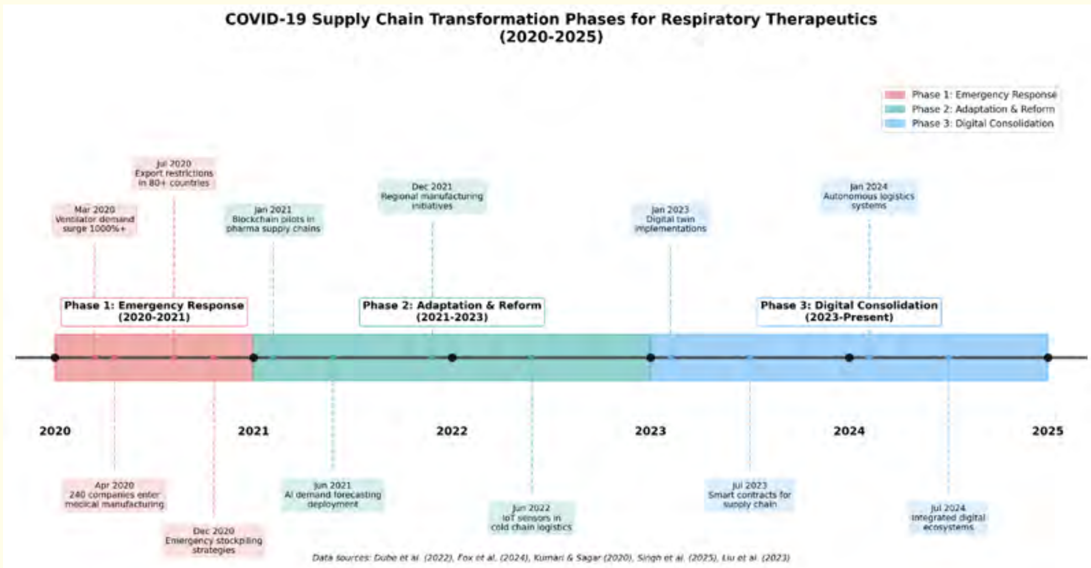
Keywords: *Respiratory Therapeutics; Supply Chain Logistics; COVID-19; Pandemic Preparedness; Blockchain; Artificial Intelligence; Oxygen Supply*

Introduction

The COVID-19 pandemic fundamentally disrupted global supply chains for respiratory therapeutics, creating unprecedented shortages that exposed deep vulnerabilities in healthcare logistics systems. Within months of the pandemic declaration, healthcare systems worldwide faced critical shortages of mechanical ventilation equipment, with demand exceeding supply by factors of 10-15 in many regions [1,2]. Oxygen supply systems collapsed under surge demand, while pharmaceutical distribution networks struggled to maintain cold chain requirements during lockdowns and border closures [3].

This crisis catalyzed rapid innovations in supply chain management, forcing stakeholders to reimagine traditional efficiency-optimized distribution models and adopt more resilient, technology-enabled approaches. The transformation reveals three distinct phases: initial disruption and emergency response (2020-2021), technological adaptation and policy reform (2021-2023), and innovation consolidation with mature digital solutions (2023-present) [4]. Each phase contributed distinct elements to current supply chain architectures, from blockchain-enabled traceability to AI-driven demand forecasting capabilities.

This literature review examines the evolution of respiratory therapeutics supply chains through the COVID-19 pandemic and its aftermath, encompassing mechanical ventilation equipment, oxygen supply systems, inhaled medications, and emerging respiratory biologics. The analysis traces how pandemic experiences transformed distribution networks and identifies key innovations, persistent challenges, and future directions that continue to shape respiratory care logistics globally.



COVID-19 crisis and emergency response

The COVID-19 pandemic created an unprecedented global crisis in respiratory therapeutics supply chains, with ventilator shortages emerging as the most visible symbol of supply chain failure. Fox., *et al*. [2] identified multiple critical factors that impacted medical ventilator supply chains, including manufacturing capacity constraints, component shortages, regulatory bottlenecks, and logistics disruptions that collectively created severe scarcity. Traditional just-in-time manufacturing approaches proved inadequate when faced with demand surges of 1000% or more, forcing healthcare systems to implement emergency protocols including ventilator sharing and alternative respiratory support strategies [3].

Government interventions played crucial roles in coordinating emergency responses, with nations implementing wartime-style procurement strategies. Dube., *et al*. [1] documented how different national approaches yielded dramatically different outcomes, with some countries successfully leveraging domestic manufacturing capacity while others struggled with international supply chain dependencies.

The emergence of rapid product development cycles represented one of the most significant transformations during emergency response. Kumari and Sagar [4] identified 240 companies from non-medical backgrounds that successfully launched respiratory medical products within 2-3 months, compared to typical development cycles of 1-4 years for medical devices. This acceleration was enabled by regulatory agencies implementing emergency use authorizations and unprecedented cross-industry collaboration.

The oxygen crisis particularly affected low- and middle-income countries, revealing fundamental infrastructure vulnerabilities. Stolbrink., *et al*. [10] highlighted how global oxygen demand increased by over 100% during peak COVID-19 waves, overwhelming production and distribution networks designed for routine medical needs rather than pandemic-scale demand. This crisis exposed long-standing inequities in global oxygen access, with many healthcare facilities in resource-limited settings lacking basic oxygen infrastructure even before the pandemic began [11]. Emergency stockpiling strategies emerged as critical adaptations, with healthcare systems rapidly building inventory buffers that contradicted decades of just-in-time optimization, representing a fundamental change in healthcare logistics philosophy that has persisted beyond the acute crisis period.

Post-pandemic technological innovations

The post-pandemic period witnessed remarkable acceleration in technological adoption across respiratory therapeutics supply chains, with innovations achieving rapid implementation in response to crisis-driven demand for more resilient logistics networks. These technological transformations represent fundamental shifts from traditional supply chain management toward digitally-enabled, intelligent systems capable of real-time adaptation and predictive optimization [14].

Blockchain technology emerged as one of the most transformative innovations in pharmaceutical supply chains, with particular relevance for respiratory therapeutics where product authenticity and supply chain integrity are critical for patient safety. Ghadge., *et al*. [5] conducted comprehensive analysis of blockchain implementation, identifying immutability, transparency, and decentralization as key attributes that address longstanding challenges in drug traceability and counterfeit prevention. The technology enables creation of tamper-proof records throughout the supply chain, from active pharmaceutical ingredient sourcing through final product delivery, providing unprecedented visibility into complex global networks.

Practical blockchain implementation has demonstrated significant potential for addressing regulatory compliance challenges and enhancing supply chain security. Yaqoob., *et al*. [6] documented how blockchain-based healthcare data management systems improve patient privacy protection while enabling secure data sharing between supply chain participants. These systems have proven particularly valuable for managing cold chain requirements in respiratory biologics, where temperature monitoring and compliance documentation are critical for maintaining product efficacy. Smart contracts embedded in blockchain platforms automatically trigger alerts when environmental conditions deviate from specified parameters, enabling rapid corrective actions that prevent product loss.

Artificial intelligence and machine learning applications have revolutionized demand forecasting and inventory optimization in respiratory therapeutics supply chains. Liu., *et al*. [15] identified multiple AI applications achieving operational deployment, including predictive analytics for ventilator demand during respiratory disease outbreaks, optimization algorithms for oxygen distribution networks, and machine learning models that anticipate pharmaceutical shortages before they occur. These systems analyze vast quantities of data from epidemiological trends, hospital utilization patterns, and global supply chain conditions to generate predictions enabling proactive rather than reactive supply chain management.

Internet of Things technologies have enabled real-time monitoring and control capabilities that transform supply chain visibility and responsiveness. Mai Dieu., *et al*. [7] documented how IoT sensors embedded in respiratory equipment, pharmaceutical packaging, and logistics infrastructure provide continuous data streams enabling unprecedented operational awareness. Temperature sensors in cold chain logistics automatically adjust cooling systems to maintain product integrity, RFID tags enable real-time inventory tracking throughout distribution networks, and connected devices automatically reorder supplies when inventory reaches predetermined thresholds. These capabilities prove particularly valuable for managing oxygen concentrators and respiratory equipment in remote or resource-limited settings.

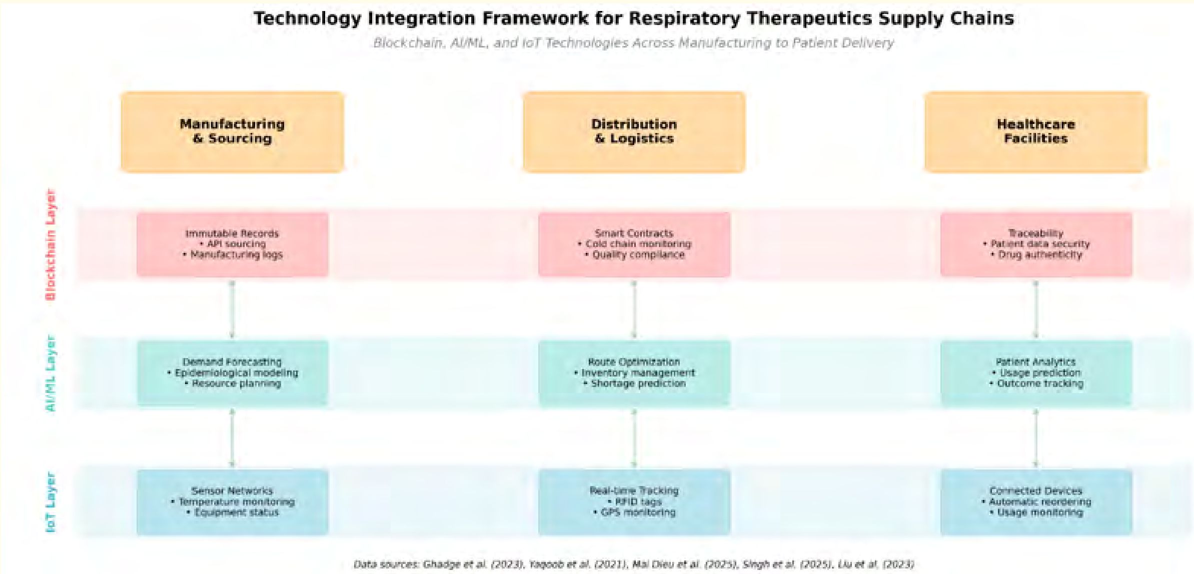


Figure 1

Regional manufacturing and supply chain restructuring

The COVID-19 pandemic catalyzed a fundamental shift away from globalized manufacturing toward regional and localized production strategies for respiratory therapeutics, driven by recognition that geographic concentration creates unacceptable vulnerabilities during health crises. This transformation represents one of the most significant structural changes in healthcare supply chains, with implications extending beyond pandemic preparedness to encompass national security considerations, economic development objectives, and health equity goals [8].

Mitchell [8] provided comprehensive analysis of pharmaceutical onshoring trends, documenting how countries including the United States, European Union members, and Australia have implemented policies specifically designed to encourage domestic manufacturing of critical medical products. These initiatives typically combine financial incentives such as tax credits and direct subsidies with regulatory advantages including expedited approval processes for domestically manufactured products. The scale of these programs represents unprecedented government intervention in pharmaceutical supply chains, with some nations allocating billions of dollars to support domestic manufacturing capacity development.

The economic rationale for regionalization extends beyond crisis preparedness to encompass broader industrial policy objectives related to high-value manufacturing and technological leadership. Regional manufacturing hubs create opportunities for developing specialized expertise and building innovation ecosystems that generate sustained competitive advantages.

Geographic risk diversification has emerged as a critical strategic consideration in post-pandemic supply chain design, with many organizations implementing multi-regional sourcing strategies that reduce dependence on any single production region. Ross and Wendel [9] examined how oxygen supply inequities during COVID-19 highlighted the vulnerability of countries dependent on imported oxygen equipment and production capacity. The analysis revealed how regional oxygen production capabilities could significantly improve access and reduce supply chain risks, particularly for resource-limited countries lacking foreign exchange reserves necessary to compete for oxygen imports during global shortage periods.

Implementation of regional manufacturing strategies faces significant challenges related to cost competitiveness, technical expertise, and regulatory compliance. Traditional offshore manufacturing locations offer substantial cost advantages due to lower labor costs, established supply networks, and economies of scale difficult to replicate in higher-cost regions. Regulatory frameworks have been adapted to support regionalization objectives while maintaining safety standards, with emergency use authorization pathways developed during COVID-19 being institutionalized in many jurisdictions, providing mechanisms for rapid approval of domestically manufactured products during crisis periods.

Persistent challenges and equity issues

Despite significant innovations in respiratory therapeutics supply chains, fundamental challenges persist that continue to limit access to life-saving treatments, particularly in low- and middle-income countries where infrastructure limitations, economic constraints, and political factors create ongoing barriers to effective distribution [11]. These persistent challenges highlight the limitations of technological solutions alone and underscore the importance of addressing systemic inequities that affect healthcare access globally.

Oxygen supply inequities represent one of the most significant persistent challenges in respiratory therapeutics logistics, with implications extending far beyond pandemic response to encompass routine care for pneumonia, asthma, chronic obstructive pulmonary disease, and other respiratory conditions. Humura., *et al*. [11] documented how oxygen supply gaps in resource-limited settings result in over 800,000 preventable deaths annually, despite oxygen being designated as an essential medicine by the World Health Organization. The infrastructure requirements for reliable oxygen supply, including electricity for concentrators, transportation networks for cylinder distribution, and technical expertise for equipment maintenance, remain inadequate in many regions despite years of development efforts.

The availability challenges identified during COVID-19 revealed fundamental weaknesses in oxygen distribution systems that persist beyond the acute crisis period. Stolbrink., *et al*. [10] highlighted how 25% of healthcare facilities in sub-Saharan Africa have no oxygen supply, while an additional 31% experience frequent supply interruptions that compromise patient care. These statistics reflect underlying infrastructure limitations that cannot be addressed through supply chain optimization alone, requiring substantial investments in electricity generation, transportation networks, and technical training that extend far beyond healthcare sector capabilities.

Economic barriers continue to limit access to respiratory therapeutics in resource-constrained settings, where costs of oxygen equipment, maintenance, and ongoing supplies often exceed healthcare budgets already strained by competing priorities. The economics of oxygen supply present particular challenges in low-volume markets where fixed costs of infrastructure development cannot be amortized across large patient populations. Traditional commercial distribution models may be economically unsustainable in these contexts, requiring alternative financing mechanisms, subsidies, or public sector provision that many governments cannot afford.

Cold chain management for respiratory biologics presents ongoing technical and economic challenges that affect access to advanced respiratory therapeutics globally. Babar., *et al*. [13] identified multiple barriers to effective cold chain management, including unreliable electricity supply, limited refrigeration infrastructure, inadequate transportation networks, and insufficient technical expertise for maintaining temperature-controlled logistics systems. These challenges are particularly acute for newer respiratory biologics requiring precise temperature control throughout distribution, limiting their availability to regions with sophisticated logistics infrastructure.

Environmental sustainability concerns present emerging challenges for respiratory therapeutics supply chains, particularly as pressure increases to reduce carbon emissions and minimize environmental impacts across healthcare logistics networks. Kumar., *et al*. [12] examined green supply chain management practices in pharmaceuticals, identifying tensions between sustainability objectives and access goals that are particularly acute for respiratory therapeutics. The persistence of counterfeit and substandard respiratory medications represents an ongoing challenge affecting both safety and access, particularly in regions with limited regulatory oversight and enforcement capabilities.

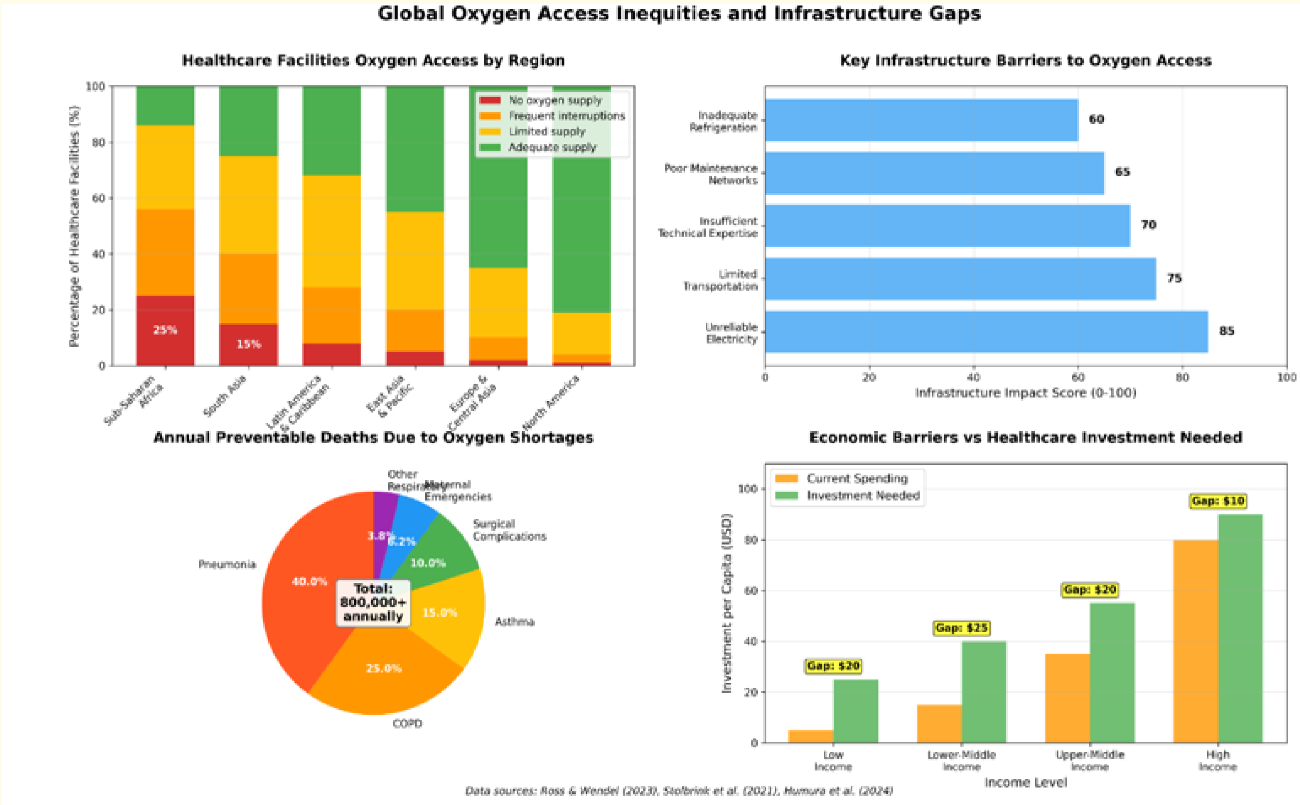


Figure 2

Future directions and implications

The trajectory of respiratory therapeutics supply chain evolution points toward increasingly sophisticated digital ecosystems that integrate predictive analytics, automated decision-making, and patient-centric delivery models to create more responsive and equitable healthcare logistics networks. These emerging technologies build upon the digital foundation established during the post-pandemic period, incorporating artificial intelligence, advanced sensors, and autonomous systems to create supply chains capable of anticipating needs, optimizing resource allocation, and adapting to changing conditions in real-time [14,15].

Artificial intelligence applications are evolving toward more sophisticated predictive models that can anticipate respiratory disease outbreaks, optimize inventory positioning, and coordinate multi-modal logistics networks with minimal human intervention. Liu., *et al.* [15] identified emerging AI capabilities including epidemiological modeling for ventilator demand forecasting, machine learning algorithms optimizing oxygen distribution routes, and natural language processing systems monitoring global supply chain conditions through real-time data analysis. These advanced AI systems represent a shift from reactive supply chain management toward proactive optimization that can prevent shortages and minimize response times during crisis periods.

Digital twin technologies are advancing toward comprehensive modeling capabilities that can simulate entire respiratory therapeutics supply networks, enabling sophisticated scenario planning and optimization strategies previously impossible. Singh., *et al.* [14] explored how these digital replicas can model complex interactions between manufacturing capacity, transportation networks, regulatory requirements, and patient demand patterns to identify optimal supply chain configurations. Future digital twin implementations may incorporate real-time data feeds from IoT sensors, blockchain transaction records, and healthcare utilization systems.

Autonomous logistics systems represent an emerging frontier that could transform last-mile delivery for respiratory therapeutics, particularly in resource-limited settings where transportation infrastructure constrains access. Drone delivery systems for oxygen concentrators, automated pharmaceutical dispensing for respiratory medications, and robotic warehouse systems for ventilator distribution could address many logistical challenges currently limiting access in remote or underserved areas.

Policy implications of these technological advances require careful consideration to ensure innovations contribute to improved access rather than exacerbating existing disparities. Regulatory frameworks must evolve to accommodate new technologies while maintaining safety standards, international cooperation mechanisms must address cross-border data sharing and technology transfer, and financing models must ensure that advanced logistics capabilities benefit all populations regardless of economic circumstances.

Conclusion

The transformation of respiratory therapeutics supply chains during and after the COVID-19 pandemic represents a fundamental shift from vulnerable, efficiency-optimized systems toward resilient, technology-enabled networks that incorporate lessons from crisis response and humanitarian logistics. This analysis reveals that while substantial progress has been achieved in addressing acute supply chain vulnerabilities through technological innovation and regional manufacturing strategies, persistent challenges related to equity, sustainability, and access continue to require innovative solutions and sustained policy attention.

The convergence of blockchain, artificial intelligence, and IoT technologies has created unprecedented opportunities for supply chain transparency, optimization, and real-time adaptation. However, implementation of these technologies requires substantial investments in infrastructure and expertise that may not be available in all settings, potentially exacerbating existing disparities in access to advanced healthcare logistics capabilities. Regional manufacturing trends reflect fundamental changes in how stakeholders balance efficiency and security considerations, but present ongoing challenges related to cost competitiveness and technical expertise.

Future directions point toward increasingly sophisticated digital ecosystems combining predictive analytics with patient-centric delivery models. Realizing this potential will require sustained investments, international cooperation, and policy frameworks ensuring technological advances contribute to improved access rather than widening existing health equity gaps. The foundation established during the post-pandemic period provides infrastructure necessary for achieving these goals, but continued commitment to innovation, equity, and international cooperation will be essential for ensuring respiratory therapeutics supply chain advances translate into improved health outcomes for all populations globally.

Bibliography

1. Dube N., *et al*. “One crisis, different paths to supply resilience: The case of ventilator procurement for the COVID-19 pandemic”. *Journal of Purchasing and Supply Management* 28.5 (2022): 100773.

2. Fox F., *et al*. “Key factors impacting a medical ventilator supply chain during the COVID-19 pandemic: Lessons for pandemic preparedness”. *Disaster Medicine and Public Health Preparedness* 18 (2024): e65.

3. Dar M., *et al*. “Mechanical ventilation supply and options for the COVID-19 pandemic: Leveraging all available resources”. *American Journal of Respiratory and Critical Care Medicine* 203.6 (2021): 718-732.

4. Kumari MC and Sagar B. "Global pandemic and rapid new product development of medical products". *Digital Government: Research and Practice* 2.2 (2020): 1-38.

5. Ghadge A., *et al*. "Blockchain implementation in pharmaceutical supply chains: A review and conceptual framework". *International Journal of Production Research* 61.5 (2023): 6633-6651.

6. Yaqoob I., *et al*. "Blockchain for healthcare data management: Opportunities, challenges, and future recommendations". *Neural Computing and Applications* 34.2 (2021): 11475-11490.

7. Mai Dieu NT., *et al*. "Pharmaceutical logistics system development through the stages of industrial revolutions: A bibliometric review". *DTU Journal of Science and Technology* 2.69 (2025): 132-144.

8. Mitchell AD. "The geography of health: Onshoring pharmaceutical manufacturing to address supply chain challenges". *World Trade Review* 23.4 (2024): 519-531.

9. Ross K and Wendel K. "Oxygen inequity: The critical need for global oxygen access in low-resource settings". *The Lancet Global Health* 11.4 (2023): e456-e457.

10. Stolbrink M., *et al*. "The global oxygen crisis: A call for international action to address the oxygen gap in low- and middle-income countries". *The Lancet* 398.10300 (2021): 596-598.

11. Humura F., *et al*. "Closing gaps in the oxygen supply chain in nations with limited resources". *Pan African Medical Journal* 48 (2024): 55.

12. Kumar S., *et al*. "Green supply chain management in pharmaceuticals: A systematic literature review and research agenda". *Journal of Cleaner Production* 394 (2023): 136846.

13. Babar A., *et al*. "Cold chain management in pharmaceutical supply chains: A comprehensive review of challenges and technological solutions". *Computers and Industrial Engineering* 158 (2021): 107393.

14. Singh A., *et al*. "Digital transformation in respiratory healthcare supply chains: Emerging technologies and implementation strategies". *npj Digital Medicine* 8.1 (2025): 413.

15. Liu H., *et al*. "Artificial intelligence applications in pharmaceutical supply chain optimization: A systematic review and future research directions". *Computers and Operations Research* 153 (2023): 106176.

Volume 14 Issue 12 December 2025
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