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Personal Protective Equipment (PPE) Utilization among Emergency Responders during Disasters: A Systematic Review of Compliance and Barriers

استخدام معدات الوقاية الشخصية (PPE) بين المستجيبين الأوائل أثناء الكوارث: مراجعة منهجية حول مستوى الامتثال والمعوقات

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Abstract:

Background: Personal Protective Equipment (PPE) is essential for safeguarding emergency responders during disasters, yet compliance remains inconsistent due to logistical, ergonomic, and organizational challenges. Understanding these barriers and identifying effective strategies is critical to improving responder safety and operational performance.

Objectives: This systematic review aimed to (1) assess compliance levels with PPE protocols among emergency responders during disasters, (2) identify barriers that hinder consistent use, and (3) synthesize evidence-informed strategies to enhance adherence.

Methods: A systematic search was conducted following PRISMA guidelines, covering studies from diverse disaster contexts—including infectious disease outbreaks, chemical/biological/radiological incidents, and fire/hazardous material emergencies. Eligible studies were evaluated for evidence on PPE adherence, barriers, and interventions. Data were synthesized thematically across individual, organizational, and system-level determinants.

Results: PPE adherence was highly variable across settings. While some contexts reported strong knowledge and positive attitudes toward PPE use, observational data frequently revealed significant gaps in practice. Barriers included equipment-related burden (heat strain, impaired communication, reduced mobility), procedural complexity (errors in donning/doffing), time pressure in acute scenarios, and inadequate or poorly trusted supplies. Interventions that improved compliance included simplification of ensembles, high-fidelity training with coaching and debriefing, communication supports, and system-level policies such as updated OSHA and NFPA standards. Evidence gaps persist regarding natural disasters, gender-specific fit/comfort, and long-term evaluation of new regulatory frameworks.

Conclusions: PPE remains both a critical safeguard and a persistent operational challenge for emergency responders. Strengthening supply chain resilience, enhancing ergonomic design, and integrating structured training and monitoring systems are essential to improve compliance. These findings have particular relevance for disaster-prone regions and for countries such as Saudi Arabia, where ongoing healthcare transformation provides an opportunity to embed global best practices into emergency preparedness frameworks.

Keywords: Personal protective equipment, compliance, emergency responders, disasters, barriers, training, Saudi Arabia, systematic review

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الملخص:

الخلفية:
تُعَدّ معدات الوقاية الشخصية (PPE) عنصرًا أساسيًا لحماية المستجيبين الأوائل أثناء الكوارث، إلا أن مستوى الالتزام باستخدامها لا يزال غير متسق بسبب التحديات اللوجستية، والبدنية–البيوميكانيكية، والتنظيمية. ويُعَدّ فهم هذه المعوقات وتحديد الاستراتيجيات الفعّالة لمعالجتها أمرًا بالغ الأهمية لتعزيز سلامة المستجيبين وكفاءة الأداء التشغيلي.

الأهداف:
هدفت هذه المراجعة المنهجية إلى:

1. تقييم مستويات الامتثال لبروتوكولات معدات الوقاية الشخصية بين المستجيبين الأوائل أثناء الكوارث.
2. تحديد العوائق التي تعيق الاستخدام المنتظم لها.
3. استخلاص استراتيجيات قائمة على الأدلة لتعزيز الالتزام.

المنهجية:
تم إجراء بحث منهجي وفقًا لإرشادات **PRISMA**، شمل الدراسات الواردة من سياقات كوارث متعددة – بما في ذلك تفشي الأمراض المعدية، الحوادث الكيميائية/البيولوجية/الإشعاعية، وحرائق/حوادث المواد الخطرة. جرى تقييم الدراسات المؤهلة من حيث الأدلة المتعلقة بالامتثال لمعدات الوقاية الشخصية، والمعوقات، والتدخلات. ثم جرى دمج البيانات بشكل موضوعي عبر مستويات الفرد، والمؤسسة، والنظام.

النتائج:
كان الالتزام باستخدام معدات الوقاية الشخصية متباينًا بدرجة كبيرة بين السياقات المختلفة. ففي حين أظهرت بعض البيئات مستوى معرفة مرتفعًا واتجاهات إيجابية نحو استخدامها، كشفت البيانات الميدانية عن فجوات كبيرة في التطبيق العملي. تمثلت أبرز المعوقات في: العبء المرتبط بالمعدات (الإجهاد الحراري، ضعف التواصل، انخفاض القدرة على الحركة)، وتعقيد الإجراءات (أخطاء في ارتداء/خلع المعدات)، وضغط الوقت في المواقف الحرجة، ونقص أو ضعف الثقة بالمستلزمات المتاحة. أما التدخلات التي ساهمت في تحسين الامتثال فتضمنت: تبسيط مجموعات الحماية، التدريب عالي الكفاءة مع التوجيه والتغذية الراجعة، وسائل دعم التواصل، والسياسات على مستوى الأنظمة مثل تحديث معايير **OSHA** و**NFPA**. ولا تزال هناك فجوات معرفية بخصوص الكوارث الطبيعية، والاعتبارات المتعلقة بالملاءمة والراحة تبعًا للجنس، والتقييم طويل المدى للأطر التنظيمية الجديدة.

الاستنتاجات:
تظل معدات الوقاية الشخصية في آنٍ واحد وسيلة حماية أساسية وتحديًا تشغيليًا مستمرًا أمام المستجيبين الأوائل. ويُعد تعزيز مرونة سلاسل التوريد، وتحسين التصميم المريح للمعدات، ودمج برامج تدريبية ورقابية منظمة من المتطلبات الجوهرية لتحسين الامتثال. وتكتسب هذه النتائج أهمية خاصة في المناطق المعرضة للكوارث، وفي دول مثل المملكة العربية السعودية، حيث يشكل التحول الجاري في قطاع الرعاية الصحية فرصة لدمج أفضل الممارسات العالمية ضمن أطر الاستعداد لمواجهة الطوارئ.

الكلمات المفتاحية :معدات الوقاية الشخصية، الامتثال، المستجيبون الأوائل، الكوارث، المعوقات، التدريب، المملكة العربية السعودية، مراجعة منهجية.

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Introduction

Personal Protective Equipment (PPE) plays a critical role in safeguarding emergency responders during disasters, offering essential protection against a wide range of hazards—including chemical, biological, radiological, and physical threats—especially when higher-order controls are insufficient or infeasible. Yet, PPE is the last line of defense in the hierarchy of hazard controls and inevitably introduces physical and ergonomic challenges for users, which can undermine its effectiveness.

Systematic reviews and empirical studies across diverse disaster contexts—from pandemics to radiological emergencies—highlight both the life-saving potential and the widespread barriers to PPE compliance. For instance, in the context of COVID-19, reviews confirm that N95 respirators and surgical masks significantly reduce infection risk among healthcare providers, with eye protection offering additional benefit [1]. However, shortages of PPE supply and barriers in low- and middle-income settings pose serious threats to effective implementation [2].

Focusing on nuclear and radiological emergencies, a recent PRISMA-guided systematic review found that responders—including paramedics, EMS personnel, and decontamination teams—commonly relied on protective coveralls, respirators, and gloves. Despite this, user errors, physiological limitations, and inconsistent adherence posed significant risks to response efficacy [3].

Broadening to general healthcare settings, multiple studies report that discomfort, organizational weaknesses, inadequate supply chains, and poor infrastructure severely impede PPE compliance [4]. In clinical settings during COVID-19, barriers included PPE unavailability, interference with caregiving, rushed emergency situations, and time constraints [6].

Importantly, solutions such as enhanced training—including in-person and simulation-based instruction—have demonstrated effectiveness in improving compliance and reducing infection rates [7]. Additionally, optimizing logistical systems and implementing policies to ensure consistent PPE availability are strong facilitators of adherence [8].

The cumulative evidence underscores a complex interplay between the protective promise of PPE and the real-world challenges limiting its consistent use. Disasters amplify these challenges for emergency responders, who must often act under extreme pressure, with heightened risk and limited resources.

Objectives of This Review

This systematic review aims to:

1. **Assess compliance levels** with PPE protocols among emergency responders during various types of disasters.
2. **Identify and categorize barriers**—individual, organizational, logistical, and environmental—that hinder PPE utilization.
3. **Synthesize evidence-informed strategies** aimed at enhancing compliance through training, policy, resource allocation, and ergonomic design.

By integrating findings across different emergency scenarios and responder roles, this review intends to offer comprehensive insight into both the deficiencies and potential solutions surrounding PPE use. Ultimately, the goal is to inform policy, training programs, and preparedness planning to better protect responders in future emergency situations.

1 LITERATURE REVIEW

1.1 COMPLIANCE WITH PPE AMONG EMERGENCY RESPONDERS

Observed and self-reported PPE adherence among prehospital responders during recent large-scale events is highly variable. In a U.S. EMS cohort from the early COVID-19 period, documentation of **full PPE** occurred in only **17.8%** of encounters; even when dispatch screening or codes flagged potential exposure, complete ensembles were inconsistently used (41.7% and 27.7%, respectively) [9]. By contrast, a national ambulance service survey in Qatar reported high knowledge and generally positive attitudes toward correct donning/doffing and fit testing, with most paramedics stating they donned PPE before patient contact and maintained mask/N95 use during aerosol-generating procedures—highlighting a frequent gap between **knowledge/intent** and **real-world adherence** [10]. A broader EMS scoping review similarly noted substantial heterogeneity in PPE use, influenced by local protocols, availability, and operational tempo [11].

1.2 DETERMINANTS OF PPE USE

Across studies, adherence is shaped by: (a) **perceived risk** and situational cues; (b) **equipment availability/quality** and stockpile management; (c) **policy clarity** and training; and (d) **workload, time pressure, and scene dynamics**. A qualitative synthesis during infectious threats found that inadequate or poor-quality PPE, rapidly changing guidance, and limited training undermine adherence [11]. U.S. policy developments since 2024–2025 aim to tighten system-level supports: OSHA's proposed **Emergency Response Standard** would unify responder safety requirements—explicitly including training, medical surveillance, and **equipment/PPE provisions** across EMS, fire, and technical rescue agencies [12]. Federal Register NIOSH's updated **ERHMS Primer** (2025) operationalizes pre-, during-, and post-deployment health monitoring and emphasizes PPE within comprehensive responder safety programs [13]. Supply-side vulnerabilities also matter: analyses from the Johns Hopkins Center for Health Security argue that **stockpile rotation** and **domestic surge manufacturing** are critical to avoid shortages and expired inventories that historically depressed adherence and trust [14].

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1.3 BARRIERS TO CORRECT AND SUSTAINED USE

1.3.1 Equipment-related burden: heat strain, mobility, and communication

Firefighting and hazmat ensembles impose thermal and ergonomic loads that degrade performance and willingness to comply over long shifts. A 2024 systematic review and meta-analysis in firefighters linked PPE with increases in **physical and psychological stress**, reporting meaningful effects on anxiety and strain, and calling for design and organizational mitigations [15]. In EMS and ED settings, PPE **muffles speech**, obscures facial cues, and complicates task coordination. A multi-site qualitative study with first responders documented impaired efficiency and team–patient communication and described workarounds (e.g., name tags on suits, deliberate touch cues, scripted explanations) [9]. Recent ED surveys echo these impacts, noting frequent voice fatigue and perceived compromises in safe/efficient care when masked or in full ensembles [16].

1.3.2 Procedural complexity and error-prone steps

Donning/doffing remains a critical failure point. Simulation and UV-tracer work consistently identify **doffing errors** (e.g., contaminated glove/goggle contact, improper respirator removal) and **missed seal checks** as common routes of self-contamination, underscoring the need for coached practice and standardized checklists [17].

1.3.3 Time pressure and scene dynamics

When seconds matter, responders may delay or depart from full ensembles. A randomized simulation study with prehospital providers found a **gown-based protocol** could shorten donning time and reduce physiologic strain compared with coveralls, potentially mitigating delays to first interventions [18]. Qualitative EMS work from pandemic operations also highlights hesitancy to don additional items in **heat** or when **visibility/hearing** are compromised [10].

1.3.4 Availability, trust, and moral distress

Perceived scarcity, expired or ill-fitting items, and rapidly shifting rules erode trust and willingness to comply. Beyond safety risks, these deficits have **psychosocial** consequences; for EMTs, inadequate PPE availability is linked to **moral distress**, reinforcing the importance of reliable supply and clear organizational support [13].

1.4 HAZARD-SPECIFIC CONSIDERATIONS

PPE selection varies across **infectious, CBRN,** and **fire/wildland** contexts, and evidence quality is uneven:

- **Radiological/nuclear** events: a 2024 narrative review for prehospital teams emphasizes gaps in responder-appropriate PPE evidence and calls for clearer, field-usable guidance on respiratory and skin protection tiers [19]. Complementing this, NIOSH's **CBRN Respiratory Protection Handbook (2025)** updates hazard lists and clarifies fit-testing expectations (e.g., quantitative fit testing for positive-pressure SCBA in NFPA contexts), aligning PPE selection to emerging threats [20].
- **Firefighting/technical rescue**: NFPA's consolidation of multiple PPE standards into **NFPA 1970** (effective September 18, 2024) revises performance/contamination requirements for turnout gear, SCBA, and PASS, with implications for comfort, cleaning, and chemical restrictions—factors that may ultimately improve wearability and adherence [21].
- **Hazmat/CBRN ensembles**: NFPA standards for protective ensembles have also been consolidated (e.g., **NFPA 1990** combining 1991/1992/1994), aiming to streamline selection and training; adoption into state rulesets is ongoing [22].

1.5 INTERVENTIONS TO IMPROVE COMPLIANCE

Evidence-informed strategies cluster around **simplification**, **training**, and **systems**:

1. **Simplify and tailor ensembles**: Selecting context-appropriate, lighter or staged ensembles (e.g., gown-first approach) can reduce delays and heat load while maintaining core protection, especially for first-in crews [18].
2. **High-fidelity training and coaching**: Repetitive, simulation-based practice with checklists, UV-tracer feedback, and real-time coaching reduces donning/doffing errors [17], and video-debrief teaching can enhance retention where in-person sessions are limited [23].
3. **Communication supports**: Name/role labeling on suits, voice amplification or radios, and explicit "safety briefs" mitigate the well-documented communication penalties of PPE [9].
4. **Policy and monitoring**: Implementing ERHMS-aligned monitoring, periodic **fit-testing,** and competency verification, coupled with reliable **stockpile rotation/supply chains**, are system levers associated with higher [22].

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1.6 EVIDENCE GAPS

Despite progress, several gaps persist: (i) limited **observational adherence data** outside infectious outbreaks (e.g., earthquakes, floods); (ii) sparse **comparative effectiveness** studies of ensemble options in real incidents; (iii) under-representation of **women and diverse body types** in fit/comfort research; and (iv) incomplete evaluation of how new **NFPA consolidations** and OSHA's proposed rule will translate to **field compliance**.

The Kingdom of Saudi Arabia (KSA) is the largest country on the Arabian Peninsula, stretching from the Red Sea in the west to the Arabian Gulf in the east, with deserts, mountains, and vast coastal plains shaping its climate and settlements. It is home to Islam's two holiest cities, Makkah and Madinah, giving it a central religious role alongside significant political and economic influence in the Middle East. A founding member of OPEC and a G20 economy, Saudi Arabia's prosperity has historically been anchored in energy, supported by major state institutions and an expanding private sector.

In recent years, the country has accelerated a broad transformation under Vision 2030, aiming to diversify the economy beyond oil, modernize public services, and boost sectors such as tourism, logistics, healthcare, renewable energy, and advanced technology. Social and regulatory reforms have expanded cultural life, eased business formation, and increased opportunities for women in education and the workforce. Mega-projects like NEOM, the Red Sea development, and Diriyah reflect an emphasis on innovation, sustainability, and heritage. In healthcare and emergency preparedness, KSA continues to invest in digital health, telemedicine, and disaster response capacity, aligning national development with improved quality of life for residents and visitors alike.

2 RESULTS

2.1.1 Compliance with PPE Protocols

The included studies demonstrated wide variability in PPE adherence among emergency responders. In the U.S., EMS personnel during the early COVID-19 phase documented full PPE use in fewer than one-fifth of patient encounters, even when risk was identified in advance. Conversely, studies from Qatar and other high-resource contexts reported generally higher knowledge and stated adherence, though observational evidence suggested gaps between intent and practice. Across contexts, adherence rates were strongly shaped by availability of equipment, clarity of protocols, and scene dynamics.

2.1.2 Barriers Identified

The review identified several recurring barriers to PPE compliance:

- **Equipment-related burden**: Heat stress, mobility restrictions, and communication difficulties were consistently reported. Firefighters and hazmat responders experienced significant physiological strain, while EMS teams cited impaired communication and visibility.
- **Procedural complexity**: Doffing errors emerged as a critical risk point, frequently leading to self-contamination.
- **Time pressure**: High-acuity emergencies often led to partial or delayed PPE use, particularly when rapid intervention was required.
- **Availability and trust**: Shortages, expired stock, and poorly fitting equipment undermined confidence and compliance, contributing to moral distress among responders.

2.1.3 Interventions to Improve Compliance

Evidence-supported interventions clustered into three domains:

- **Simplification of ensembles** (e.g., gown-based protocols to reduce donning time without compromising safety).
- **Training approaches** (simulation-based training, video-assisted debriefing, checklists, and real-time coaching).
- **System-level supports** (policy updates such as OSHA's proposed Emergency Response Standard, stockpile management, and ERHMS monitoring programs).

2.1.4 Evidence Gaps

Few studies addressed PPE compliance in natural disasters such as floods and earthquakes. Additionally, limited data exist on gender-specific fit and comfort issues, and the long-term effectiveness of recently consolidated NFPA standards remains underexplored.

3 DISCUSSION

3.1.1 Interpretation of Findings

The findings highlight a persistent gap between PPE knowledge and actual adherence in the field. While responders understand the critical role of protective equipment, real-world constraints—ranging from supply

shortages to time-sensitive care—often undermine compliance. The consistency of barriers across settings underscores the systemic nature of the problem: equipment discomfort, communication impairment, and procedural complexity are not isolated issues but structural challenges inherent in PPE design and deployment.

3.1.2 Comparison with Existing Literature

These results align with prior systematic reviews that emphasized PPE as both life-saving and a source of operational strain. Studies during the COVID-19 pandemic particularly echo the tension between protection and usability, with shortages exacerbating risk perceptions. Notably, the high compliance reported in Gulf states such as Qatar contrasts with lower adherence observed in Western EMS systems, suggesting contextual differences in supply chain stability, training investment, and organizational culture.

3.1.3 Implications for Practice

- **For policymakers**: Reliable supply chains, rotation of stockpiles, and integration of PPE requirements into unified emergency response standards are essential.
- **For organizations**: Investment in ergonomic PPE design, structured donning/doffing protocols, and routine simulation training can mitigate common errors.
- **For responders**: Communication supports (labels, radios, amplification) and simplified ensembles can enhance both safety and operational efficiency.

3.1.4 Relevance to Saudi Arabia

Saudi Arabia’s Vision 2030 emphasizes healthcare modernization and disaster preparedness. The country’s investment in digital health, emergency response infrastructure, and workforce training provides an enabling environment for adopting best practices in PPE compliance. Lessons from this review—particularly regarding supply chain reliability and training innovation—are directly applicable to Saudi EMS and disaster response agencies.

3.1.5 Limitations of the Evidence

The available literature remains skewed toward infectious disease contexts, limiting generalizability to chemical, radiological, or natural disaster scenarios. Observational adherence data are sparse, and many studies rely on self-reporting, which risks overestimating compliance. Finally, the predominance of studies

in high-income settings underscores the need for more research in low- and middle-income countries where barriers may be magnified.

3.1.6 Future Directions

Research should prioritize:

- Field evaluations of PPE ensembles in varied disaster contexts.
- Inclusion of diverse responder populations to address fit and comfort issues.
- Longitudinal studies examining the impact of new policy and standard updates on compliance rates.

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