

A Guide for Healthcare Workers for Implementation of Infection Control Measures

Ali Abdulrahman Muzhir Al-Shehri ⁽¹⁾, Abdulaziz Abdulrahman Muzhir Al-Shehri ⁽²⁾, Eissa Ali Eissa Ali Alineze ⁽³⁾, Azzam Obaid Bin Mishal Alrakhimi ⁽⁴⁾, Shulaywih Faleh Alotaibi ⁽⁵⁾, Tahany Saud Alshammry ⁽⁶⁾, Abdulrahman Eid Ghedayan ALonazi ⁽⁷⁾, Nouf Shayeh Salama AlSharari ⁽⁸⁾, Abdullah Mohammed Alshehri ⁽⁹⁾, Khairiah Yahya M Bajawi ⁽¹⁰⁾, Hala Mefdhi Aljohani ⁽¹¹⁾, Ahmed Ayidh Salah Alharbi ⁽¹²⁾, Mousa Ahmed Alajam ⁽¹³⁾, Ebrahim Ahmed zacfe ⁽¹⁴⁾, Yousef Jazaa Safir Alotaibi ⁽¹⁵⁾, Ibrahim Ahmed Jabril Shuwayhi ⁽¹⁶⁾.

1. *Specialist - health Administration, Ministry of Health, Kingdom of Saudi Arabia. Alalsheri@moh.gov.sa*
2. *Specialist - health Administration, Ministry of Health, Kingdom of Saudi Arabia. Alalsheri@moh.gov.sa*
3. *Consultant-Health administration, Ministry of Health, Kingdom of Saudi Arabia. ealali@mohgov.sa*
4. *Emergency Medical Services, Alartawiyh Genral Hospital, Ministry of Health, Kingdom of Saudi Arabia. aalrikami@moh.gov.sa*
5. *Emergency Medical Services, Al Bjadyah Hospital, Ministry of Health, Kingdom of Saudi Arabia. shleweha@moh.gov.sa*
6. *Nurse, Northern Borders - Rafha, Ministry of Health, Kingdom of Saudi Arabia. taahaany119900@hotmail.com*
7. *Anesthesia Tech, ALiman General Hospital, Ministry of Health, Kingdom of Saudi Arabia. ksa-2002@live.com*
8. *Nursing Health Assistant, Forensic Medical Services Center in Al-Qurayyat Governorate, Ministry of Health, Kingdom of Saudi Arabia. noshalsharari@moh.gov.sa*
9. *Nursing Specialist, Aliman General Hospital, Ministry of Health, Kingdom of Saudi Arabia. Abdullah.m.shehri@hotmail.com*
10. *Medical Secretary, AL Diriyah Hospital, Ministry of Health, Kingdom of Saudi Arabia. KyBajawi@moh.gov.sa*
11. *Nursing Technician, Alrass General Hospital, Ministry of Health, Kingdom of Saudi Arabia. Ana-71a1989h@hotmail.com*
12. *Nursing, Umm Aldoom General Hospital, Ministry of Health, Kingdom of Saudi Arabia. Aealhrbi@Moh.Gov.Sa*
13. *Epidemiology Technician, Bish General Hospital, Ministry of Health, Kingdom of Saudi Arabia. maalajam@moh.gov.sa*
14. *Public Health, General Baish hospital, Ministry of Health, Kingdom of Saudi Arabia. ezacfe@moh.gov.sa*
15. *Emergency Medical Services, Ministry of Health, Kingdom of Saudi Arabia. Yousef.0056@hotmail.com*
16. *Health Informatics Specialist, Al-Iman General Hospital , Ministry of Health, Kingdom of Saudi Arabia. ii.140902@gmail.com*

Abstract

Healthcare-associated infections (HAIs) pose a significant threat to patient safety, with hand hygiene adherence, proper use of personal protective equipment (PPE), and central line-associated bloodstream infections (CLABSI) being critical areas of concern. Despite the recognized importance of infection prevention and control measures, adherence to best practices remains suboptimal. This review explores the application of human factors engineering (HFE) principles to address these challenges. HFE offers a sociotechnical systems perspective that considers the complex interplay between individuals, tasks, technologies, and organizational factors influencing healthcare delivery. Regarding hand hygiene, HFE insights can guide the strategic placement of hand sanitizer dispensers, improve the usability of dispensers, and optimize workflows to facilitate adherence. For

PPE, HFE can inform the design of intuitive donning and doffing procedures, enhance PPE comfort and compatibility, and identify barriers to compliance. HFE principles have also been successfully applied to reduce CLABSI rates through the development of a standardized central line maintenance kit that promotes adherence to best practices. Future research should explore the integration of advanced technologies, such as real-time monitoring systems and interactive training tools, to further enhance infection prevention efforts. Ultimately, a holistic HFE approach that addresses both technical and organizational aspects is essential for achieving sustainable improvements in infection control practices and patient safety outcomes.

Keywords: healthcare workers, HCWs, infection control

Introduction

Healthcare operates as a multifaceted sociotechnical system composed of numerous interconnected components, making it an ideal candidate for advancements through human factors engineering (HFE). This system includes individual factors such as the people involved, tasks, tools and technologies, organizational dynamics, and the surrounding environment. Beyond the confines of healthcare settings, additional elements, including insurance reimbursement policies and regulatory as well as legal frameworks, also exert significant influence on healthcare delivery. These components collectively underscore the need for a holistic approach to healthcare delivery, one that incorporates human factors principles to optimize outcomes.

While HFE has been utilized in various aspects of healthcare to enhance delivery systems, its application in infection prevention and control remains underexplored despite its potential impact. Infection prevention and control represent a practical, evidence-based strategy aimed at protecting both patients and healthcare workers from preventable infections. The critical importance of these practices is further highlighted by the emergence of life-threatening infections such as severe acute respiratory syndrome (SARS) and Ebola. According to WHO, these outbreaks underscore the necessity of robust infection prevention protocols within healthcare systems. Similarly, the U.S. Department of Health and Human Services has identified the prevention of infectious organism transmission—including those caused by antibiotic-resistant pathogens—as a top priority for hospitals and healthcare networks. This focus is particularly relevant for organisms like *Clostridium difficile* and methicillin-resistant *Staphylococcus aureus*, which often lead to symptomatic infections in hospitalized patients following colonization (Magill et al., 2014). The increasing prevalence of drug-resistant pathogens further amplifies the urgency of effective infection control measures.

Despite the recognized need for advancements in infection prevention and control, the application of HFE in this domain has been relatively limited. As Jacob, Herwaldt, and Durso highlight, significant opportunities exist to leverage HFE methodologies to address these persistent challenges. This guide aims to bridge that gap by presenting concrete examples of how HFE principles, models, and methods have been effectively employed to identify and implement solutions to infection control challenges. In subsequent sections, this guide will delve into specific HFE contributions aimed at improving critical areas such as hand hygiene, personal protective equipment (PPE) utilization, and central line-associated activities (Jacob et al., 2018).

To strengthen the integration of infection prevention measures, it is essential to consider the unique dynamics of healthcare environments. These environments are characterized by high levels of complexity, variability, and unpredictability, which pose significant challenges to maintaining consistent infection control practices. By incorporating HFE principles, healthcare systems can design interventions that are not only evidence-based but also tailored to the operational realities of clinical settings. For example, understanding how cognitive workload, environmental distractions, and task sequencing affect hand hygiene compliance can lead to

Ali Abdulrahman Muzhir Al-Shehri ⁽¹⁾, Abdulaziz Abdulrahman Muzhir Al-Shehri ⁽²⁾, Eissa Ali Eissa Ali Alineze ⁽³⁾, Azzam Obaid Bin Mishal Alrakhimi ⁽⁴⁾, Shulaywih Faleh Alotaibi ⁽⁵⁾, Tahany Saud Alshammry ⁽⁶⁾, Abdulrahman Eid Ghedayan Alonazi ⁽⁷⁾, Nouf Shayeh Salama AlSharari ⁽⁸⁾, Abdullah Mohammed Alshehri ⁽⁹⁾, Khairiah Yahya M Bajawi ⁽¹⁰⁾, Hala Mefdhi Aljohani ⁽¹¹⁾, Ahmed Ayidh Salah Alharbi ⁽¹²⁾, Mousa Ahmed Alajam ⁽¹³⁾, Ebrahim Ahmed zacfe ⁽¹⁴⁾, Yousef Jazaa Safir Alotaibi ⁽¹⁵⁾, Ibrahim Ahmed Jabril Shuwayhi ⁽¹⁶⁾.

the development of more effective strategies for improving adherence to these essential practices.

Moreover, the design and use of PPE represent another critical area where HFE can have a transformative impact. Challenges such as improper donning and doffing procedures, limited comfort, and compatibility issues with other medical equipment often compromise the effectiveness of PPE. Applying HFE techniques, such as usability testing and ergonomic assessments, can guide the creation of PPE that aligns better with the needs and workflows of healthcare workers. Furthermore, these methods can help identify potential barriers to compliance and develop targeted solutions to address them.

Central line-associated bloodstream infections (CLABSIs) provide yet another example of an infection control challenge that benefits from HFE applications. The implementation of standardized protocols and checklists, informed by HFE principles, has been shown to significantly reduce CLABSI rates. By examining factors such as task design, team communication, and workflow integration, HFE can further refine these interventions to ensure their long-term sustainability and effectiveness.

This guide not only underscores the critical role of infection prevention and control in healthcare but also advocates for the systematic application of HFE as a powerful tool to overcome existing challenges. Through evidence-based examples and actionable recommendations, it aims to equip healthcare workers with the knowledge and strategies needed to implement infection control measures effectively and sustainably.

Improving Hand Hygiene Adherence

In the United States, healthcare-associated infections (HAIs) impact approximately 1.7 million patients each year, leading to nearly 100,000 deaths. A fundamental approach to preventing HAIs is ensuring that healthcare personnel (HCP) adhere to proper hand hygiene practices. However, adherence rates are alarmingly low, with an average compliance of around 40% among HCP. Research shows that even modest improvements in hand hygiene adherence can lead to substantial reductions in HAIs. Despite the recognized importance of hand hygiene, the success and sustainability of interventions aimed at improving adherence remain inconsistent. Hand hygiene sits at the intersection of human behavior and technology, such as dispenser design, where human factors engineering (HFE) can offer theoretical insights and practical strategies for developing more effective interventions.

The work of Sax et al. highlights the potential of human factors design by framing proper hand hygiene around the "five moments" where infectious organism transmission might occur. These moments include before patient contact, before performing aseptic tasks, after exposure to bodily fluids, after patient contact, and after contact with a patient's environment. However, adherence to hand hygiene practices aligned with these five moments remains disappointingly low, with compliance rates averaging 42% (Scheithauer et al., 2017).

A common explanation for poor hand hygiene adherence is inadequate training. While training deficits undoubtedly contribute to noncompliance, a broader sociotechnical systems perspective can uncover additional explanations and enable the creation of more effective, sustainable interventions. For instance, Sax and Clack propose that inaccurate mental models held by HCP regarding hand hygiene can lead to breakdowns in practice. These authors argue that improving these mental models through experience and workplace alignment can enhance adherence. HFE-based modifications to the work environment, such as strategically placing hand sanitizer dispensers in highly visible and easily accessible locations, may also address this issue by increasing the salience of hand hygiene opportunities (Sax & Clack, 2015).

Research by Cure and Van Enk examined how the usability of hand sanitizer dispensers impacts adherence. Usability factors included visibility, proximity to room entrances and points of care, unobstructed access, alignment with the physical workflow, and appropriate installation height.

Interestingly, while increased visibility and proximity to entrances were associated with higher adherence, standardizing dispenser placement across units did not significantly improve compliance (Cure & Van Enk, 2015).

Further investigations by Patterson et al. identified additional barriers to hand hygiene adherence. These barriers included inconsistent dispenser placement, separation of glove storage areas from sanitizer dispensers, and the misuse of sinks for storage, rendering them unavailable for handwashing (Patterson et al., 2014). Nurses in this study emphasized the importance of increasing the visibility and prominence of hand sanitizer dispensers. Consistent with this finding, Nevo et al. demonstrated that adding blinking LED lights to dispensers significantly improved adherence rates. Another environmental modification proposed by Muder et al. involves demarcating the patient care area using visual markers, such as tape on the floor, to emphasize the need for hand hygiene upon entering or leaving the designated space. Multimodal interventions, which integrate several strategies targeting different psychological and behavioral aspects, have been shown to outperform single-strategy interventions in improving hand hygiene adherence (Huis et al., 2012). WHO guidelines for multimodal interventions emphasize five key areas for improvement: system-level changes, education and training, evaluation and feedback, workplace reminders, and fostering a culture of institutional safety.

A systematic qualitative review by Smiddy, O'Connell, and Creedon further highlights factors influencing HCP compliance with hand hygiene guidelines. The review aligns with a sociotechnical perspective, identifying the interplay between individual characteristics, tasks, technologies, and organizational elements as critical determinants of hand hygiene performance (Smiddy et al., 2015).

Expanding on these findings, understanding the specific cognitive and environmental factors influencing HCP behavior is essential for designing effective interventions. For example, incorporating behavioral nudges, such as automated reminders when entering a patient care zone, could enhance adherence by addressing forgetfulness or inattentiveness. Similarly, leveraging insights from ergonomics to optimize dispenser design and placement can ensure that hand hygiene practices integrate seamlessly into the clinical workflow.

Moreover, cultural and organizational factors should not be overlooked. Establishing a safety-oriented organizational culture that prioritizes infection prevention can significantly impact adherence rates. Leadership commitment to hand hygiene, combined with ongoing education and visible support for infection prevention initiatives, fosters an environment where adherence is normalized and expected.

Finally, technological advancements, such as real-time adherence monitoring systems, can provide valuable feedback to HCP while identifying areas for targeted improvement. These systems, coupled with regular data-driven evaluations, can create a cycle of continuous improvement in hand hygiene practices. Future research should explore the integration of these technological solutions with HFE principles to develop comprehensive, scalable strategies for improving adherence across diverse healthcare settings.

In summary, enhancing hand hygiene adherence requires a multifaceted approach that considers usability, workflow, cognitive factors, and organizational culture. By addressing these aspects through the lens of HFE, interventions can achieve greater effectiveness and sustainability. Further research is needed to deepen our understanding of these dynamics and refine strategies for promoting hand hygiene adherence in healthcare environments.

Use of Personal Protective Equipment (PPE)

Personal protective equipment (PPE) plays a critical role in safeguarding healthcare personnel (HCP) from potential exposure to infectious agents transmitted via contact, droplet, or airborne routes, as well as from contaminated body fluids. The significance of proper PPE usage is exemplified by outbreaks of severe viral infections, such as the Ebola virus and severe acute

Ali Abdulrahman Muzhir Al-Shehri ⁽¹⁾, Abdulaziz Abdulrahman Muzhir Al-Shehri ⁽²⁾, Eissa Ali Eissa Ali Alineze ⁽³⁾, Azzam Obaid Bin Mishal Alrakhimi ⁽⁴⁾, Shulaywih Faleh Alotaibi ⁽⁵⁾, Tahany Saud Alshammry ⁽⁶⁾, Abdulrahman Eid Ghedayan Alonazi ⁽⁷⁾, Nouf Shayeh Salama AlSharari ⁽⁸⁾, Abdullah Mohammed Alshehri ⁽⁹⁾, Khairiah Yahya M Bajawi ⁽¹⁰⁾, Hala Mefdhi Aljohani ⁽¹¹⁾, Ahmed Ayidh Salah Alharbi ⁽¹²⁾, Mousa Ahmed Alajam ⁽¹³⁾, Ebrahim Ahmed zacfe ⁽¹⁴⁾, Yousef Jazaa Safir Alotaibi ⁽¹⁵⁾, Ibrahim Ahmed Jabril Shuwayhi ⁽¹⁶⁾.

respiratory syndrome-associated coronavirus (SARS-CoV). The West African Ebola outbreak of 2014–2016, which resulted in over 28,000 cases and 11,000 deaths, underscores the necessity of appropriate PPE practices. Similarly, the early 2000s SARS-CoV outbreak demonstrated the risks to HCP, with numerous infections attributable to improper PPE removal practices.

The effective use of PPE involves a complex interplay between the equipment itself, the user, and the environment, which includes physical, social, and policy dimensions. There are three critical phases during which potential contamination can occur: donning, patient care, and doffing. During donning, risks include improper PPE storage, contamination from previous usage, and incorrect techniques. Patient care introduces hazards such as PPE damage, design inadequacies, or circumvention of PPE protocols due to distractions, such as using personal devices. The doffing phase poses significant risks through incorrect removal techniques, improper handling and disposal of PPE, or inadvertent damage to the equipment. The following sections review literature addressing PPE donning and doffing practices, as well as design-related efforts to enhance safety and usability.

PPE Donning and Doffing

Puro and Nicastrì identified substantial gaps in HCP knowledge regarding proper PPE removal during the SARS outbreak. They noted that existing guidelines often lacked sufficient detail or included contradictory recommendations, which heightened contamination risks. This highlights the critical need for clear, standardized protocols to mitigate errors during PPE use. A simulator study conducted by Beam, Gibbs, Boulter, Beckerdite, and Smith investigated PPE use for pathogens requiring airborne and contact precautions. Participants engaged in simulated care tasks, with contamination assessed using fluorescent markers. All participants committed at least one breach during the three phases of PPE use. Common donning errors included failing to perform a respirator seal check, improper gown tying, and incorrect donning sequences. Doffing errors involved deviations from the recommended sequence and improper removal of masks. Moreover, participants often carried potentially contaminated items out of the isolation area. During patient care, breaches frequently included touching unprotected body areas with contaminated PPE. The study concluded that improving HCP understanding of contamination pathways through simulation-based training could enhance adherence (Beam et al., 2011).

Similarly, Zellmer, Van Hoof, and Safdar conducted an observational study that revealed 57% of HCP removed PPE in an incorrect order, 53% failed to remove contaminated PPE before exiting the patient's room, and 40% disposed of PPE improperly (Zellmer et al., 2015). These findings align with those of Mitchell et al. who documented that 66% of HCP failed to don the recommended PPE and 56% removed PPE in the wrong sequence, emphasizing the prevalence of deviations from established protocols (Mitchell et al., 2013).

Mumma et al. employed a human factors risk analysis to evaluate doffing practices for Ebola-level PPE in a simulator study. Their findings linked errors in hand hygiene and powered air-purifying respirator removal to heightened risks of self-contamination. The authors underscored the dual role of PPE as both a protective and potentially hazardous tool, advocating for design improvements to minimize risks to HCP (Mumma et al., 2018).

Using an HFE framework, Krein et al. conducted a qualitative observational study of 325 isolation precaution rooms across various hospitals to examine PPE-related failures. Observers identified 283 self-contamination events, categorized as violations (e.g., entering rooms without required PPE), procedural mistakes (e.g., errors in doffing sequence), and slips (e.g., wiping one's face with a contaminated gown sleeve). The study concluded that a multifaceted approach is necessary to address the diverse causes of self-contamination (Krein et al., 2018). This conclusion aligns with earlier findings by Casanova, Alfano-Sobsey, Rutala, Weber, and Sobsey, who reported that even when protocols were reviewed before PPE removal, significant

mistakes persisted. Similarly, Kang et al. assessed contamination rates using fluorescent powder in simulations involving two PPE types—simple and full-body sets. They observed contamination in 92% of doffing attempts with simple PPE and 66% with full-body PPE. Even after training, 91% of participants experienced contamination during follow-up simulations. The authors attributed these failures to inherent challenges in doffing, though they did not fully explore the potential impact of improved PPE design (Kang et al., 2017).

Contrasting with these findings, Casalino et al. offered a more optimistic view on the impact of training. Their study compared conventional and reinforced training programs involving both theoretical instruction and hands-on practice sessions for basic and enhanced PPE. Reinforced training, which included real-time guidance during donning and doffing, resulted in better adherence and reduced contamination over three sessions. However, even with reinforced training, optimal performance was not achieved, indicating the need for continuous improvement in both training methods and PPE design (Casalino et al., 2015, p. 2).

To build on these findings, future research should explore the integration of advanced technologies into PPE design. For instance, incorporating feedback mechanisms such as visual or auditory cues during donning and doffing could guide HCP in real-time, reducing errors. Additionally, ergonomic improvements in PPE, such as intuitive fastening systems or tear-resistant materials, could address common issues related to improper handling and damage.

Furthermore, fostering a safety-oriented organizational culture is essential. Leadership support for PPE adherence, combined with regular training and the availability of clear, standardized protocols, can enhance compliance. Incorporating simulation-based training into routine practice may further reinforce proper techniques, allowing HCP to build muscle memory and confidence in PPE use.

In conclusion, improving PPE use among HCP requires a holistic approach that integrates better design, comprehensive training, and a supportive organizational culture. By addressing these factors, healthcare systems can reduce contamination risks and enhance the safety of both patients and HCP.

Training on the proper use of personal protective equipment (PPE) remains a significant challenge. Published guidelines frequently lack clarity or are insufficiently detailed, and the protocols often vary based on the specific PPE product in use, such as differences between gowns that are tied versus those donned over the head. Moreover, there is uncertainty surrounding the most effective and efficient training methods, including whether immediate feedback or proficiency demonstrations should be mandatory. Given the resource-intensive nature of effective training, which requires tracking completion and evaluating proficiency, it is not surprising that comprehensive training is not universally accessible. This aligns with perspectives that consider training a "weaker" intervention compared to others (Bagian et al., 2011).

John et al. (2016) conducted a survey to capture HCP perspectives on PPE training, identifying insufficient training and the absence of proficiency assessments as contributors to errors during glove and gown removal. The study revealed disparities among professionals, with 15% of physicians reporting no prior PPE training compared to only 1.4% of nurses. Additionally, annual training was reported by 12% of physicians and 47% of nurses, while on-the-job training was the most prevalent mode of instruction (47.3%). Many participants also underwent mandatory annual computerized infection prevention training; however, only 43% could recall participating in such sessions, highlighting the limited impact of these approaches (John et al., 2016).

An effective method of training involves delivering immediate performance feedback. Tomas et al. examined contamination rates during glove and gown removal using fluorescent markers, finding that contamination occurred in 46% of cases and was particularly high when proper techniques were not followed. Immediate feedback on contamination events during PPE

Ali Abdulrahman Muzhir Al-Shehri ⁽¹⁾, Abdulaziz Abdulrahman Muzhir Al-Shehri ⁽²⁾, Eissa Ali Eissa Ali Alineze ⁽³⁾, Azzam Obaid Bin Mishal Alrakhimi ⁽⁴⁾, Shulaywih Faleh Alotaibi ⁽⁵⁾, Tahany Saud Alshammry ⁽⁶⁾, Abdulrahman Eid Ghedayan Alonazi ⁽⁷⁾, Nouf Shayeh Salama AlSharari ⁽⁸⁾, Abdullah Mohammed Alshehri ⁽⁹⁾, Khairiah Yahya M Bajawi ⁽¹⁰⁾, Hala Mefdhi Aljohani ⁽¹¹⁾, Ahmed Ayidh Salah Alharbi ⁽¹²⁾, Mousa Ahmed Alajam ⁽¹³⁾, Ebrahim Ahmed zacfe ⁽¹⁴⁾, Yousef Jazaa Safir Alotaibi ⁽¹⁵⁾, Ibrahim Ahmed Jabril Shuwayhi ⁽¹⁶⁾.

doffing reduced skin and clothing contamination during subsequent attempts. Encouragingly, the authors observed that the intervention's effects were sustained during follow-ups conducted one and three months later (Tomas et al., 2015).

In response to the Ebola outbreak, the Centers for Disease Control and Prevention (CDC) funded the development of a web-based training program aimed at complementing and clarifying PPE guidelines (Gurses et al., 2018). This program applied human factors engineering (HFE) principles to reduce guideline ambiguity, redesign work systems, and enhance teamwork among HCP managing Ebola patients. However, the program's effectiveness remains to be rigorously evaluated.

PPE-Related Redesign Efforts

Research focused on redesigning PPE to improve usability is still in its early stages. Singleton and Johnson designed an HFE-based storage cart for PPE, evaluating compliance before and after its implementation. The cart incorporated standardized components, picture labels, and clear instructions for PPE use. The introduction of the cart significantly improved compliance, increasing adherence from a baseline of 47% to 81% (Singleton & Johnson, 2018).

DuBose et al. investigated the impact of the built environment on PPE adherence by observing 41 HCP performing donning and doffing procedures in four Ebola treatment centers and one high-fidelity mock-up. Their findings highlighted issues such as poor communication between observers and HCP, limited visibility of HCP, and environmental factors, including the size and layout of the doffing areas. For example, the absence of clear demarcation lines separating contaminated zones led to confusion among HCP, further complicating adherence to protocols (DuBose et al., 2018).

In addition to these challenges, other studies have underscored the role of sociotechnical factors in PPE adherence. For instance, the integration of real-time guidance tools, such as augmented reality (AR) systems or interactive checklists, could potentially bridge the gap between training and practice. These tools could provide HCP with step-by-step instructions during donning and doffing, reducing reliance on memory and minimizing errors.

Furthermore, ergonomic improvements in PPE design, such as the development of self-adjusting gowns or gloves with intuitive sizing, could address common usability challenges. Incorporating materials resistant to tearing and contamination could further enhance safety during use. Additionally, implementing standardized designs for PPE storage and disposal stations across healthcare facilities could simplify processes and reduce variability, promoting consistent adherence.

The organizational culture surrounding PPE use also requires significant attention. Leadership support and the establishment of safety-oriented environments are crucial for reinforcing the importance of PPE adherence. Regular audits, combined with feedback mechanisms, can help sustain adherence over time. Providing financial and logistical resources to support ongoing training programs and design improvements is equally vital.

In conclusion, while the challenges associated with PPE training and usage are well-documented, adopting a comprehensive sociotechnical systems perspective offers a pathway to integrate various strategies into a cohesive approach. By addressing the interplay between equipment design, user behavior, and environmental factors, healthcare systems can enhance adherence, ultimately improving both HCP safety and patient outcomes.

Reducing Central Line-Associated Bloodstream Infections (CLABSI)

Each year, over 400,000 intensive care unit (ICU) patients acquire healthcare-associated infections, with bloodstream infections accounting for the highest mortality rates (Zimlichman et al., 2013). In the past decade, substantial efforts have contributed to an 80% reduction in CLABSI rates within U.S. ICUs. This significant decline is partially attributed to the implementation of interventions such as those pioneered by the Michigan Keystone Project, a

collaborative involving 103 ICUs. These interventions targeted behavioral changes among healthcare professionals (HCP) and incorporated both technical and organizational strategies (Pronovost et al., 2016).

To address organizational barriers, participating hospitals initiated a comprehensive unit-based safety program (CUSP) designed to enhance the safety culture within units. This program focused on training staff to recognize hazards, improve safety culture, foster teamwork, and strengthen communication practices. A bundle of interventions specifically aimed at reducing CLABSI included educational components, providing central line carts stocked with necessary supplies, implementing checklists for safe line insertion practices, granting authority to staff to halt procedures when protocols were violated, and conducting daily reviews to assess the necessity of central lines. A similar implementation effort in Spain initially utilized checklists alone and failed to achieve a reduction in CLABSI; only when the full program was implemented were significant reductions observed (Palomar et al., 2013). These findings underscore the necessity of employing a sociotechnical systems approach to address complex healthcare challenges.

Line Maintenance and Adherence Engineering

Issues related to central line maintenance represent another critical factor contributing to CLABSI. The conceptual framework of adherence engineering provides a strategy for improving adherence to protocols, particularly in the context of complex tasks. This framework operates on the premise that task behavior is shaped in part by external factors and that these factors can be leveraged to enhance protocol adherence. Seven principles guide adherence engineering: (1) deliberately designing object affordance to promote specific actions, (2) embedding task-intrinsic guidance to provide users with directions during task performance, (3) utilizing nudging to optimize decision-making, (4) implementing smart defaults to predefine commonly used settings, (5) delivering real-time feedback, (6) reducing cognitive effort required for task completion, and (7) minimizing the physical effort necessary to perform tasks.

Using this framework, a central line maintenance kit was developed based on human factors engineering (HFE) principles (Drews et al., 2017). This kit incorporated design elements that adhered to the seven principles of adherence engineering, each aimed at promoting adherence to maintenance protocols and reducing errors. For example, the kit's design utilized affordances to simplify access to necessary tools and materials, included intrinsic guidance to ensure proper sequencing of maintenance steps, and incorporated feedback mechanisms to reinforce correct practices.

Clinical Outcomes of HFE-Based Kit Implementation

The effectiveness of the HFE-based central line maintenance kit was evaluated through a 29-month pre- and post-implementation observational study. Results demonstrated that the kit significantly improved adherence to maintenance protocols, leading to a marked reduction in CLABSI rates. These findings highlight the potential of applying HFE design principles to the development of medical kits as a means of enhancing clinical outcomes.

Beyond its immediate impact on CLABSI reduction, the adoption of adherence engineering principles offers a framework for addressing other protocol adherence challenges in healthcare. For instance, integrating visual cues and ergonomic designs into other medical procedures could similarly improve compliance and safety outcomes. Moreover, the introduction of the kit revealed organizational opportunities for reinforcing adherence, such as integrating the tool with training programs to standardize practices across varying levels of HCP experience.

Extending HFE Applications

The success of the central line maintenance kit underscores the broader implications of human factors engineering in healthcare. Expanding the application of HFE principles to other areas, such as surgical safety checklists or infection control measures, could yield comparable

Ali Abdulrahman Muzhir Al-Shehri ⁽¹⁾, Abdulaziz Abdulrahman Muzhir Al-Shehri ⁽²⁾, Eissa Ali Eissa Ali Alineze ⁽³⁾, Azzam Obaid Bin Mishal Alrakhimi ⁽⁴⁾, Shulaywih Faleh Alotaibi ⁽⁵⁾, Tahany Saud Alshammry ⁽⁶⁾, Abdulrahman Eid Ghedayan Alonazi ⁽⁷⁾, Nouf Shayeh Salama AlSharari ⁽⁸⁾, Abdullah Mohammed Alshehri ⁽⁹⁾, Khairiah Yahya M Bajawi ⁽¹⁰⁾, Hala Mefdhi Aljohani ⁽¹¹⁾, Ahmed Ayidh Salah Alharbi ⁽¹²⁾, Mousa Ahmed Alajam ⁽¹³⁾, Ebrahim Ahmed zacfe ⁽¹⁴⁾, Yousef Jazaa Safir Alotaibi ⁽¹⁵⁾, Ibrahim Ahmed Jabril Shuwayhi ⁽¹⁶⁾.

improvements in protocol adherence and patient safety. Future research should explore how digital technologies, such as augmented reality and machine learning algorithms, could further enhance adherence through real-time guidance and predictive analytics.

Additionally, a systems-level focus incorporating leadership support and policy alignment is critical. Institutional policies should prioritize regular updates to protocols based on HFE insights and ensure access to resources necessary for implementation. These efforts, combined with frontline engagement and feedback loops, can help sustain improvements over time and foster a culture of safety and continuous learning.

In conclusion, the integration of adherence engineering principles, supported by human factors engineering, provides a robust approach to improving protocol adherence and reducing CLABSI. As demonstrated by the success of the HFE-based central line maintenance kit, thoughtful design coupled with a sociotechnical perspective can effectively address complex challenges in healthcare delivery, ultimately improving patient outcomes and enhancing overall safety.

Conclusions

The application of human factors engineering (HFE) within the realm of infection prevention and control remains relatively limited. However, the sociotechnical systems perspective that underpins the HFE methodology offers considerable potential for enhancing healthcare provider (HCP) performance and ensuring patient safety. HFE frameworks exhibit extensive applicability in guiding future intervention strategies, emphasizing the capacity to address challenges at individual, group, and systemic levels.

This review indicates that HFE can significantly improve performance in several key areas. Potential contributions include: (1) the creation and application of conceptual frameworks for understanding human performance, (2) enhancing knowledge of HCP cognitive processes such as individual and collective mental models, (3) simplifying or redesigning workflows to improve efficiency and safety, (4) optimizing the design of medical equipment to align with user needs, (5) developing and refining standardized training programs and their associated requirements, (6) addressing ambiguities in communication and procedural guidelines, (7) implementing task-specific improvements in the built environment alongside standardization of equipment placement across and within healthcare facilities, and (8) fostering a robust organizational safety climate to support adherence and safety practices.

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