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Crisis-Ready Nursing: Building Resilient Systems To Counteract Personal Protective Equipment Shortages

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Abstract:
The COVID-19 pandemic exposed critical vulnerabilities in healthcare systems, particularly concerning personal protective equipment (PPE) shortages. This crisis highlighted the need for resilient systems to ensure adequate PPE supply and effective resource allocation. Nurses, as frontline healthcare workers, play a vital role in mitigating these challenges through advocacy, resource management, and adaptation to limited supplies. This review explores the impact of PPE shortages on nursing and healthcare systems, identifies economic and logistical barriers, and emphasizes the importance of building resilient supply chains. Additionally, innovations in sustainable PPE development and advancements in technology for resource allocation are discussed as key strategies to strengthen preparedness for future crises.
Keywords: Personal Protective Equipment (PPE), Nursing Resilience, Supply Chain Management, Healthcare Preparedness, COVID-19, Sustainable PPE, Resource Allocation, Technological Innovations, Healthcare Worker Safety, Crisis Management

Aim of Work:
To analyze the impact of personal protective equipment shortages on nursing and healthcare systems, identify systemic barriers to effective PPE management, and propose innovative solutions to build resilient systems capable of addressing current and future healthcare crises.

Introduction
Personal protective equipment (PPE) is crucial in healthcare settings as it serves as the last line of defense against various hazards, including biological, chemical, and physical threats. During the COVID-19 pandemic, PPE became indispensable for healthcare workers (HCWs) to reduce the risk of infection transmission. However, its use also introduced significant challenges, such as physical discomfort and psychological stress. The importance of PPE in healthcare is multifaceted, encompassing protection, compliance, and the need for tailored preventive measures.

Protection Against Hazards: PPE provides essential protection against infectious diseases, as demonstrated during the COVID-19 pandemic, where it was vital in reducing transmission among HCWs and patients (Pradhan et al., 2024) (Batov et al., 2024). It includes various equipment like masks, gloves, gowns, and face shields, each designed to protect specific body parts from different hazards ("Personal Protective Equipment", 2024).

Psychological and Physical Impact: Prolonged use of PPE can lead to psychological effects such as anxiety and apprehension, with 33% of HCWs reporting anxiety and 68.1% experiencing discomfort during the pandemic (Chavan et al., 2024). Physical issues include adverse skin

reactions like rashes and pressure marks, affecting all categories of HCWs (Pradhan et al., 2024).

Compliance and Usage: Compliance with PPE standards is crucial for effective protection. However, studies show suboptimal compliance rates, particularly in wearing eye protection among surgical personnel (Diress et al., 2024). Proper donning and doffing procedures are essential to prevent contamination and ensure safety (Diress et al., 2024).

Preventive Measures and Challenges: The use of PPE can lead to functional disorders and health impairments due to increased physical stress and heat-related injuries (Batov et al., 2024). Tailored preventive measures, such as well-fitting equipment and regular breaks, are necessary to mitigate adverse reactions and enhance HCW safety (Pradhan et al., 2024) (Batov et al., 2024). While PPE is vital for protecting healthcare workers, it also presents challenges that need addressing through comprehensive support systems and preventive strategies. Balancing protection with comfort and compliance is essential to ensure the well-being of HCWs in high-risk environments. Nursing plays a crucial role in healthcare, significantly impacting patient care quality and outcomes. Nurses are integral to healthcare systems, providing direct patient care, supporting medical procedures, and ensuring patient safety. Their role has evolved with advancements in healthcare, emphasizing the need for continuous professional development and adaptation to changing patient expectations. The following sections outline the multifaceted role of nursing in healthcare.

Direct Patient Care and Support: Nurses administer medications, perform injections, and assist physicians in diagnosis and treatment, ensuring comprehensive patient care (Almutairi et al., 2024) (Wasik, 2020). They develop personalized care plans by understanding patients' unique needs, which enhances patient experience and outcomes (Tamshan et al., 2022).

Patient Advocacy and Safety: Nurses serve as patient advocates, guiding them through the healthcare system and ensuring informed decision-making (Tamshan et al., 2022). They prioritize patient safety by mitigating risks, reducing medical errors, and ensuring safe medication administration (Tamshan et al., 2022).

Leadership and Professional Development: Nursing leaders play a pivotal role in healthcare transformation by promoting evidence-based practices and fostering a culture of safety (Al-Naemi, 2023). They are responsible for mentoring and providing professional development opportunities to nursing staff, which enhances job satisfaction and retention (Al-Naemi, 2023).

Holistic Care and Health Education: Nurses adopt a holistic approach, addressing patients' physical, psychological, social, and spiritual needs, contributing to well-rounded recovery (Tamshan et al., 2022). They empower patients through health education, equipping them with the knowledge necessary for effective health management (Tamshan et al., 2022). Despite the critical role nurses play, challenges such as insufficient staffing and resources persist, impacting their ability to deliver optimal care(Al-Naemi, 2023). Additionally, the nursing profession continues to strive for recognition as a distinct and diverse field, emphasizing the need for a well-defined body of knowledge(Anwar, 2022). These challenges highlight the importance of support from healthcare planners and stakeholders to enhance the nursing profession's status and effectiveness.

- **The Impact Of Personal Protective Equipment Shortages On Nursing And Healthcare Systems**

Disruptions In Patient Care Due to Personal Protective Equipment Shortages on Nursing: The shortage of personal protective equipment (PPE) has significantly disrupted patient care, particularly affecting nursing staff. This disruption is evident in various contexts, from increased occupational health risks to the psychological and operational challenges faced by healthcare workers. The lack of adequate PPE not only compromises the safety of nurses but also impacts the quality of care provided to patients. The following sections explore the multifaceted effects of PPE shortages on nursing and patient care.

Occupational Health Risks: In Nepal, nurses face increased occupational health risks due to limited access to PPE and inadequate training on its use, which heightens their vulnerability to

infectious diseases and other hazards (Giri et al., 2023). In Indonesia, the scarcity of PPE has led to adverse effects such as nasal blisters and dehydration among nurses, indicating the physical toll of prolonged PPE use (Sampe et al., 2021).

Impact on Patient Care: In the United States, PPE shortages in nursing homes have been linked to increased COVID-19 infection rates among residents and staff, highlighting the direct impact on patient safety and care quality (Kang & Kim, 2022). The lack of PPE has forced nurses to modify or extend the use of available equipment, potentially compromising infection control measures and patient care standards (Sampe et al., 2021).

Psychological and Operational Challenges: Nurses in the US reported concerns about safety and PPE supply, which contributed to stress and frustration, affecting their ability to provide care effectively (Simonovich et al., 2022). Healthcare workers have demonstrated resilience by adapting to PPE shortages, but this has also required them to critique and resist inadequate systems, adding to their psychological burden (Hintz et al., 2021). While PPE shortages have posed significant challenges, they have also catalyzed resilience and adaptation among healthcare workers. This situation underscores the need for systemic changes, such as improved PPE supply chains and comprehensive training, to ensure the safety and efficacy of patient care in future crises.

Increased Risk To Healthcare Workers Personal Protective Equipment Shortages: The shortage of personal protective equipment (PPE) during the COVID-19 pandemic significantly increased the risk to healthcare workers (HCWs) by exposing them to infectious diseases and other occupational hazards. This issue was prevalent across various regions, including Denmark, Nepal, and several low- and middle-income countries (LMICs). The lack of adequate PPE not only heightened the risk of infection but also led to functional disorders and impaired health among HCWs. The following sections delve into the specific challenges and implications of PPE shortages.

Insufficient PPE and Infection Risk: In Denmark, insufficient PPE use was associated with a slightly increased risk of COVID-19 infection among HCWs, although the data were not statistically conclusive due to potential misclassification bias from self-reported PPE use (Bungum et al., 2024). In LMICs, a significant portion of health facilities reported stock-outs of essential PPE items, such as medical masks and gloves, which compromised the ability to protect HCWs from COVID-19 transmission (Drouard et al., 2023).

Challenges in PPE Availability and Utilization: In Nepal, patient care nurses faced significant challenges due to limited access to high-quality PPE and inadequate training on its proper use, increasing their vulnerability to occupational hazards (Giri et al., 2023). A study in Nigeria highlighted that while PPE was available, it was not consistently used, indicating a gap between availability and optimal utilization (Bakare & Aniaku, 2024).

Health Implications and Safety Measures: The use of PPE during the pandemic was associated with increased physical stress and risk of functional disorders among HCWs, necessitating the development of preventive measures to enhance safety (Batov et al., 2024). The high incidence of COVID-19 among HCWs at a military medical academy underscored the need for specific measures to mitigate infection risk, including addressing the physical demands of PPE use (Batov et al., 2024). While the availability of PPE is crucial, its proper use and the training of HCWs are equally important to ensure safety. The studies suggest that even when PPE is available, improper use can still lead to increased infection risk. Therefore, comprehensive strategies that include improving PPE access, training, and awareness are essential to protect HCWs effectively.

- **Challenges In Personal Protective Equipment Distribution**

Inadequate Supply Chains and Logistics During Global Crises for Personal Protective Equipment Distribution: The COVID-19 pandemic highlighted significant inadequacies in global supply chains and logistics for distributing personal protective equipment (PPE). These inadequacies were primarily due to disruptions in supply chains, lack of transparency, and

inefficient distribution systems, which led to critical shortages and increased vulnerability of healthcare systems worldwide. Addressing these issues requires a multifaceted approach involving improved supply chain resilience, transparency, and strategic resource allocation.

Supply Chain Resilience: The pandemic exposed the fragility of supply chains, with disruptions leading to worldwide stockouts of essential PPE. A proposed dynamic framework using a stochastic population model and optimization techniques can enhance supply chain resilience by prioritizing social gain over profit, ensuring PPE is distributed where most needed during crises (Lucas et al., 2024). A centralized logistical triage platform can optimize resource allocation by connecting healthcare organizations with suppliers, facilitating real-time tracking and need-based distribution, particularly in low-middle income countries (Ahmed et al., 2022).

Transparency and Governance: The lack of transparency in the global PPE market exacerbated supply shortages and price volatility. A joint WTO/WHO initiative is proposed to enhance market supply transparency, which would improve cooperation and preparedness for future pandemics (Klerk & Garcia-Santaolalla, 2022). Improved governance and integration of supply chains, including the use of advanced technologies like blockchain, are essential to mitigate the impact of pandemics and ensure sustainable healthcare systems (Bhaskar et al., 2020).

Strategic Resource Allocation: Various supply strategies, such as stockpiling, domestic production, and innovative supply strategies, were analyzed to address PPE shortages. Purchasing from the world market or through direct tender was found to be most effective in reducing shortages, although these strategies are susceptible to delays (Götz et al., 2024). A system dynamics model linking disease transmission with supply availability can help decision-makers develop crisis frameworks to accelerate procurement processes and improve health system resilience during pandemics (Götz et al., 2024). While these strategies offer potential solutions, challenges remain in implementing them effectively. The balance between global cooperation and national interests, as well as the economic constraints faced by low-income countries, complicates the establishment of robust supply chains. Future efforts must focus on creating adaptable and equitable systems that can withstand global crises.

Economic Barriers to Ensuring Adequate Supplies for Personal Protective Equipment: Ensuring adequate supplies of personal protective equipment (PPE) faces several economic barriers, primarily due to supply chain vulnerabilities, cost inefficiencies, and market dependencies. These barriers have been highlighted during the COVID-19 pandemic, revealing critical weaknesses in both domestic and international supply chains. The economic challenges are multifaceted, involving issues of cost-effectiveness, supply chain management, and global inequities. Below are the key economic barriers identified from the research papers.

Supply Chain Vulnerabilities: Heavy reliance on imports, particularly from countries like China, makes the supply chain susceptible to disruptions. For instance, 90% of N95 masks in the USA are imported, creating a high-risk dependency (Dai et al., 2020). The existing supply chain is not designed to handle sudden spikes in demand, as seen during the COVID-19 pandemic, leading to significant delays and shortages (Mehrotra et al., 2020).

Cost Inefficiencies: The cost-effectiveness of PPE varies significantly across different diseases. While PPE is highly cost-effective for diseases like Ebola, it is less so for others like MRSA, which can influence investment decisions (Bolas et al., 2023). Hospital operating systems often use dysfunctional costing models that prioritize efficiency and price over preparedness, exacerbating shortages during crises (Cohen et al., 2020).

Global Inequities: Low and middle-income countries are often priced out of the market, facing severe shortages due to their inability to compete financially with wealthier nations (Garber et al., 2020). The global supply chain's structural inequities mean that during a crisis, wealthier countries can outbid poorer ones, leading to uneven distribution of PPE (Garber et al., 2020). While these economic barriers present significant challenges, they also highlight the need for strategic policy

interventions. For instance, diversifying the supply base and developing domestic production capabilities could mitigate some of these risks. Additionally, removing the profit motive from hospital purchasing models and treating health as a public good could ensure more equitable distribution of PPE(Cohen et al., 2020).

- **Building Resilient Systems to Counter Personal Protective Equipment Shortages**

Improving Supply Chain Management and Forecasting for Personal Protective Equipment: Improving supply chain management and forecasting for personal protective equipment (PPE) is crucial, especially in the context of pandemics like COVID-19. The pandemic highlighted significant vulnerabilities in PPE supply chains, leading to shortages and inflated prices. To address these challenges, various strategies and models have been proposed to enhance resilience and forecasting accuracy. These strategies focus on optimizing distribution, managing risks, and improving inventory management. Below are key aspects derived from the research papers:
Supply Chain Resilience and Optimization: A dynamic framework using a stochastic population model and optimization techniques can improve PPE distribution during pandemics. This approach prioritizes social objectives over profit, ensuring PPE reaches areas of greatest need (Lucas et al., 2024). Multi-objective programming models, incorporating stochastic and chance-constrained programming, help manage supply chain risks by minimizing costs and shortages. These models consider various pandemic scenarios to optimize emergency inventory levels (Ash et al., 2023).
Forecasting and Inventory Management: Accurate forecasting of PPE demand is essential. The ARIMA model has been identified as the most effective for predicting hospital PPE needs, based on metrics like MAPE, RMSE, and MAD. The Economic Order Quantity (EOQ) model remains effective for inventory control, even during pandemics (Christie, 2021).
Data Transparency and Stress Testing: Enhancing data transparency and conducting regular stress tests are vital for managing high-risk PPE supply chains. Diversifying supply sources and preparing for worst-case scenarios can mitigate risks associated with heavy reliance on imports (Dai et al., 2020).
Mitigation Strategies and System Dynamics: A system dynamics approach identifies key feedback loops and delays in global PPE supply chains. Coordinated mitigation strategies across countries and sectors are necessary to address disruptions effectively. Early implementation of these measures is crucial to prevent persistent shortages (Sigala et al., 2022). While these strategies offer robust solutions, challenges remain in balancing cost-efficiency with resilience. The focus on social objectives over profit may not align with all stakeholders' interests, and the reliance on complex models requires significant data and expertise. Additionally, geopolitical factors and global supply chain interdependencies can complicate efforts to diversify supply sources.
Leveraging Technology For Better Resource Allocation For Personal Protective Equipment: Leveraging technology for better resource allocation of personal protective equipment (PPE) involves utilizing advanced data analytics, cloud computing, and ethical frameworks to optimize distribution and usage. This approach is crucial in managing PPE shortages during pandemics like COVID-19, ensuring that healthcare providers and other essential workers have the necessary protection. By integrating technology, healthcare systems can enhance their responsiveness and efficiency in PPE management. The following sections detail various technological strategies and frameworks proposed in the literature.
Big Data and Cloud Computing: Big data analytics can improve PPE distribution by analyzing electronic medical records and other relevant data to predict and manage supply shortages (Ma & Tsai, 2020). Cloud-based systems, such as the smart resource allocation advisor, can dynamically allocate resources based on pandemic severity, optimizing cost-benefit outcomes (Coşgun & Umar, 2020).

Ethical Frameworks: Ethical rationing systems ensure fair distribution of PPE, emphasizing transparency, collaboration, and accountability. These systems help minimize moral residue among healthcare providers during shortages (Binkley & Kemp, 2020).

Predictive and Management Tools: Software tools, like the PPE calculator, assist hospitals in managing PPE by predicting future needs and optimizing purchasing and distribution processes. These tools offer features like cost management and supply chain optimization (Abdollahzade et al., 2022). Systems that analyze corporate information and benchmark data can prioritize PPE recommendations, ensuring that the most critical needs are met first (Zircher & Morris, 2014). While technology offers significant advantages in PPE allocation, challenges such as data privacy, system integration, and ethical considerations must be addressed. Additionally, the effectiveness of these technological solutions depends on the availability of accurate data and the willingness of stakeholders to adopt new systems. Balancing technological innovation with ethical and practical considerations is essential for successful PPE management.

- **Role Of Nursing In Addressing Shortages In Personal Protective Equipment**

Nurses play a crucial role in addressing shortages of personal protective equipment (PPE) by advocating for better resources, adapting to limited supplies, and ensuring the safety of both healthcare workers and patients. The COVID-19 pandemic has highlighted the critical need for adequate PPE in healthcare settings, with nurses often at the forefront of managing these shortages. Their involvement is essential in implementing strategies to mitigate the impact of PPE scarcity and maintain high standards of care. The following sections detail the specific roles and actions taken by nurses in this context.

Advocacy and Policy Influence: Nurses have been instrumental in advocating for improved access to PPE by raising awareness among policymakers and healthcare organizations about the risks associated with inadequate PPE supplies (Giri et al., 2023). In Indonesia, nurses have shown readiness to propose solutions to leaders regarding PPE shortages, demonstrating their proactive role in influencing policy and resource allocation (Sampe et al., 2021).

Adaptation and Resource Management: In response to PPE shortages, nurses have adapted by modifying existing PPE to extend its usability, as seen in Indonesia where 51% of nurses reported modifying PPE (Sampe et al., 2021). Nurses in Nepal face challenges due to limited PPE availability and have been involved in efforts to improve training and awareness about proper PPE use to maximize existing resources (Giri et al., 2023).

Education and Training: Educating healthcare workers on the rational use of PPE is a key strategy proposed to address shortages. This involves training nurses to use PPE efficiently and safely, reducing unnecessary consumption (Shrivastava & Shrivastava, 2020). The importance of behavioral knowledge and communication in hospital settings is emphasized to enhance PPE use and biosafety practices among nursing staff (Sousa et al., 2022).

Challenges and Consequences: Despite these efforts, nurses continue to face significant challenges, such as adverse effects from prolonged PPE use, including nasal blisters and dehydration (Sampe et al., 2021). In the US, nursing homes report severe PPE shortages, particularly in facilities with COVID-19 cases, highlighting the ongoing need for targeted resource allocation (McGarry et al., 2020). While nurses play a pivotal role in managing PPE shortages, the responsibility also lies with public health authorities to ensure rational use and optimal availability of PPE. Coordinated efforts across the supply chain and strategic policy measures are essential to support nurses and healthcare workers in maintaining safety and care standards during crises (Shrivastava & Shrivastava, 2020).

- **Case Study**

The COVID-19 pandemic exposed significant vulnerabilities in healthcare systems worldwide, particularly concerning the availability of personal protective equipment (PPE) for nurses. Various countries have adopted different strategies to build resilient systems to counteract PPE shortages,

showcasing diverse approaches to crisis readiness. This response highlights case studies from Indonesia, Turkey, and the efforts of Médecins sans Frontières (MSF) to illustrate these strategies.

Indonesia: PPE Shortages: Indonesia faced substantial PPE shortages, with only 80% of N95 masks and 71% of hazmat suits available, while gloves were critically low at 30% availability (Sampe et al., 2021). Nurse Responses: Despite shortages, 60.7% of nurses exhibited positive behavioral responses, such as proposing solutions to leaders and modifying PPE usage (Sampe et al., 2021). Adverse Effects: Prolonged PPE use led to nasal blisters, headaches, and dehydration among nurses, highlighting the need for urgent policy interventions (Sampe et al., 2021).

Turkey: Workforce Planning: In Turkey, the pandemic underscored the need for a robust nursing services management model, as nurses faced challenges in workforce planning and PPE management (Çelik et al., 2022). Shift Satisfaction: Nurses working 8-hour shifts and those notified in advance of assignments reported higher satisfaction, indicating the importance of structured workforce management during crises (Çelik et al., 2022).

Médecins sans Frontières (MSF): Supply Chain Resilience: MSF demonstrated resilience by adapting procurement and supply processes to manage international and local supply chain disruptions (Vega et al., 2022). Adaptive Strategies: The organization utilized both exploitation and exploration capabilities to reconfigure supply management, showcasing a socio-ecological approach to resilience (Vega et al., 2022). While these case studies highlight successful strategies in crisis management, they also reveal ongoing challenges. For instance, the need for international collaboration and standardized policies remains critical to enhance preparedness and resilience across healthcare systems globally. Addressing these issues can lead to improved public health outcomes and better crisis readiness in future pandemics.

- **Innovations And Alternatives To Personal Protective Equipment**

Development Of Reusable and More Sustainable Personal Protective Equipment: The development of reusable and more sustainable personal protective equipment (PPE) is a critical response to the environmental challenges posed by the widespread use of disposable PPE during the COVID-19 pandemic. This shift towards sustainability involves innovations in materials, manufacturing processes, and waste management strategies. The transition to sustainable PPE is supported by several key developments and strategies.

Material Innovations: The use of degradable polymers and natural fibers is being explored as alternatives to traditional plastics, which are non-biodegradable and contribute to environmental pollution (Lyu et al., 2024). Bacterial cellulose-derived biomaterials offer a biodegradable option for PPE, with the ability to decompose rapidly in soil, thus reducing environmental impact (Veerubhotla et al., 2022).

Design and Manufacturing: Multi-use PPE, such as isolation suits made from three-layer laminated fabrics, are being developed to withstand repeated washing and drying, offering high performance and comfort while reducing environmental impact (Öztürk et al., 2023). Equipment-free methods of producing PPE from locally-sourced organic materials provide a cost-effective and sustainable alternative, supporting rural livelihoods and reducing reliance on synthetic materials (Veerubhotla et al., 2022).

Waste Management and Policy: Recycling and upcycling methods are crucial for converting PPE waste into valuable products or energy, thereby minimizing environmental impact (Lyu et al., 2024). Implementing a closed-loop supply chain model can enhance the sustainability of PPE by reducing carbon emissions and promoting the reuse and recycling of materials (Yadav et al., 2023). Policymakers and regulators are encouraged to support the use of reusable PPE through guidelines and standards, promoting a shift towards sustainable practices (Walsh, 2024). While the development of sustainable PPE is promising, challenges remain in terms of scalability and widespread adoption. Collaborative efforts among governments, manufacturers, and research institutions are essential to overcome these barriers and transition to a more sustainable PPE

industry. This approach not only addresses environmental concerns but also supports economic and social sustainability.

Advancements In Technology for Creating Alternative Protective Solutions: Advancements in technology have significantly enhanced the development of alternative protective solutions across various domains, including occupational health, military applications, and personal protective equipment. These advancements leverage cutting-edge technologies such as artificial intelligence, nanotechnology, and advanced materials to improve safety and functionality. The following sections detail key technological advancements in creating alternative protective solutions.

Occupational Health and Safety Technologies: Machine Vision and AI: These technologies are increasingly used to monitor and control industrial safety, aligning with Industry 4.0 standards. They facilitate data acquisition, transmission, and storage, enhancing workplace safety by providing real-time monitoring and feedback (Reyes et al., 2022). Intelligent Devices: Devices that monitor vital signs, physical variables, and worker behavior have been developed to improve safety. These technologies provide alerts and feedback, promoting safer work practices and reducing operational risks by automating tasks (Flor-Unda et al., 2023).

Military and Structural Protection: Multiscale Material Development: The U.S. Army's research focuses on developing materials that provide protection against high-strain rate events. These materials are lightweight and designed to meet operational constraints while offering enhanced protection against emerging threats (Roth et al., 2008). Advanced Computational Methods: These methods are used to simulate and validate protective systems, ensuring they can withstand severe conditions and provide effective protection (Roth et al., 2008).

Protective Clothing and Textiles: Nanotechnology and Smart Textiles: Protective clothing now incorporates nanotechnology to enhance properties such as flame retardancy, UV protection, and antibacterial capabilities. These textiles are designed to be multifunctional, providing comfort and protection simultaneously (Zhong & Pan, 2011) (Demir et al., 2020). Electrospinning Techniques: This method produces breathable, lightweight, and functionalizable textiles. Electrospun materials are used in protective clothing due to their ability to incorporate various functional agents, offering protection against chemical and biological threats (Demir et al., 2020). While these advancements offer significant improvements in protective solutions, challenges remain in balancing protection with comfort and usability. Future research may focus on further integrating these technologies to create even more effective and user-friendly protective solutions.

Conclusion:

Personal protective equipment shortages during global crises, such as the COVID-19 pandemic, have underscored the need for resilient systems to safeguard healthcare workers and maintain care quality. Nurses have demonstrated adaptability and leadership in addressing these challenges, yet systemic reforms in supply chain management, policy frameworks, and training remain essential. Innovations in sustainable PPE design and leveraging advanced technologies for resource allocation are promising steps toward long-term resilience. By fostering collaboration among healthcare stakeholders and prioritizing investment in preparedness, healthcare systems can better counteract future PPE shortages, ensuring both worker safety and patient care continuity.

References

- Abdollahzade, S., Rafiei, S., Namdar, P., & Ghashghaee, A. (2022). Developing a Personal Protective Equipment Calculator During the COVID-19 Pandemic. *Disaster Medicine and Public Health Preparedness*. https://doi.org/10.1017/dmp.2022.238
- Ahmed, K. S., Noorali, A. A., Ehsan, A. N., Zafar, M. H., Thobani, H., & Urooj, F. (2022). *Establishing a Centralized Logistical Triage Platform to facilitate Supply Chain Optimization for Critical Resources during COVID-19 in a Developing Country*. https://doi.org/10.52314/gjms.2022.v2i1.23

- Almutairi, D. A., Alosilan, A. A. R., Alotaibi, M., & Almutairi, M. (2024). Nurses' Role in Healthcare Quality Improvement. *International Journal of Medical Science and Clinical Research Studies*. https://doi.org/10.47191/ijmscrs/v4-i10-19
- Al-Naemi, Ibrahim. A. (2023). Nursing Leadership Role in Healthcare Transformation – A Critical Overview. *Saudi Journal of Nursing and Health Care*. https://doi.org/10.36348/sjnhc.2023.v06i09.004
- Anwar, S. (2022). The Versatile but Undermined Role of the Nursing Profession Needs the Attention of Health Planners and other Stakeholders. *Annals of King Edward Medical University*. https://doi.org/10.21649/akemu.v28i2.5104
- Ash, C., Venkatadri, U., Diallo, C., Vanberkel, P. T., & Saif, A. (2023). PPE Supply Optimization Under Risks of Disruption from the COVID-19 Pandemic. *Operations Research Forum*. https://doi.org/10.1007/s43069-023-00209-4
- Bakare, O. Q., & Aniaku, I. E. (2024). A study of availability and utilization of personal protective equipment among healthcare workers of a tertiary institution in South-west, Nigeria. *Cross River Journal of Medicine*. https://doi.org/10.5455/crjmed.193705
- Batov, V. E., Kuznetsov, S. M., Logatkin, S. M., & Lizunov, Yu. V. (2024). Safety of medical personnel when using personal protective equipment during the liquidation of a biological and social emergency. *Mediko-Biologičeskie i Social'no-Psihologičeskie Problemy Bezopasnosti v Črezvyčajnyh Situaciâh*. https://doi.org/10.25016/2541-7487-2023-0-4-56-66
- Bhaskar, S., Bhaskar, S., Tan, J. C. K., Bogers, M., Bogers, M., Bogers, M., Minssen, T., Badaruddin, H., Israeli-Korn, S., Israeli-Korn, S., Chesbrough, H., & Chesbrough, H. (2020). At the Epicenter of COVID-19-the Tragic Failure of the Global Supply Chain for Medical Supplies. *Frontiers in Public Health*. https://doi.org/10.3389/FPUBH.2020.562882
- Binkley, C. E., & Kemp, D. S. (2020). Ethical Rationing of Personal Protective Equipment to Minimize Moral Residue During the COVID-19 Pandemic. *Journal of The American College of Surgeons*. https://doi.org/10.1016/J.JAMCOLLSURG.2020.03.031
- Bolas, T., Werner, K., Alkenbrack, S., Uribe, M. V., Wang, M., & Risko, N. (2023). The economic value of personal protective equipment for healthcare workers. *PLOS Global Public Health*. https://doi.org/10.1371/journal.pgph.0002043
- Bungum, A. B., Tøttenborg, S. S., Begtrup, L. M., Petersen, K. U., Worm, M. S., Bonde, J. P., Dalbøge, A., Kinnerup, M. B., Würtz, E. T., Kolstad, H. A., Schlünssen, V., Cramer, C., Biering, K., Nielsen, K. J., & Flachs, E. M. (2024). Risk of SARS-CoV-2 infection in healthcare workers with insufficient use of personal protective equipment in Denmark. *Annals of Work Exposures and Health*. https://doi.org/10.1093/annweh/wxae075
- Çelik, S. Ş., Özbaş, A. A., Kovanci, M. S., Savas, H., & Çelik, Y. (2022). Experience and views of nurses on nursing services and personal protective equipment in Covid-19 pandemic the case of Turkey: A cross-sectional study. *Journal of Nursing Management*. https://doi.org/10.1111/jonm.13625
- Chavan, M., Sharma, S. K., Chenchula, S., Rangari, G., Misra, A. K., & Saggurthi, P. (2024). Psychological and physical impact of wearing personal protective equipment among health care workers during the COVID-19 pandemic. *Bioinformation*. https://doi.org/10.6026/973206300200822
- Christie, N. (2021). *Personal Protective Equipment Demand Forecasting and Inventory Management during COVID-19 Case Study: Public Hospital at Bandung, Indonesia*. https://doi.org/10.33422/3RD.ICMEF.2021.02.135
- Cohen, J., Cohen, J., & Rodgers, Y. van der M. (2020). *Contributing Factors to Personal Protective Equipment Shortages during the COVID-19 Pandemic*.

- Coşgun, Ö., & Umar, A. (2020). *Smart Resource Allocation Advisor in the Cloud for COVID-19 and Other Pandemics*. https://doi.org/10.1109/IEEECLOUDSUMMIT48914.2020.00025
- Dai, T., Bai, G., Anderson, G. F., & Anderson, G. F. (2020). PPE Supply Chain Needs Data Transparency and Stress Testing. *Journal of General Internal Medicine*. https://doi.org/10.1007/S11606-020-05987-9
- Demir, D., Vaseashta, A., & Bölgen, N. (2020). *Recent Advances of Electrospinning and Multifunctional Electrospun Textile Materials for Chemical and Biological Protection*. https://doi.org/10.1007/978-94-024-2018-0_22
- Diress, F. T., Fentie, D. Y., Endalew, N. S., & Admass, B. A. (2024). *Surgical team member's application of personal protective equipment: an observational study*. https://doi.org/10.1097/ms9.0000000000001765
- Drouard, S., Ahmed, T., Fernandez, P. A., Baral, P., Hansen, P. M., Hashemi, T., Sieleunou, I., Karibwami, A.-D., Yansane, M. L., Wesseh, C. S., Mwansambo, C., Nzelu, C., Uddin, H., Tassembedo, M., & Shapira, G. (2023). Availability and use of personal protective equipment in low- and middle-income countries during the COVID-19 pandemic. *PLOS ONE*. https://doi.org/10.1371/journal.pone.0288465
- Flor-Unda, O., Davila, D., Rivera, M., & Acosta-Vargas, P. (2023). Innovative Technologies for Occupational Health and Safety: A Scoping Review. *Safety*. https://doi.org/10.3390/safety9020035
- Garber, K., Ajiko, M. M., Gualtero-Trujillo, S. M., Martínez-Vernaza, S., & Chichom-Mefire, A. (2020). Structural inequities in the global supply of personal protective equipment. *BMJ*. https://doi.org/10.1136/BMJ.M2727
- Giri, S., Khanal, A., & Aryal, P. (2023). *Usage of Personal Protective Equipment by Patient Care Nurses to Reduce Occupational Health Risk: Challenges and Related Policy Measures in Nepal*. https://doi.org/10.3126/jomra.v1i1.55099
- Götz, P., Auping, W., & Hinrichs-Krapels, S. (2024). Contributing to health system resilience during pandemics via purchasing and supply strategies: an exploratory system dynamics approach. *BMC Health Services Research*. https://doi.org/10.1186/s12913-023-10487-7
- Hintz, E. A., Betts, T., & Buzzanell, P. M. (2021). Caring for Patients without Personal Protective Equipment (PPE): Material Conditions as Multidimensional Cascading Triggers for Resilience Processes. *Health Communication*. https://doi.org/10.1080/10410236.2021.1953727
- Kang, S., & Kim, C. T. (2022). Effect of Shortages of Personal Protective Equipment and Staff on COVID-19 Infection in Nursing Homes: The Moderating Role of Quality. *Han'gug Saengsan Gwanli Haghoeji*. https://doi.org/10.32956/kopoms.2022.33.2.325
- Klerk, K. de, & Garcia-Santaolalla, N. (2022). Ensuring Market Supply Transparency for Personal Protective Equipment: Preparing for Future Pandemics. *Global Policy*. https://doi.org/10.1111/1758-5899.13103
- Lucas, T., Guimarães, R. D., Vasconcellos, M. S. G., Lins, I. D., Moura, M. das C., & Siqueira, P. G. S. C. de. (2024). Resilience of critical supply chains in pandemics: a model proposal for health personal protective equipment socially optimal distribution. *Operations Research for Health Care*. https://doi.org/10.1016/j.orhc.2024.100420
- Lyu, L., Bagchi, M., Markoglou, N., & An, C. (2024). Innovations and development of sustainable personal protective equipment: a path to a greener future. *Environmental Systems Research*. https://doi.org/10.1186/s40068-024-00350-x
- Ma, K. S.-K., & Tsai, A. S.-Y. (2020). Big Data-driven personal protective equipment stockpiling framework under Universal Healthcare System for Disease Control and Prevention

in the COVID-19 Era. *Infection Control and Hospital Epidemiology*. https://doi.org/10.1017/ICE.2020.387

- McGarry, B. E., Grabowski, D. C., & Barnett, M. L. (2020). Severe Staffing And Personal Protective Equipment Shortages Faced By Nursing Homes During The COVID-19 Pandemic. *Health Affairs*. https://doi.org/10.1377/HLTHAFF.2020.01269
- Mehrotra, P., Malani, P. N., Yadav, P., Yadav, P., & Yadav, P. (2020). *Personal Protective Equipment Shortages During COVID-19—Supply Chain–Related Causes and Mitigation Strategies*. https://doi.org/10.1001/JAMAHEALTHFORUM.2020.0553
- Öztürk, S., İnceoğlu, S., & Kurt, A. (2023). *Development of a Multi-Use Personal Protective Isolation Suit Suitable for Repeated Washing - Drying Process*. https://doi.org/10.56038/oprd.v3i1.364
- *Personal Protective Equipment*. (2024). https://doi.org/10.1016/b978-0-323-80932-0.00049-5
- Pradhan, S., Nimavat, N., Mangrola, N., Singh, S. S. S., Lohani, P., Mandala, G., Kumar, R., Sinha, N., & Singh, S. K. (2024). Guarding Our Guardians: Navigating Adverse Reactions in Healthcare Workers Amid Personal Protective Equipment (PPE) Usage During COVID-19. *Cureus*. https://doi.org/10.7759/cureus.58097
- Reyes, L. A., Almeida, D., & Flores, A. (2022). Information Technologies for Occupational Health and Safety. *Athenea*. https://doi.org/10.47460/10.47460/athenea.v3i8.40
- Roth, M. J., Boone, N., Kinnebrew, P. G., Davis, J. L., & Rushing, T. S. (2008). *Development of New Protective Solutions to Counter Emerging and Adaptive Threats*.
- Sampe, S. A., Endah, P. M. M. S., Sambo, M., & Abdu, S. (2021). Shortage of personal protective equipment and nurse safety in the coronavirus disease-19 pandemic: A cross-sectional study in indonesia. *Open Access Macedonian Journal of Medical Sciences*. https://doi.org/10.3889/OAMJMS.2021.6953
- Shrivastava, S. R., & Shrivastava, P. S. (2020). Responding to the challenge of shortage of personal protective equipment in the corona virus disease 2019 outbreak. *Journal of Dr. NTR University of Health Sciences*. https://doi.org/10.4103/JDRNTRUHS.JDRNTRUHS_32_20
- Sigala, I. F., Sirenko, M., Comes, T., & Kovács, G. (2022). Mitigating personal protective equipment (PPE) supply chain disruptions in pandemics – a system dynamics approach. *International Journal of Operations & Production Management*. https://doi.org/10.1108/ijopm-09-2021-0608
- Simonovich, S. D., Aquino, E., Lattner, C., Soco, C., Ponder, T. N., Amer, L., Howard, S., Nwafor, G., Shah, P., Badowski, D., Krawczyk, S., Wiesemann, L. M., Spurlark, R. S., Webber-Ritchey, K. J., & Lee, Y.-M. (2022). US Nurses' Challenges with Personal Protective Equipment during COVID-19: Interview Findings from the Frontline Workforce. *Psych*. https://doi.org/10.3390/psych4020019
- Sousa, R. K. de, Gonçalves, N., Silva, T. L., & Echevarría-Guanilo, M. E. (2022). Personal protective equipment in hospital nursing care: a scoping review. *Texto & Contexto Enfermagem*. https://doi.org/10.1590/1980-265x-tce-2021-0421en
- Tamshan, A., Shimah Alhulw, Ayed, A. S., Salma Salamh, Ayed, A. S., Salma Salamh, Tamshan, A., Shimah Alhulw, Dhaher, A. S., Faizah Atallah, & Rafi, A. M., Abdullah. (2022). Critical impact: the indispensable role of nursing services in elevating healthcare quality. *EPH-International Journal of Medical and Health Science*. https://doi.org/10.53555/eijmhs.v8i2.184
- Veerubhotla, R. S., Bandopadhyay, A., & Chakraborty, D. (2022). Equipment-Free Personal Protective Equipment (PPE) Fabrication from Bacterial Cellulose-Derived Biomaterials via Waste-to-Wealth Conversion. *bioRxiv*. https://doi.org/10.1101/2022.11.02.514716

- Vega, D. V. G., Arvidsson, A. P., & Saïah, F. (2022). Resilient supply management systems in times of crisis. *International Journal of Operations & Production Management*. https://doi.org/10.1108/ijopm-03-2022-0192
- Walsh, L. J. (2024). Reusable Personal Protective Equipment Viewed Through the Lens of Sustainability. *International Dental Journal*. https://doi.org/10.1016/j.identj.2024.07.1270
- Wasik, M. A. (2020). The role of the nurse in improving the quality of healthcare. *Journal of Education, Health and Sport*. https://doi.org/10.12775/JEHS.2020.10.04.008
- Yadav, S., Mangla, S. K., Priyamvada, P., Borkar, A. J., & Khanna, A. (2023). An energy-efficient model for PPE waste management in a closed-loop supply chain. *Business Strategy and The Environment*. https://doi.org/10.1002/bse.3541
- Zhong, W., & Pan, N. (2011). *Developments in clothing protection technology*. https://doi.org/10.1533/9780857092878.269
- Zircher, L. A., & Morris, R. W. (2014). *System for determining personal protective equipment recommendations based on prioritized data*.