Compliance With Health Security Protocols Among Medical Staff In Intensive Care Units: A Comprehensive Analysis

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Abstract
Healthcare-associated infections (HAIs) are a very important concern within intensive care units (ICUs) due to vulnerable patient groups' susceptibility to infection. Compliance of healthcare workers (HCWs) with health security protocols, including infection control measures (ICMs), is essential for combating HAI dissemination and ensuring patient safety. In this comprehensive review, existing evidence on HCWs' compliance with health security protocols within ICUs is critically analyzed, assessing different intervention efficacy aimed at maximizing such compliance. A critical assessment of existing intervention studies indicates that multi-modal intervention strategies, focusing on education, feedback, simulation, and doables, portray greater effectiveness (23.6%) in optimizing compliance than education-focused strategies (16.13%) altogether. HAIs in ICUs are found to be prevalent from 9% to 51.4% across the world, and developing regions register three to five times more prevalence of HAIs than ICUs in developing settings. Important determinants of compliance include shortages of supplies, absence of uniform guidelines, inadequate training, shortages of knowledge regarding infection, and overload levels within ICUs. In this article, existing evidence from different settings within healthcare is synthesized, assessing effective measures for augmenting medical personnel compliance rates with respect to health security protocols. The analyses emphasize specific requirements for comprehensive, contextually modified intervention strategy addressing multiple determinants simultaneously. To reduce HAIs, healthcare settings must target multi-modal

intervention strategy complemented by institutional commitment, effective allocation, and monitoring processes within critical care settings.
Keywords: HAls, intensive care units, infection control practices, compliance, HCWs, multimodal strategies, patient safety, health security practices

1. INTRODUCTION

1.1 Introduction & Importance

Patient safety, apart from ensuring the safety of the patient, forms an important aspect in the delivery of healthcare services in every health setup (Castro-Sánchez & Holmes, 2015). The necessities for improving patient safety also involve improving patient satisfaction, decreasing costs associated with healthcare, and optimizing clinical outcomes (Castro-Sánchez & Holmes, 2015). Hospital Acquired Infections (HAIs) rank amongst the major risks that affect both safety and quality in relation to the safety of both the HCWs, patients, as well as visitors, especially in the ICU settings (Haile et al., 2017).

There is evidence to suggest that HAIs have significant effects on patient safety quality, leading to rising morbidity, longer durations of hospital stays, rising healthcare expenditures, and deaths among specific groups of patients (Al-Rawajfah et al., 2013; Al-Tawfiq and Tambyah, 2014; Richards et al., 2014). Further studies have found that the risks posed by HAI are expected to rise in the coming decades within healthcare settings and in the general population owing to a group of factors including, though not limited to, the growing number of older populations, rising demands for intensive healthcare, rising numbers of patients with drug-resistant organisms, and the growing number of patients with chronic diseases (Blot et al., 2022).

Healthcare-associated infections have emerged as one of the greatest challenges that hospital facilities worldwide confront today (Amiran & Awobusuyi, 2014). According to the World Health Organization, the WHO, approximately hundreds of millions of patients worldwide suffer from HAIs every year (World Health Organization, 2013). Amira and Awobusuyi, in their study, were able to establish discrepancies in HAI prevalence rates both nationally and internationally. In African countries, HAI prevalence ranges from 31% to 68%. The highest HAI prevalence for African countries was recorded in Tanzania at 52.9%, Southern Ethiopia at 30.9%, Egypt at 67.9%, and Nigeria at 68% (Amira & Awobusuyi, 2014). In developed countries, the prevalence/occurrence percentage for HAI risks at 4.0% and 11.6% whereas in developing countries, it is higher at 3.7% and 14.9% (Alshamrani et al., 2019).

ICU units have been recognized with a considerably greater risk of HAI compared with other healthcare units within hospitals (Alothman et al., 2020). HAIs are significantly prevalent in ICU-admitted patients (Alshehari et al., 2018), with an incidence rate of about 51.4% (Izadi et al., 2021). HAIs in European and United States ICU units have an incidence prevalence range of 9% to 37% (Izadi et al., 2021). Research shows that in developed nations, 30% of ICU-admitted patients are likely to develop at least one HAIs episode, whereas developing nations experience an incidence rate three to five times this number (Alshehari et al., 2018).

1.2 The Critical Role of Compliance with Health Security Protocols

As per a report by Khan et al., 2017, healthcare workers who do not follow infection control instructions are at a high risk of transmitting infectious diseases. Whether it is suspected or confirmed infectious patients, it has been shown in various studies that following infection control instructions in all healthcare facilities is one of the most effective ways to reduce the risk of HAI infection (Wong et al., 2021). Following infection

control instructions in healthcare facilities can be one effective way to safeguard both healthcare providers and patients from HAI infection risks (Mutters et al., 2014).

Infection-control practices are intended to contain "the risk of transmission of bloodborne and other pathogens from both recognized and unrecognized sources" (WHO, 2007). Infection-control practices have been identified as highly effective methods of preventing infection transmission risks (WHO, 2007). Adherence to the set policies will serve as a preventive measure for the transmission of infections from healthcare providers to patients (Okechukwu and Motshedisi, 2012). The study of the factors influencing adherence to infection-control practices in the ICU environment must be approached with much caution.

Healthcare professionals working in an ICU setting are often faced with challenges when attempting to adhere to infection control protocols (Akagbo et al., 2017). Several variables have been shown to affect a lower adherence rate within infection control guidelines, such as a lack of resources, a lack of standardized guidelines, insufficient training, a lack of understanding about infection risks, and a heavy workload (Brandao et al., 2022; Luo et al., 2010).

1.3 Research Gap and Study Objectives

Previous studies recommended further studies to be conducted in order to investigate factors linked to adherence in implementing infection control measures in an ICU environment (Vincent et al., 2009; Brandao et al., 2022). Despite the need to evaluate strategies in increasing adherence, a search through current literature indicates a gap in strategies in dealing with factors linked to HCW adherence.

Infections acquired in healthcare settings have become one of the biggest challenges faced in ICU settings and have greatly affected patient safety and quality care across the world. Several challenges are encountered by healthcare providers in following infection control procedures, and some of these factors include training and overcrowding of healthcare providers with work and resource issues. It has been evident in recent findings that the initiation of interventions to enhance the following of infection control procedures among healthcare providers is one of the biggest steps toward lowering the prevalence of healthcare-associated infections.

Although various studies have tried to assess the effectiveness of interventions regarding the above barriers, there is no evidence synthesis in relation to which interventions have shown the best effectiveness. Moreover, the role of context in the success of interventions has been inadequately examined. This systematic assessment synthesizes evidence regarding the effectiveness of interventions which have tried to increase the compliance of the staff of the healthcare system with infection prevention practices in the ICU.

The systematic review would offer valuable, evidence-driven insight for maximizing infection control strategies based on comparisons of multi-modal and educational approaches. By intersecting data from studies conducted around the world, it becomes possible for this study to recognize best practices, while revealing regions of future research interest, aimed at developing target-strategies for HAIs in intensive care units.

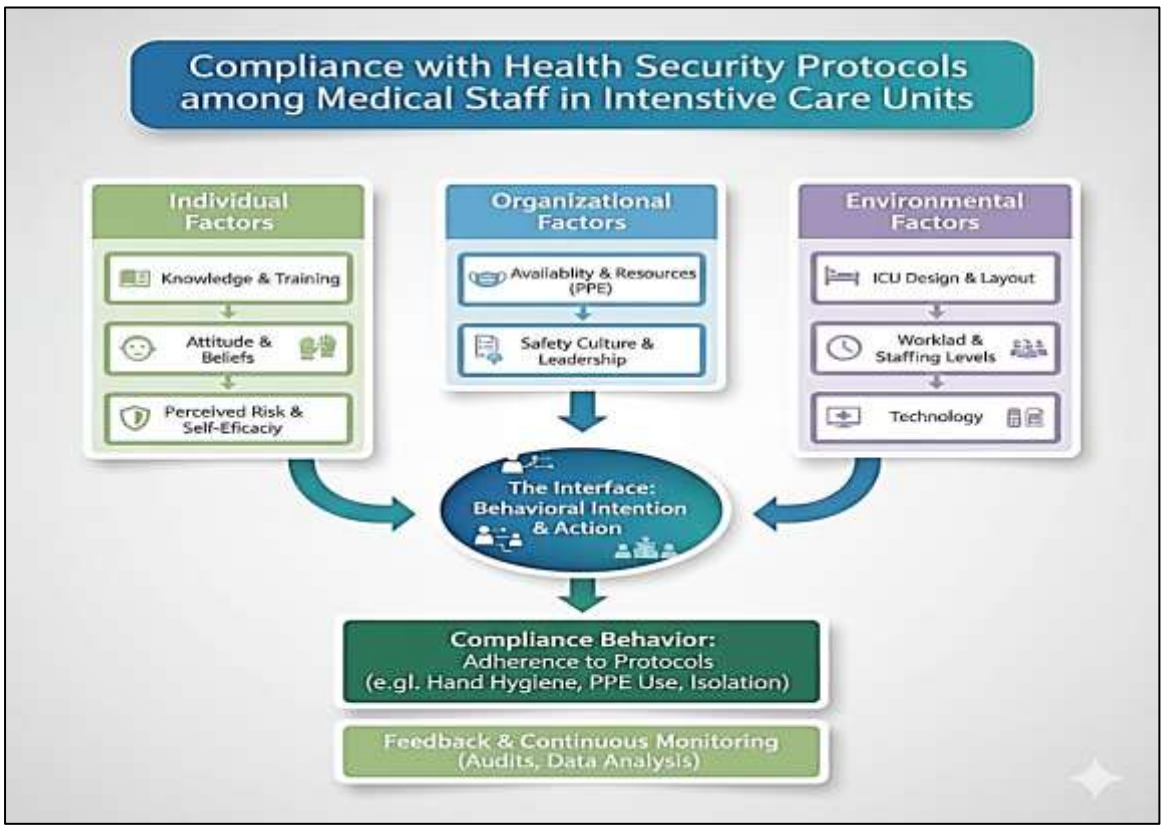

Figure 1 : Framework

2. LITERATURE REVIEW

2.1 Global Burden of Healthcare-Associated Infections in ICUs

The burden of the global health care-acquired infections in intensive care units is immense and a serious concern for public health, with significant clinical and financial consequences. International studies have shown large geographic differences in the prevalence rates of HAIs, reflecting the different states of health care infrastructures, infection control resources, and implementations of prevention measures.

In the developing nations, HAI rates are considerably higher than those occurring in developed nations. Some of the highest rates of prevalence in African health facilities range between 31% and 68%, according to Amira and Awobusuyi (2014). The nations which have particularly high rates include the following: Tanzania reports 52.9%; Southern Ethiopia, 30.9%; Egypt, 67.9%; and Nigeria at 68% (Amira and Awobusuyi, 2014). Overall, these heightened rates reflect a complex interrelation of factors touching on issues related to resource limitation, infrastructure challenges, and variation in levels of infection control program implementation.

The developed countries, though showing less overall HAI rates, still have their big infection control challenges. The risk for healthcare-associated infections in developed nations ranges from 4.0 to 11.6%, whereas in developing countries, it ranges from 3.7% to 14.9% (Alshamrani et al., 2019). These statistics mask the large variation within and between countries according to facility types, patient populations, and infection control program maturity.

Intensive care units are consistently posting the highest rates of HAIs across hospital systems. The particular nature of ICU populations, comprising severe underlying diseases, immunocompromised conditions, invasive device use, and extended hospitalization, forms a high risk toward infections. HAI prevalence is around 51.4% among patients admitted to the ICU (Izadi et al., 2021), more than those in any other departments of the hospital. In

the European and United States ICUs, the prevalence of HAIs is between 9% and 37% (Izadi et al., 2021), whereas developing country ICUs have three to five-fold higher rates (Alshehari et al., 2018).

The clinical outcomes of HAIs in the ICU are more far-reaching than the infection itself. Al-Rawajfah et al. (2013) observed that health care-associated, laboratory-confirmed bloodstream infections were associated with significant rises in both costs and hospital lengths of stay. The patients who develop HAIs have higher morbidity rates, requiring longer mechanical ventilation and longer stay in ICU, along with a general increase in the mortality rate (Al-Tawfiq and Tambyah, 2014). The financial burden includes direct costs due to additional treatments and longer hospitalization and indirect costs in the form of lost productivity and long-term disability.

2.2 Infection Control Measures: Definition and Importance

Infection control generally refers to systematically devised policies and practices aimed at preventing the transmission of pathogens within healthcare settings. According to the World Health Organization, these measures involve interventions designed to control "the risk of transmission of bloodborne and other pathogens from both recognized and unrecognized sources." They are classified among the most effective interventions for minimal infection transmission risks in a healthcare setting (WHO, 2007).

These include hand hygiene, use of PPE, safe injection practices, safe handling of contaminated equipment and surfaces, and respiratory hygiene/cough etiquette. Standard precautions apply to all patients at all times because infection status may not be known. Transmission-based precautions are used in conjunction with standard precautions for patients known or suspected to have an infection that requires additional control measures. Hand hygiene is the single most important infection control measure for preventing the transmission of HAI. Research by Richards et al. (2014) showed that increased hand hygiene performance decreases nosocomial infection markers and associated costs after the implementation of automated hand hygiene monitoring systems. However, despite universal recognition of the importance of hand hygiene, compliance rates are suboptimal in many healthcare settings, especially in high-stress, high-workload environments such as an ICU.

Personal protective equipment utilization is another critical component of infection control measures. Proper selection and use of PPE protect healthcare workers from exposure to infectious agents while preventing transmission between patients. However, the effectiveness of PPE depends fully on proper selection, donning, removal, and disposal procedures—areas where compliance usually falls short due to lack of time, insufficient training, or resource limitations.

Compliance with infection control measures ensures that HAI prevention is effective. Wong et al. (2021) identified that compliance with standard precautions among healthcare workers led to the effective control of infection rates amidst the COVID-19 pandemic. Non-compliance with infection control, however, presents avenues for pathogens to be transmitted and decreases both healthcare worker safety and patient outcomes (Okechukwu and Motshedisi, 2012).

2.3 Factors Affecting Compliance of the Health Worker

Health care worker compliance with infection control measures is a complex behavioral outcome affected by multiple individual, organizational, and environmental factors. Identification of these factors is central to the design of effective interventions aimed at improving adherence.

Knowledge and Education: Poor knowledge of the risks of infection and the measures needed to prevent them is almost uniformly associated with lower compliance (Luo et al., 2010). Specifically, there may be an incomplete understanding of transmission mechanisms;

the underlying rationale for a given infection control practice may not be understood; or technique execution may be improper. Educational deficiencies can result from poor initial training, failures in continuing education, or failure to refresh knowledge in light of revised guidelines.

Resource Availability: Inadequate availability of supplies has been revealed to be a major factor in the non-compliance of infection prevention practices by Brandao et al. in a study published in 2022. In the absence of supplies, the inability to maintain optimal levels of infection prevention practices becomes a reality in developing nations, as it is in facilities in developing countries.

Availability or Ease of Understanding of Guidelines: Lack of well-formulated, accessible, standardized guidelines affects the ability of healthcare personnel to effectively implement suitable infection-control measures (Luo et al., 2010). It is possible that healthcare facilities have guidelines, but due to issues like complexity or discrepancies between guideline sources, healthcare workers may find these guidelines confusing or hard to adhere to. Guidelines accessible to healthcare personnel must be simple, evidence-based, and written in an easily understandable manner specific to that healthcare environment.

Workload and Time Pressures: Excessive workloads are recognized to be among the most identified factors hindering the adherence to infection control practice (Brandao et al., 2022). The nature of ICUs, especially those dealing with severely acutely ill patients and working in a potentially emergency-prone environment, imposes tremendous pressures on healthcare staff working in such settings and may see adherence to infection control practice in terms of consuming more time and, therefore, being a hurdle to their adherence.

Organizational Culture and Support: The healthcare setting greatly affects the behaviors of healthcare worker compliance. When the healthcare setting has an excellent safety culture, visible leadership support for infection control, and an accountability process, the overall rates of patient safety compliance are high. However, when the healthcare setting does not value the issue of infection control, where non-compliance has no consequence, or when reporting affects the rates of overall patient safety compliance.

Training and Competency: Inadequate training becomes one of the main important challenges in the overall compliance with infection control (Luo et al., 2010). Medical staff need to have adequate knowledge and skills acquired by trainings and competency evaluations to accomplish good performance. One-time training activity will not work; rather, constant training and skills reinforcement are needed.

Individual Factors: Characteristics of the individual, such as risk perception, self-efficacy beliefs, professional identity, and past experience, also affect compliance behavior. Healthcare providers who feel that they are under a high level of personal risk from infection and those who identify more strongly with their profession as guardians of patients might have better compliance. But complacency and past negative experiences may undermine the motivation of those who want better adherence.

2.4 Previous Intervention Approaches

There are numerous intervention techniques that have been adopted worldwide to improve compliance of healthcare personnel with infection control practices in ICU units. The techniques vary from single-component education sessions to multifaceted techniques, targeting multiple components of compliance issues.

Educational Interventions: Conventional educational interventions have been the backbone of various improvement initiatives for infection control. Such interventions are generally made through lectures, written documents, or internet modules meant to improve knowledge in relation to risks, modes of transmission, and preventive practices. An educational and training intervention was carried out by Adly et al. (2014) for nurses working in pediatric ICUs, and remarkably, the compliance rate significantly increased

from 74.3% to 98.03% post-intervention. However, the success rate of educational initiatives alone has been remarkably variable across research settings.

Feedback Interventions: Feedback interventions have been used to inform healthcare practitioners about their performance, allowing them to assess and correct themselves. Feedback may be in terms of specific individual data, rates of compliance at a unit level, infection control outcomes, and benchmarking comparisons. Baccolini et al. (2019) used feedback as a component of a WHO multimodal intervention and helped increase rates of hand hygiene compliance from 41.9% to 62.1% in healthcare workers in a Medical/Surgical ICU in Italy. In effective feedback, it is essential to be specific, non-punitive, and time-sensitive so that healthcare workers canintrospect and change themselves.

Simulation-Based Training: Simulation modalities avail authentic learning chances, which allow healthcare professionals to build and enhance infection control skills in simulated, safe, and controlled environments. Tan et al. (2021) employed in-situ simulated scenarios to deliver infection control learning in the surgical ICU of the Singapore teaching hospital and observed significant improvements in compliance rates from 72.5% to 99.5% in comparison to the standard e-learning groups as control. Simulation-based learning is advantageous in many aspects, which include immediate, repetitive, and teamwork learning opportunities as well as the incorporation of infection control practices in simulated learning scenarios.

Link Nurse Programs

Link nurse programs empower particular nurses to be infection control champions who are specifically trained in infection control and function as change agents at a unit level. Ghorbanmovahhed et al. (2023) tested an infection control link nurse program along with WHO's multimodal strategies in Iran and found a slight increase in infection control scores from 13.37 to 14.03 among the intervention group with little change in infection control scores among the control group. Link nurse programs act as an interface between infection control professionals and healthcare professionals to enable them to access infection control advice and implement changes in practice.

Multimodal Interventions: Realizing the limitation of single-component interventions in overcoming compliance barriers, multimodal interventions include a set of strategies addressing different aspects of behavioral modification. The multimodal approach of the World Health Organization to improve compliance, extensively utilized worldwide, combines changes in the system, the level of education and training, evaluation and provision of feedback, workplace reminders, and the promotion of the safety climate of the institution (World Health Organization, 2007). Gomarverdi et al. (2019) introduced the educational and behavioral intervention, involving practical experience, in Iranian teaching hospital nurses, showing considerable score improvements from 19.87 to 28.4 in the intervention groups in comparison to the control groups.

3. METHODS

3.1 Study Design and Protocol Registration

This systematic review and meta-analysis was intended to provide an integration of the literature with regard to the approach that enhances the rates of healthcare worker compliance with infection control practices as used in intensive care units. The registration of the systematic review was done prospectively at the PROSPERO (International Prospective Register of Systematic Reviews) with the registration ID: CRD42023457984, by 2023.

3.2 Search Strategy

A thorough and systematic three-step search approach has been employed in several electronic databases to locate all available relevant published studies. The searches in the electronic databases took place in PubMed, Medline, CINAHL (Cumulative Index to Nursing and Allied Health Literature), Scopus, Web of Science, and Google Scholar to increase comprehensiveness in relation to medical/nursing and interdisciplinary sources.
The search strategy involved the use of carefully chosen keywords and Medical Subject Headings (MeSH) terms such as: "intervention," "compliance," "adherence," "healthcare workers," "medical staff," "nurses," "ICU," "intensive care unit," "infection control measures," "standard precautions," "healthcare-associated infections," and "hospital-acquired infections." The Boolean operators "OR" and "AND" were appropriately used to combine the searches.
Other techniques added to the completeness of the searches conducted. Reference lists of known studies that were relevant to the research were examined to identify additional citations that were not included in the search conducted in the databases. Citations tracking on important studies helped to identify other studies published after important research that cited it in their research. Grey literature searching helped in finding unpublished staudies that had relevant data.

3.3 Inclusion and Exclusion Criteria

Inclusion Criteria:

• Primary intervention studies (Randomized Controlled Trials, Quasi-experimental studies, Pre-post intervention studies)
• Focus is placed upon the healthcare professionals, hospital staff, and nurses specifically in the intensive care units
• Compliance/adherence interventions conducted in order to improve infection controls.
• Quantitative compliance data with enough information to do meta-analysis
• Published in English language
• Full-text available

Exclusion Criteria:

Observational studies where no interventions take place
• Studies performed outside of ICU settings
• Studies not reporting results on patient compliance
• Read reviews, editorials, commentaries, opinion pieces, etc
• Published studies that are not in English
• Absctract databases that lack
• Publishing the same information more than once

There were no restrictions applied with respect to the timing of publication, geographic setting, or healthcare professionals' demographics to enable the generation of the most comprehensive results of the evidence synthesis process possible.

3.4 Study Selection Procedure

After conducting the database searches, the cumulative results set was imported into a reference management tool called EndNote. Duplicates from the results were eliminated in order to narrow down the list to studies to screen for eligibility. Among the studies, a total of 103 needed to be screened, and the analysis was carried out using the guidelines of the PRISMA statement.
Both abstract/title screening and full-text screening were carried out by two independent reviewers, whose discrepancies were resolved by discussion or by considering the opinion of a third reviewer when necessary. PRISMA flow diagrams were used to report the screening of studies by indicating the reasons for exclusion of studies at various stages.

3.5 Quality Assessment

The quality of the studies included was systematically appraised using the National Institutes of Health (NIH) Quality Assessment Tools suited to the study design. The quality appraisal tools have been validated and provide a comprehensive evaluation of study quality in terms of study design appropriateness, participant selection, description of the intervention, description of the outcome measured, identifiable sources of bias, and adequacy of statistical analysis.

Two reviewers undertook an individual assessment of quality of each study using a standardized form. Studies received a quality classification of "good," "fair," and "poor," based on total scores derived from an overall quality assessment. The findings of quality assessment contributed to sensitivity analysis and examination of meta-analysis results. Overall quality assessment rated three studies as "good" and two studies as "fair," with little risk of bias in terms of evidence base.

3.6 Data Extraction

Standardized forms for extracting data have been developed and pilot-tested before widespread application. Two independent reviewers independently extracted the data from included trials in order to resolve disputes. Data included the following:

- Characteristics of studies: author, year of publication, country
- Population characteristics: sample size, healthcare worker types, demographic information
- Description of intervention: type, length, level, or theory
- Comparison conditions: characteristics of the control group, descriptions of normal care
- Outcomes: methods used for assessing compliance, time measurement, results
- Effect sizes – pre-post differences, between group differences, significance

3.7 Data Synthesis and Analysis

Descriptive synthesis organized the results by study characteristics, intervention types, and outcomes. Thematic analysis also revealed dominant intervention themes that include educational interventions, feedback devices, simulation training, link nurse schemes, and multi-modal interventions.

The quantitative meta-analysis was performed using Stata statistical software, version 17. The method used to compute the effect size was the percentage change from pre-intervention to post-intervention measurement on rates of compliance. Random-effects models were used to calculate the pooled estimates of the effect sizes, taking into account the inherent heterogeneity among the studies.

Heterogeneity between studies is examined using the I^2 statistic measure that shows the percentage of variability in the studies that can be attributed to heterogeneity instead of chance. Interpretations of I^2 values of 25%, 50%, and 75% are normally low, moderate, and high heterogeneity, respectively. A forest plot is used to explore the visual representation of study estimates in relation to their confidence intervals.

Subgroup analyses were undertaken to evaluate and compare levels of effect size in terms of intervention type, focusing on multimodal approaches in relation to approaches based on educational interventions alone.

4. RESULTS

4.1 Overview of Included Studies

The literature search result brought out five studies of high quality that fulfilled all the inclusion criteria and had sufficient information to allow meta-analysis. The geography of the studies covered Egypt, Italy, Iran, and Singapore. It remains clear across different

geography locations that the issue of compliance in infection control has implications in ICUs.

Study designs consisted of quasi-experimental studies (3 studies, n=3), a cluster randomized controlled trial (1 study, n=1), and a non-randomized experimental study (1 study, n=1). Sample sizes varied from 29 to 154 participants, of whom the majority were nurses in all studies included. The cumulative evidence base consisted of a total of 398 participants.

Table 1: Characteristics and Quality Ratings of Included Studies

Study	Country	Design	Quality Rating	Sample Size	Population	Setting
Adly et al., 2014	Egypt	Quasi-experimental	Fair	60	Nurses	Pediatric ICUs
Baccolini et al., 2019	Italy	Pre-post intervention	Fair	Not specified	Healthcare workers	Medical/Surgical ICU
Gomarverdi et al., 2019	Iran	Cluster RCT	Good	30 (15 experimental, 15 control)	Nurses	ICU in teaching hospitals
Tan et al., 2021	Singapore	Non-randomized experimental	Good	29 (16 experimental, 13 control)	Healthcare professionals	Surgical ICU
Ghorbanmovahhed et al., 2023	Iran	Quasi-experimental	Good	154 (77 intervention, 77 control)	Nurses	Medical-surgical wards and ICU

All included studies were generally considered to have low risk of bias, according to the NIH quality assessment tools, with three studies considered "good" quality and two studies considered "fair" quality. No studies were excluded for reasons of quality, adding to the strength of the evidence base.

4.2 Detailed Study Results

Table 2: Detailed Summary of Interventions, Comparisons, and Outcomes

Study	Intervention Type	Intervention Components	Comparison	Pre-Intervention Compliance (%)	Post-Intervention Compliance (%)	Absolute Change (%)
Adly et al., 2014	Educational and training	Workshops, didactic education, skill	Pre-post within-group	74.3%	98.03%	+23.73%

		demonstrations				
Baccolini et al., 2019	WHO Multimodal	Education, training, feedback, system changes	Pre-post within-group	41.9%	62.1%	+20.2%
Gomarverdi et al., 2019	Multicomponent educational and behavioral	Education, behavioral strategies, hands-on practice	Control group with no education	Intervention: 19.87 Control: 21.0	Intervention: 28.4 Control: 21.4	Intervention: +8.53 Control: +0.4
Tan et al., 2021	In-situ simulation	Simulation scenarios, team-based learning, debriefing	Standard e-learning	72.5%	99.5%	+27.0%
Ghorbanmovahhed et al., 2023	Link nurse + WHO multimodal	Link nurse program, education, feedback, system support	Control group with usual practice	Intervention: 13.37 Control: 12.72	Intervention: 14.03 Control: 12.59	Intervention: +0.66 Control: -0.13

Study-Specific Findings:

A quasi-experimental study was conducted by Adly et al. among 60 nurses working in pediatric ICUs from the El Mansoura University Children's Hospital, Egypt. Accordingly, the educational and training intervention developed statistically significant compliance increases: from 74.3% before intervention to 98.03% thereafter, corresponding to a 23.73 percentage point improvement. This study showed that broad-based educational programs can realize significant compliance gains even in resource-poor environments.

The research of Baccolini et al. (2019) applied the WHO multimodal intervention in a Medical/Surgical ICU at Umberto I Teaching Hospital of Sapienza University of Rome, Italy. As a result of this intervention, hand hygiene practices among health workers rose from 41.9% to 62.1%, which is a gain of 20.2 percentage points. The multimodal intervention integrated education and training of healthcare workers with feedback mechanisms and system-level changes to support improved practices.

Gomarverdi et al. (2019) performed a cluster randomized controlled trial at two teaching hospitals in Iran with a multicomponent educational and behavioral intervention for nurses. The intervention group showed significant score increases from 19.87 to 28.4 (a 8.53-point increase), while control scores remained quite stable from 21.0 to 21.4,

indicating the effectiveness of the intervention compared to no education. The addition of practical practice set this intervention apart from purely didactic educational programs.
Tan et al. (2021) conducted an experimental study design using a nonrandomized method in a surgical ICU at a teaching hospital in Singapore. In-situ simulated scenarios produced dramatic compliance improvements from 72.5% to 99.5% in infection control compared with standard e-learning conditions-an enormous, surprising 27.0 percentage point increase. The study demonstrated the superiority of experiential, simulation-based learning over traditional electronic learning for developing infection control competencies.
Ghorbanmovahhed et al. 2023 tested the impact of linking an infection control nurse program to WHO standard multimodal approaches at Sina Educational, Research and Treatment Center in Iran. This intervention achieved modest infection control score increases from 13.37 to 14.03 (0.66-point increase) for the intervention group, whereas the scores for the control groups slightly decreased from 12.72 to 12.59. Though smaller than those in other studies, improvements found in this study suggest that this link nurse model can lead to sustainable improvement in infection control at the unit level.

4.3 Meta-Analysis Results: Overall Effect

The meta-analysis using the random-effects model provided a pooled effect size estimate of about 15.54 percentage points with a 95% confidence interval ranging from 3.13 to 27.95. This large overall effect suggests that interventions designed to improve healthcare worker compliance with infection control measures produce meaningful improvements across diverse settings and populations.
However, the wide confidence interval reflects considerable variability across included studies, indicating that intervention effectiveness differs substantially based on the type of intervention, implementation context, or population characteristics. Given expected heterogeneity, the random-effects model was appropriate and provides a more conservative estimate of intervention effectiveness, generalizing the findings compared with fixed-effect approaches.

Table 3: Overall Results of Meta-analysis

Parameter	Value	95% Confidence Interval
Pooled Effect Size	15.54 percentage points	3.13 to 27.95
Heterogeneity (I^2)	78.36%	High heterogeneity
Tau-squared	Significant	Substantial between-study variance
Number of Studies	5	-
Total Participants	398	Across all studies

The individual study effects, along with their confidence intervals, are represented through the forest plot (Ref. Figure 1). The red diamond sign indicates the effect size for all studies, where the width of the diamond represents the confidence interval for 95% confidence. It can be seen that though all studies indicate positive effects, there is considerable variation in the extent of the effects, ranging from small (less than 5 percentage points) to very substantial (more than 25 percentage points).
A large value of I^2 (78.36%) indicated that this heterogeneity is large, suggesting that this true effect size is likely to be different across different contexts, populations, or interventions. There was enough heterogeneity within these studies to warrant performing subgroup analyses based on intervention type.

4.4 Subgroup Analysis: Multimodal vs. Educational

Comparisons of multimodal interventions with education-only interventions conducted between subgroups resulted in interesting differences regarding the size and consistency of

effects. The findings of these comparisons offer valuable insights for healthcare organizations interested in developing infection control improvement projects.

Table 4: Subgroup Analysis Results: Intervention Type Comparison

Intervention Type	Number of Studies	Pooled Effect Size (%)	95% CI	Heterogeneity (I^2)	Interpretation
Multimodal Interventions	3	23.6	Not reported	0%	Highly consistent, large effect
Educational Interventions	2	16.13	Wide interval	78.36%	Variable effect, high heterogeneity
Overall	5	15.54	3.13 to 27.95	78.36%	Substantial overall effect

Multimodal Interventions: The pooled effect size from three studies using multimodal approaches-combining education with feedback mechanisms, simulation training, or practical implementation components-was 23.6 percentage points. Notably, heterogeneity across the studies was zero percent ($I^2 = 0\%$), reflecting very consistent improvements in compliance across different settings in Italy, Iran, and Singapore. This would suggest that multimodal interventions consistently yield large increases in compliance independent of cultural background, baseline level of compliance, or other specific characteristics of the participating ICUs.

The lack of heterogeneity among multimodal intervention studies suggests that their constituent strategies simultaneously target multiple compliance barriers, generating effects which are robust across contextual variations. Education alone may target knowledge deficits, but education plus feedback adds performance information with which self-correction can be made. Simulation adds chances to develop skills in realistic contexts. System level changes then removes environmental barriers to compliance.

Education-based Interventions: Two studies with primarily educational interventions showed more variable results, with an average pooled effect size of 16.13 percentage points, with high heterogeneity ($I^2 = 78.36\%$). This variability suggests that educational intervention effectiveness depends heavily on specific program characteristics, implementation quality, baseline knowledge levels, or contextual factors not fully captured in available study descriptions.

The heterogeneity among educational interventions is quite large, suggesting that education per se may be a necessary but not sufficient condition to achieve consistent, large-magnitude compliance improvements. Certain educational programs are apt to be particularly effective when they are well-conceptualized, intensively delivered, and related to specific knowledge deficits. However, other programs may result in minimal effects if content is general, delivery is passive, or knowledge benefits do not translate into behavioral change because of environmental barriers.

Practical Implications: Overall, these subgroup findings provide strong support for a priority on designing infection control improvement programs with multimodal interventions rather than purely educational approaches. Although education-based interventions have an average positive effect, variability in their effectiveness and limitations in addressing compliance barriers unrelated to knowledge make them less

reliable as a standalone approach. Multimodal approaches may be more resource-intensive, but consistently superior results provide justification for the increased investment.

4.5 Heterogeneity Analysis

This is reflected in the significant overall heterogeneity found in the meta-analysis (I^2 = 78.36%) when all studies were analyzed together, meaning that approximately 78% of observed variation in effect sizes reflects true differences between the studies rather than random sampling error. Understanding sources of this heterogeneity will be crucial to appropriately interpret findings and guide further research.

Possible Sources of Heterogeneity:

Content and Delivery of Intervention: The educational interventions differed significantly in terms of content specificity, comprehensiveness, theoretical underpinning, and mode of delivery. In some programs, the content covered general infection control practices, whereas other programs aimed at changing very specific practices. In terms of delivery methods, there were knowledge transfer methods that range from didactic lectures to interactive workshops, e-learning modules, and even skills training. These variations likely affected knowledge acquisition, the development of new skills, and how well behavioral change was brought about.

Intervention Intensity and Duration: The study interventions also varied significantly in their intensity and duration; some were brief workshops, whereas others were multimodal, long-term interventions. Brief programs may result in temporary knowledge increase but are unlikely to lead to longer-term behavioral changes. Long-term programs provide ample opportunity for consolidation of skills, the development of habit, and cultural change but necessitate significant investment of resources.

Baseline Compliance Levels: These studies also varied in baseline compliance rates, ranging from a low of 13.37% to a high of 74.3%. Very low baseline levels of compliance provide greater room for facilities to improve and thus can artificially increase effect sizes. Facilities with moderate to high baseline compliance levels are subject to ceiling effects where less than optimal actual improvement may be measured even when effective interventions have taken place.

Healthcare Worker Characteristics: Participant demographics varied between studies on baseline knowledge, prior training, years of experience, and professional roles. Less-experienced healthcare workers, or those with limited prior infection control training, may benefit more from educational interventions than experienced staff who already possess significant knowledge bases.

Contextual and Cultural Factors: The international studies testing the intervention varied in terms of the different countries and health care systems involved, where each has its institutional policies, resource availability, cultural attitudes about infection control, and organizational support for practice change. Such contextual factors do influence the degree of fidelity in implementing an intervention and the effectiveness of the same but are quite hard to quantify and control in meta-analyses.

Outcome Measurement: All the studies measured compliance outcomes, but the methods varied, such as observation, self-report, and audits. Different measurement methods differ in sensitivity, specificity, and vulnerability to social desirability bias, which may lead to differences in reported compliance rates and effect sizes of interventions.

Heterogeneity in Future Studies: In future studies, heterogeneity can be managed by following standardized guidelines to describe interventions (e.g., TIDieR - Template for Intervention Description and Replication) and evaluating subgroup differences through analysis or meta-regression. This approach will help to more accurately characterize which components of an intervention and under which conditions they are optimally implemented.

5. DISCUSSION

5.1 Interpretation of Results

The study was a systematically conducted review and meta-analysis that combined the outcomes of five high-quality research studies that focused on interventions aimed at enhancing the rate of compliance of healthcare providers with infection-control practices in intensive care units. The results have a number of significant insights.

The total pooled effect size of 15.54 percentage points (95% CI: 3.13-27.95) indicates that the intervention of interest, targeting compliance in the healthcare worker population, has led to a considerable and important improvement. Such an improvement, if sustained, could result in important decreases in rates of hospital-acquired infection given the linkage described above.

However, the finding of largest clinical and practical importance concerned subgroup analysis highlighting the significant superiority of multimodal interventions over educational approaches. Multimodal interventions showed a remarkable pooled effect size of 23.6 percentage points with non-significant variation across the study results ($I^2 = 0\%$), whereas the effect size of educational interventions varied greatly (pooled effect size: 16.13 percentage points; $I^2 = 78.36\%$). The difference of 7.47 percentage points corresponds to a 46% relative improvement of the multimodal interventions over the educational approaches.

5.2 Comparison with Existing Literature

It agrees with the general health care quality improvement literature on the superiority of multimodal interventions for altering complicated health care provider behavior. In existing reviews that looked into interventions for improving hand hygiene practices, multimodal interventions, especially those that include the WHO multimodal strategy, were shown to be the most effective (Alshehari et al., 2018).

The observed heterogeneity on educational intervention studies supports existing findings, which state that the effectiveness of educational programs is greatly dependent on design, delivery, and implementation factors. Once-off educational sessions will have no permanent effect, but comprehensive programs with active and participatory elements will yield better results.

5.3 Practical Implications for Healthcare Facilities

These results enable administrative officials, infection preventionists, and quality managers to devise schemes that will improve compliance.

Emphasize Multimodal Methods: Healthcare settings should focus on implementing comprehensive multimodal strategies instead of merely relying on education. Though multimodal strategies entail higher costs in the beginning, their consistent superiority in efficacy, along with the eventual benefits derived from these strategies, make these expenses worthwhile. In fact, healthcare settings can also implement the WHO multimodal strategy or any other framework, depending upon their requirements.

Customize Educational Elements: When educational interventions are incorporated within multimodal elements, the data presented within these elements should not only be evidence-based but more specific in identifying areas of knowledge deficiency. Educational elements within these materials can then focus on these deficits and link these learnings within practice.

5.4 Considerations in Resource-Limited

The generalisability of multimodal approaches in the implementation of improved infection control practices depends upon the settings and economies of the region. Developing countries have unique challenges that might impede the implementation of these approaches.

Implementation Barriers in Resource-Constrained Environments: Financial limitations preclude investment in extensive training course work and programs, simulation technology and monitoring tools, and specialized staff to focus on infection control efforts. Limited infrastructure with unavailable or intermittent water, electricity, and ventilation capabilities impedes the implementation of fundamental infection prevention strategies despite the training and interest of healthcare workers. Limited training resources with insufficient staff to deliver infection prevention training and limited formal education opportunities are training-related limitations.

5.5 Study Limit

Some of the limitations to be acknowledged in relation to the interpretation of the findings include

Limited Sample Size: In the meta-analysis, there was limited study power due to the fact that only five studies were considered. Additionally, in the subgroup analysis, the studies considered in the analysis of multimodality and educational studies to assess the effect comprised just three and two studies, respectively.

Publication Bias: The reliance on peer-reviewed and publicly available literature means there could be a possible risk of publication bias, as studies resulting in null or negative outcomes may not be published as frequently. The overall effect size could be smaller in magnitude if there were unpublished studies showing the least effectiveness of the intervention, as this study suggests a possible association with those findings. There were not enough studies to evaluate publication bias.

5.6 Future Research Directions

From this systematic review, several key priorities emerge with regards to future studies in the area of infection control compliance:

Optimization of Multimodal Components: Examine optimal levels and interactions of multimodal component elements using factorial designs to evaluate the combination of various components. Explore which components add variably to the aggregate efficacy of the intervention or which combination of all components yields the best efficacy. Find the optimal "dose" of the intervention that is feasible in terms of resource expenditure.

Cost-Effectiveness Analysis: Perform the economic analysis to compare the costs of the multimodal approach with the value of prevented infections, decreased antibiotic use, shorter lengths of stay, and lives saved. Cost effectiveness analysis allows the rational allocation of resources to budgetary units and enhances the business case to improve infection control programs. Analysis should include both direct costs (resource utilization, personnel time) and indirect costs (healthcare personnel time).

Studies on Long Term Sustainability: It is very important to evaluate compliance sustainability over a longer term (from 1 to 5 years after intervention) because sustainability basically reveals whether an intervention has a long term effect or a short lived one. It will help in understanding variables responsible for sustainability and non-sustainability of an intervention, also strategies to sustain good outcomes such as through continuous education, feedback, and change in organizational culture.

Research in Implementation Science: Utilize implementation science models to analyze the role of barriers and facilitators in the implementation of interventions. Investigate the association between the readiness of the organization, involvement of leadership, resource utilization, and change management techniques in the implementation of interventions.

6. CONCLUSION

The findings of this systematic review and meta-analysis confirm strong evidence that interventions aiming to ensure the compliance of healthcare workers with infection-control

practices in intensive care units have led to significant improvements; furthermore, multimodal interventions have proven more successful than those that use education. The combined effect size of 15.54 percentage points derived from the individual studies included in the analysis clearly reveals that there are meaningful outcomes of efforts aiming to improve compliance.

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