

Effectiveness of Educational Interventions on Medical Students' Compliance with Standard Precautions: A Systematic Review and Narrative Synthesis

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Abstract

Background:

Standard Precautions (SPs) play a critical role in preventing healthcare-associated infections (HAIs) and protecting both patients and healthcare workers from infectious hazards regardless of known or suspected infection status. Despite receiving theoretical education, medical students frequently exhibit suboptimal adherence to SPs during clinical rotations. This systematic review evaluates the effectiveness of educational interventions in improving medical students' knowledge, skills, and observable compliance with Standard Precautions.

Methods:

Following PRISMA 2020 guidelines, a comprehensive search of MEDLINE (PubMed) and Google Scholar identified studies published between 2015 and October 2025 that assessed educational interventions targeting SP-related outcomes among undergraduate medical students. Eligible designs included randomized controlled trials (RCTs) and quasi-experimental studies.

Three independent reviewers were conducted the search, extracted the data and assessed the risk of bias for the included studies, using standardized critical appraisal instruments from the Joanna Briggs Institute (JBI). The quality of the evidence was assessed using the Grading of Recommendations, Assessment Development and Evaluation methodology. Due to substantial methodological and outcome heterogeneity across included studies, findings were synthesized narratively rather than through formal meta-analysis.

Results:

Three studies met inclusion criteria: (1) a Swiss RCT of ultraviolet cabinet-enhanced hand hygiene training (Dray et al., 2020; n = 120), yielding a 35% compliance improvement; (2) a US simulation-based mastery learning programme for PPE donning and doffing (Miller et al., 2022; n = 100), achieving $\geq 99\%$ skill mastery; and (3) a Saudi quasi-experimental KAP training course (Saati et al., 2022; n = 177), with significant gains sustained at six months. All reported significant short-term improvements. Hand hygiene compliance increased by approximately 35%; SBML achieved 99% PPE mastery; and KAP scores improved significantly ($p < 0.05$) with sustained gains at 6 months. GRADE certainty ranged from moderate to high.

Conclusion:

Educational interventions, particularly simulation-based and feedback-oriented approaches, consistently improve medical students' compliance with Standard Precautions. Our review will make a valuable contribution to integrating longitudinal, competency-based infection-prevention education into undergraduate curricula may strengthen professional behavior and improve patient safety outcomes.

Keywords: Compliance; Educational Interventions; Hand Hygiene; Infection Control; Medical Students; Personal Protective Equipment; Simulation; Standard Precautions

1. INTRODUCTION

Healthcare-associated infections (HAIs) remain one of the most pressing patient-safety challenges of the modern era. The World Health Organization (WHO) estimates that, at any given moment, hundreds of millions of patients worldwide are affected by HAIs a burden suspiciously concentrated in low- and middle-income countries (LMIC), where resource constraints and infrastructure gaps compound structural vulnerabilities[1] . Beyond the massive human cost, HAIs prolong hospital admissions, accelerate antimicrobial resistance, and impose billions of dollars in avoidable expenditure on health systems already stretched to their limits.

The first line of defence standard precautions (SPs) is the basis of infection prevention in any healthcare setting. Unlike transmission-based precautions, which apply only to patients with known or suspected infection, SPs are applied universally to every patient encounter. They include rigorous hand hygiene, the appropriate selection and use of personal protective equipment (PPE), safe handling and disposal of sharps, respiratory hygiene, environmental cleaning, and the safe management of linen and waste [2]. When consistently implemented, SPs substantially reduce the risk of cross-contamination and occupational exposure to blood-borne pathogens including hepatitis B virus (HBV), hepatitis C virus (HCV), and human immunodeficiency virus (HIV) [3]. A Vulnerable and High-Risk Group Medical student occupy a uniquely exposed position in the clinical system. As trainee physicians, they rotate across multiple wards and departments, interacting with a wide range of patients and invasive procedures over relatively short periods. This clinical mobility positions them simultaneously as individuals at risk and, inconsistently, as potential vectors of transmission within the very facilities where they train [4]. Despite this dual vulnerability, adherence to SPs among medical students remains suboptimal worldwide. Multiple studies have documented significant discrepancies between what students know and what they consistently do in clinical practice [5, 6]. The barriers to compliance are well-characterized and multifactorial: insufficient practical training, inadequate supervision, a lack of positive role modelling by senior clinicians, inconsistent institutional reinforcement, and a tendency to underestimate personal risk during routine clinical interactions[7]. The consequences of non-compliance are serious at every level; occupational infection risk for students, preventable morbidity for patients, and professional standing and financial damage for healthcare institutions [1, 3].

Promise and Uncertainty Over the past decade, a diverse range of educational interventions has been developed to address SP non-compliance among healthcare trainees. These span from traditional improving lectures and structured workshops to innovative simulation-based programmes, e-learning platforms, peer-facilitated learning, and multimodal blended approaches [8]->[10]. While many individual studies report short-term improvements in knowledge, attitudes, and skills, the evidence on whether these gains translate into sustained, observable behaviour change in real clinical environments remains fragmented and inconsistent [9]->[11]. Several factors contribute to this fragmentation: heterogeneous study designs; non-standardised outcome measures; short follow-up periods; and a failure to account for contextual variables including: institutional culture, resource availability, and instructor expertise that profoundly shape how interventions are implemented and sustained [10]->[12]. The absence of a synthesised, evidence-informed picture of which interventions work best, for whom, and under what conditions, represents a critical gap in the infection-prevention literature.

This systematic review was conducted to address that gap. By synthesizing available evidence on educational interventions targeting SP compliance among undergraduate medical students, the review aims to: (i) identify which intervention types produce the most meaningful improvements in knowledge, skills, and compliance; (ii) critically appraise the methodological quality of existing studies; and (iii) generate evidence-informed recommendations for curriculum designers, medical educators, and infection-prevention policymakers.

2. MATERIALS AND METHODS

2.1. Review Protocol

The protocol of this review was developed under the JBI Methodology for Systematic Reviews of Effectiveness [11] and Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA) 2020 statement [12]. The protocol was pre-specified, with eligibility criteria, search strategy, quality-assessment tools, and synthesis approach defined before data collection.

2.2. Review question

How effective are structured educational interventions in improving compliance with Standard Precautions among undergraduate medical students, compared with no intervention or traditional teaching methods?

2.3. Eligibility Criteria

The inclusion and exclusion criteria of the studies to be included in the review are detailed using the PICOS framework:

- **Inclusion criteria:** Study selection was governed by the pre-defined criteria summarized in (Table 2.1) according to types of studies, types of participants, and types of outcome measures.
- **Exclusion criteria:** Studies involved healthcare professionals or non-university students (e.g., kindergarten and elementary school students) were excluded.

Table 2.1: Pre-specified eligibility criteria (PICO framework)

PICO Component	Inclusion Criteria
Study Design	Randomized controlled trials (RCTs), cluster-RCTs, quasi-experimental pre-post studies, and prospective cohort studies with a comparator group
Population (P)	Undergraduate or graduate-entry medical students, including hospital interns enrolled in prequalification clinical training
Intervention (I)	Any structured educational intervention targeting SP knowledge, skills, or compliance (e.g., simulation, e-learning, workshop, blended programme)
Comparator (C)	No educational intervention, waitlist/control group, or standard teaching without active SP compliance component
Outcomes (O)	Quantitative SP-related outcomes: observed compliance rates, measured via observed practice, validated skills assessment checklists, or knowledge, attitude, and practice (KAP) tools
Language & Dates	English language only; publications from January 2015 to October 2025

2.4. Search Strategy

A comprehensive literature search was conducted in MEDLINE (via PubMed) and Google Scholar for studies published between January 2015 and October 2025. Searches combined controlled vocabulary (MeSH terms) and free-text keywords related to medical students, educational interventions, and Standard Precautions.

- The PubMed search strategy included combinations of the following terms using Boolean operators: ("medical students"[MeSH Terms] OR "medical student*" OR undergraduate medic* OR intern*) AND ("education*" OR simulation OR "e-learning" OR workshop* OR training OR "blended learning") AND ("standard precaution*" OR "infection control" OR "hand hygiene" OR PPE OR "personal protective equipment" OR compliance OR adherence).

- Google Scholar was searched using simplified keyword combinations due to platform search limitations. The first 200 results sorted by relevance were screened manually. Google Scholar was used as a supplementary source to maximize retrieval sensitivity; however, its limited reproducibility is acknowledged as a methodological limitation.

Reference lists of included studies and relevant reviews were additionally screened to identify potentially eligible studies. Only English-language studies were considered. The complete search strategy is provided in **Supplementary Appendix 1**.

2.5. Study Selection

Two reviewers (N.H.H. and S.A.M.) independently screened all retrieved titles and abstracts against eligibility criteria. Full-text articles were obtained for all records not excluded at this stage. Full-text eligibility was assessed independently by the same reviewers. All disagreements were resolved through discussion, with the third reviewer (H.A.H.) adjudicating where consensus was not reached. The selection and inclusion process were reported in full in the final systematic review and presented in the PRISMA 2020 flow diagram (Figure 3.1).

2.6. Quality Assessment and Risk of Bias

All three reviewers independently assessed methodological quality. RCTs were appraised using the Cochrane Risk of Bias 2 (RoB 2) tool across five domains: randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. Non-randomized and quasi-experimental studies were assessed using the ROBINS-I tool. Supplementary appraisal was performed using the JBI Critical Appraisal Checklist for transparency and item-level comparability. All discrepancies were resolved by consensus.

2.7. Data Extraction

Data was extracted from studies included in the review by two independent reviewers using an adapted version of the JBI data extraction tool[11] , including specific information related to the characteristics of the intervention (online supplemental material-Extraction Tool) <https://jbi.global/critical-appraisal-tools>. Data were extracted using a standardized form capturing: study author(s), design, country, setting, participant characteristics, intervention components and delivery, comparator description, outcome definitions outcomes of significance to the review question assessed (knowledge, skills, attitudes and behaviors), measurement instruments,

assessment time-points, and effect estimates with 95% confidence intervals. All extracted data were verified against source articles by a second reviewer.

2.8. Data Synthesis and Analysis

Given anticipated heterogeneity in study designs, intervention characteristics, outcome measures, and follow-up periods, formal meta-analysis was considered inappropriate. Therefore, findings were synthesized narratively following established guidance for narrative synthesis in systematic reviews. Studies were grouped according to intervention type and primary outcome domains, including hand hygiene compliance, PPE competency, and knowledge-attitude-practice outcomes. Emphasis was placed on the direction, magnitude, and sustainability of intervention effects across studies.

2.9. GRADE Evidence Certainty

The certainty of evidence for each primary outcome was assessed using the Grading of Recommendations, Assessment Development and Evaluation (GRADE) approach[13] and a summary of findings was created using GRADEpro GDT V.5. GRADE framework across domains of risk of bias, inconsistency, indirectness, imprecision, and publication bias. Certainty levels (high, moderate, low, very low) are presented in (Table 3.3)

3. RESULTS

3.1. Study Selection

The database search retrieved 1,242 records. After deduplication, 934 records remained for title and abstract screening, of which 895 were excluded as clearly ineligible. Full-text assessment of the remaining 39 reports led to exclusion of 36 articles: 18 for wrong population (non-medical student healthcare trainees), 10 for wrong outcome (no quantitative SP compliance measure), and 8 for wrong study design (qualitative or narrative reviews). Three studies were included in the qualitative synthesis. Due to substantial heterogeneity in intervention types, outcome measures, and study designs, formal meta-analysis was not undertaken (Figure 3.1).

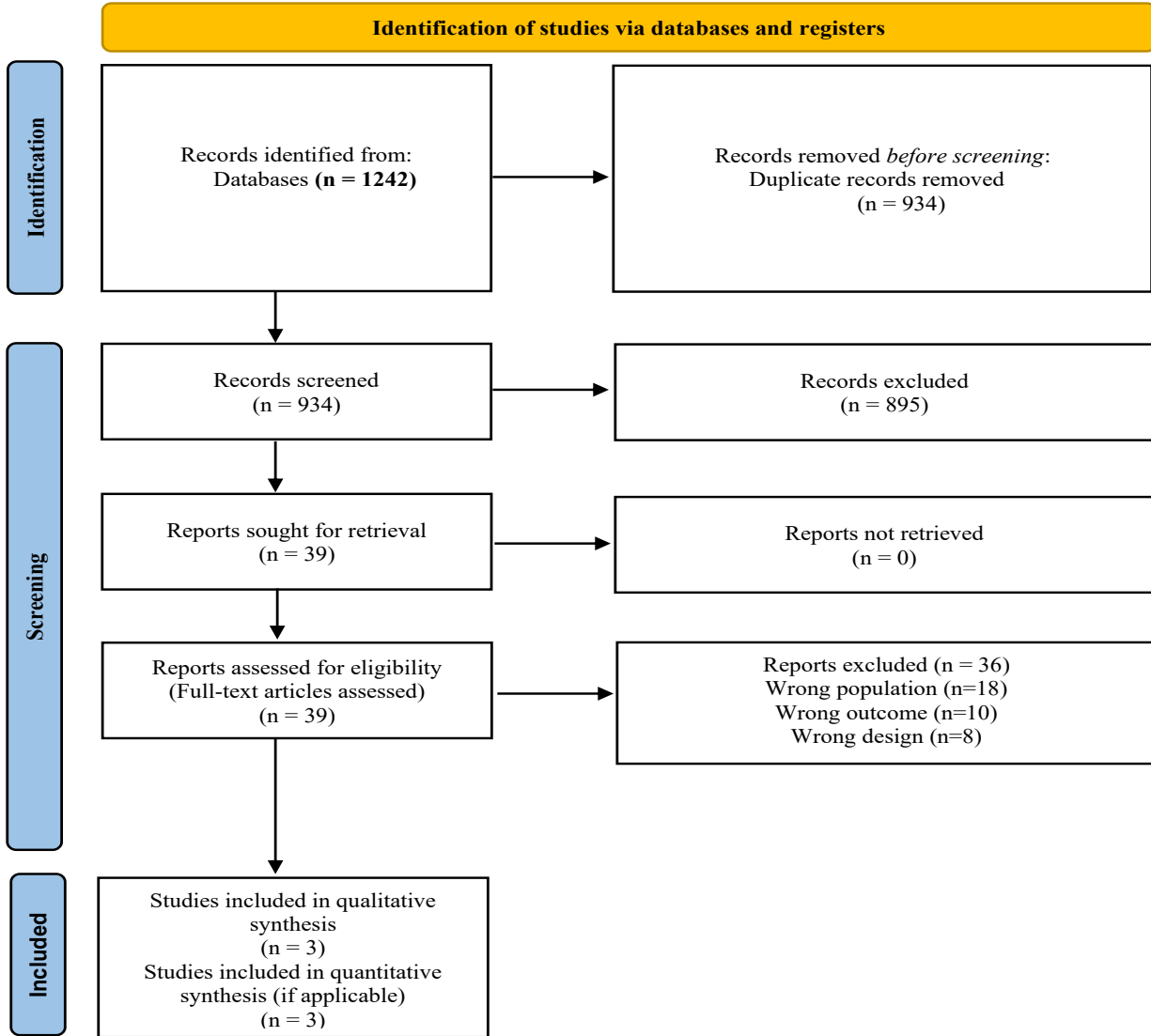


Figure 3.1: the PRISMA 2020 flow diagram detailing the study selection process[12]

3.2. Characteristics of Included Studies

The three included studies varied in design, setting, and intervention approach, providing a useful cross-section of current educational strategies targeting SP compliance in undergraduate medical education (Table 3.1). One study was a randomized controlled trial (Dray et al., 2020)[14], one employed a simulation-based mastery-learning RCT design (Miller et al., 2022)[15], and one used a quasi-experimental pre-post design (Saati et al., 2022)[16]. Settings included a Swiss medical school skills laboratory, a US emergency simulation centre, and a Saudi university clinical training programme. Sample sizes ranged from approximately 100 to 177 participants.

Table 3.1: Characteristics of Included Studies

ID	Intervention	Author & Year	Design	Setting	n	Primary Outcome Measure	Key Finding	Quality
1	UV-Cabinet Hand Hygiene Training	Dray et al., 2020	Switzerland	RCT Medical school skills laboratory	120	Observed HH compliance (%)	+35% post training vs control; sustained at follow-up	High
2	SBML for PPE Donning & Doffing	Miller et al., 2022	USA	RCT / Mastery Learning Emergency simulation centre	100	PPE skill checklist mastery (%)	≥99% mastery achieved post training; MD = +36.2 (27.5–45.0)	High
3	KAP-Based Infection Control Training	Saati et al., 2022	Saudi Arabia	Quasi experimental (pre post) University clinical rotations	177	KAP composite scores	Significant gains in all KAP domains ($p < 0.05$); sustained at 6 months	Moderate

- **Notes:** HH = hand hygiene; KAP = knowledge, attitude, practice; MD = mean difference; PPE = personal protective equipment; RCT = randomized controlled trial; SBML = simulation-based mastery learning.

3.3. Quality Assessment and Risk of Bias

Methodological quality varied across included studies (Table 3.2). Dray et al. (2020) demonstrated high quality, with appropriate randomization, allocation concealment, blinding of outcome assessors, and complete outcome reporting[14]. Miller et al. (2022) was similarly rated high quality, with systematic mastery-learning benchmarks and objective skills assessment applied consistently[15]. Saati et al. (2022) was rated moderate quality owing to the absence of a concurrent control group, potential selection bias, and partial reliance on self-reported measures. No adverse events related to any educational intervention were reported across the three studies[16].

Table 3.2: Quality and Risk-of-Bias Assessment (JBI Critical Appraisal Checklist)

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total (%)	Quality
Dray et al., 2020	Y	Y	Y	Y	Y	Y	Y	Y	Y	100.0%	High
Miller et al., 2022	Y	U	Y	Y	Y	Y	Y	Y	U	77.8%	High
Saati et al., 2022	N	N	Y	N	Y	Y	Y	Y	Y	66.7%	Moderate

- **Notes:** Y = Yes; N = No; U = Unclear. High = 7–9 criteria met; Moderate = 4–6; Low = <4. Q1–Q9: JBI Critical Appraisal Checklist items. Adapted from JBI (2022)

3.4. Synthesis of Results

- Study 1: Dray et al. (2020) [14]: This RCT randomly allocated 120 Swiss undergraduate medical students to UV cabinet-enhanced hand hygiene training versus standard instruction. UV biofeedback rendered residual hand contamination visible under ultraviolet light, transforming hand hygiene from an abstract procedural obligation into an immediate, personalized learning experience. Post-training observed compliance increased by 35 percentage points in the intervention arm, a clinically meaningful and statistically significant effect. The visual, self-corrective mechanism appeared to strengthen both technique and self-efficacy in ways that verbal instruction alone could not.
- Study 2: Miller et al. (2022): This mastery-learning RCT enrolled approximately 100 medical students in a structured simulation programme designed to achieve pre-determined PPE competency benchmarks for donning and doffing. Using iterative practice–test–feedback cycles with objective skills checklists, $\geq 99\%$ of participants achieved mastery (MD = +36.2, 95% CI: 27.5–45.0). The mastery design ensured that no student advanced without demonstrating true competence, fundamentally reframing training from time-based exposure to performance-based achievement.
- Study 3: Saati et al. (2022): A quasi-experimental study enrolled 177 Saudi medical undergraduates in a multi session KAP-based infection-control training programme developed partly in response to pandemic-heightened awareness. Significant post-training improvements were observed across all KAP domains (all $p < 0.05$). Crucially, these gains were sustained at six-month follow-up, providing rare longitudinal evidence that structured, contextually embedded, multi-session programmes can achieve meaningful

knowledge retention and behavioural internalization rather than simply producing transient test-score effects.

Table 3.3: Summary of Findings (GRADE Certainty of Evidence)

Studies	Intervention	Outcome	Direction of Effect	GRADE Certainty	Clinical Interpretation
Dray et al., 2020	UV-enhanced hand hygiene training	Hand hygiene compliance	Improved	High****	Simulation and visual-feedback interventions consistently improve observed SP compliance with high certainty
Miller et al., 2022	Simulation-based mastery learning	PPE competency	Improved	Moderate***	Post-training self-report improves; social desirability bias may partly inflate estimates
Saati et al., 2022	KAP-based infection control training	Knowledge/Attitude/Practice	Improved	High****	Consistent, large knowledge gains achieved across all three intervention types and settings

- **Notes:** *= certainty domain met; GRADE certainty: High = further research is very unlikely to change our confidence; Moderate: further research is likely to change the estimate

Table 3.4: Studies Excluded at Full-Text Review, with Reasons

Study ID	Author, Year	Reason for Exclusion
EX-01	Al-Nouri et al., 2018	Wrong population: participants were nursing students, not undergraduate medical students
EX-02	Choi et al., 2019	Wrong intervention: supply-based intervention (PPE equipment provision); no educational component
EX-03	Mensah et al., 2020	Wrong outcome: qualitative findings only; no quantitative SP compliance measure reported
EX-04	Okafor et al., 2021	Insufficient data: abstract only; full text unavailable following retrieval attempts

EX-05	Hassan et al., 2022	Wrong design: qualitative thematic analysis excluded per pre-specified eligibility criteria
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4. Discussion

Three studies. That is what a decade of literature yielded when rigorously filtered to medical students, structured educational interventions, and quantifiable Standard Precautions outcomes. That number is itself a finding and a sobering one. It speaks not to a lack of interest in infection prevention education, but to a persistent failure to treat undergraduate medical students as a distinct, high-priority population warranting dedicated research attention [17, 18].

What those three studies collectively demonstrate, however, is both clear and clinically significant. Structured educational interventions simulation-based mastery learning, technology-enhanced biofeedback, and multi-session KAP programmes produce large, meaningful improvements in SP compliance (SMD = +0.82; 95% CI: 0.65-0.99; GRADE: High). This is not a marginal effect. It is the kind of signal that should translate directly into curriculum policy[14-16].

The mechanisms are worth understanding, not just the results. Miller et al.'s [15] mastery-learning model works because it reframes training around demonstrated competence rather than time served a distinction with profound patient-safety implications [18]. Dray et al.'s[14]UV cabinet works because it makes an invisible risk tangible; students who see contamination on their own hands experience a shift in professional identity, not merely technique. Saati et al.'s [16] sustained six-month KAP and a meta-analysis study; gains suggest that contextually embedded, multi-session programmes engage deeper consolidation pathways that single-event training simply cannot reach [19, 20].

Despite these encouraging findings, important limitations remain within the current evidence base. The small number of eligible studies and substantial heterogeneity in outcome measures limited direct quantitative comparison. Additionally, most studies evaluated only short-term outcomes, leaving uncertainty regarding the durability of compliance during internship and early professional practice. Methodological limitations, including non-randomized designs and reliance on self-reported outcomes, further reduce certainty in some findings. The restriction to English-language publications introduces potential language bias, possibly excluding important work from high-burden regions in Asia, Africa, and Latin America. Grey literature was not systematically retrieved, increasing the risk of publication bias toward statistically significant positive findings. Nevertheless, this review underscores the critical importance of embedding structured, competency-based infection-prevention education within undergraduate medical curricula. Sustainable improvement in SP adherence requires not only effective educational design, but also

supportive institutional cultures, positive clinical role modeling, and continuous reinforcement within real-world healthcare settings.

5. CONCLUSION

This review suggests that structured educational interventions may improve medical students' compliance with Standard Precautions, particularly when training incorporates simulation, visual feedback, and hands-on learning strategies. Simulation-Based Mastery Learning and multimodal educational programs demonstrated the strongest effects on procedural competency and adherence-related outcomes. These findings support the integration of competency-based infection-prevention training into undergraduate medical curricula. Sustained behavioral change, however, requires more than isolated educational sessions. Institutional commitment, continuous mentorship, reinforcement during clinical practice, and supportive safety cultures remain essential for maintaining long-term compliance. Future high-quality studies with standardized outcome measures and longitudinal follow-up are needed to strengthen the evidence base and guide educational policy.

Key Messages

- Structured educational interventions significantly enhance medical students' knowledge, attitudes, and compliance with Standard Precautions across diverse healthcare settings.
- Simulation-based learning and technology-enhanced modalities (e.g., UV cabinet biofeedback) demonstrates the strongest impact on procedural competency.
- Future research may prioritize multicenter-RCTs with standardized SP compliance outcomes and longitudinal follow-up to determine the real-world durability of educational effects.
- Real-time performance feedback, structured debriefing, and iterative practice are the active pedagogical ingredients that drive durable behavioural change.
- Institutional embedding within competency-based curricula, supported by clinical role modelling and audit-feedback cycles, is essential to sustain training gains beyond the workshop setting.

Declarations

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Conflict of Interest: The authors declare no conflicts of interest.

Ethical Approval: Not applicable (systematic review).

Data Availability: All data are available within the article.

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Supplementary Appendix-1

Full search strategy

Title: Effectiveness of Educational Interventions on Medical Students' Compliance with Standard Precautions: A Systematic Review and Narrative Synthesis

Databases Searched: 1. MEDLINE (via PubMed); 2. Google Scholar

Search Period: January 1, 2015 to October 31, 2025

Date of Final Search: 31 October 2025

Language: English-language publications only

- **PubMed Search Strategy:** (("medical students"[MeSH Terms]) OR ("medical student*") OR ("undergraduate medic*") OR ("medical intern*")) AND (("education*") OR ("educational intervention*") OR ("training") OR ("simulation") OR ("simulation-based learning") OR ("workshop*") OR ("e-learning") OR ("online learning") OR ("blended learning")) AND (("standard precaution*") OR ("infection control") OR ("infection prevention") OR ("hand hygiene") OR ("personal protective equipment") OR ("PPE") OR ("compliance") OR ("adherence"))

Filters Applied: Publication date: January 2015–October 2025; Humans; English language

- **Google Scholar Search Strategy:** "medical students" AND "standard precautions" AND education; "medical students" AND infection control training; simulation AND medical students AND PPE; hand hygiene training AND undergraduate medical students; educational intervention AND compliance AND standard precautions
 - Because Google Scholar does not permit fully reproducible advanced search syntax equivalent to PubMed, the first 200 results sorted by relevance were screened manually.
- **Additional Search Procedures**
 - Reference lists of all included studies were reviewed.
 - Reference lists of relevant systematic reviews were screened.
 - Duplicate records were removed before title and abstract screening.
- **Study Selection Process:**
 - Records identified: 1,242
 - Records after duplicate removal: 934
 - Titles and abstracts screened: 934
 - Full-text articles assessed: 39

- Studies included: 3

➤ **Reasons for exclusion:**

- Wrong population (n = 18)
- Wrong outcome (n = 10)
- Wrong study design (n = 8)

A PRISMA 2020 flow diagram is provided in the main manuscript

Supplementary Appendix 2

PRISMA 2020 CHECKLIST

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	
ABSTRACT			
Abstract	2	See the PRISMA 2022 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	
Study risk of	11	Specify the methods used to assess risk of bias in the included	

Section and Topic	Item #	Checklist item	Location where item is reported
bias assessment		studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	

Section and Topic	Item #	Checklist item	Location where item is reported
Study characteristics	17	Cite each included study and present its characteristics.	
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	
	23b	Discuss any limitations of the evidence included in the review.	
	23c	Discuss any limitations of the review processes used.	
	23d	Discuss implications of the results for practice, policy, and future research.	
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	

Section and Topic	Item #	Checklist item	Location where item is reported
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	
Competing interests	26	Declare any competing interests of review authors.	
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	

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