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Human factors and ergonomics strategies in cardiopulmonary resuscitation: A systematic review of rescuer fatigue and CPR quality outcomes

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Abstract

Background: High-quality cardiopulmonary resuscitation (CPR) is physically and cognitively demanding, while rescuer fatigue can reduce chest-compression performance. Human Factors and Ergonomics (HFE) provides a systems-based approach integrating posture, workload, teamwork, technology, and the clinical environment.
Purpose: To synthesize primary evidence regarding the effects of HFE-informed CPR education and performance strategies on rescuer fatigue and CPR quality.
Method: This systematic review followed the PRISMA 2020 guidelines. PubMed, ScienceDirect, SpringerLink, and Google Scholar were searched for peer-reviewed primary studies published between January 2020 and December 2025. Eligible studies examined at least one HFE component and reported fatigue, CPR-quality, or team-performance outcomes. Twenty primary studies were included, critically appraised using design-appropriate Joanna Briggs Institute tools, and narratively synthesized because of methodological heterogeneity.
Results: Real-time feedback, ergonomically appropriate positioning, workload management, planned compressor rotation, effective leadership, and team-based simulation generally improved compression depth, compression rate, chest-compression fraction, and team coordination. Conversely, prolonged chest compressions, suboptimal posture, forward leaning, personal protective equipment, and demanding patient positions increased rescuer fatigue. Nevertheless, evidence directly evaluating a comprehensive HFE-based CPR training program specifically for nurses remained limited.
Conclusion: HFE-informed strategies can improve immediate CPR performance, strengthen team coordination, and support fatigue management. However, a standardized nurse-focused HFE training program should be evaluated through robust multicenter clinical studies assessing fatigue, CPR quality, skill retention, musculoskeletal effects, and patient-centered outcomes.

Keywords: Cardiopulmonary Resuscitation; Ergonomics; Fatigue; Human Factors; Nurses; Simulation Training.

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INTRODUCTION

Cardiac arrest requires immediate recognition and high-quality CPR. Contemporary resuscitation guidance emphasizes a compression rate of 100–120 min−1, adequate adult compression depth, complete chest recoil, and minimal interruptions because these elements support coronary and cerebral perfusion (Merchant et al., 2020; Olasveengen et al., 2021; Panchal, 2020). Nurses frequently initiate and sustain resuscitation in emergency departments, intensive care units, high-dependency units, and inpatient wards. Their performance therefore has direct relevance to patient safety.

Manual chest compressions impose repeated loading on the shoulders, arms, trunk, and lower limbs. Physiological demand and perceived exertion rise as compression continues, while personal protective equipment, constrained space, patient position, bed height, and suboptimal body mechanics may further increase workload. Tian et al., (2021) demonstrated that N95-mask use increased rescuer fatigue and reduced simulated compression quality, whereas Bae et al., (2021) found that real-time heart rate tracked perceived fatigue. These findings indicate that fatigue is not merely discomfort; it is a performance and system-design problem.

HFE examines interactions among people, tasks, tools, environments, and organizations. Applied to CPR, it encompasses compressor posture and anthropometry, bed and patient position, allocation and switching of roles, feedback technology, cognitive workload, leadership, closed-loop communication, and debriefing. Resuscitation education guidance supports feedback, deliberate practice, team training, and contextualized learning to improve technical and non-technical performance Cheng et al., (2020). Existing evidence, however, is dispersed across simulation, training, quality-improvement, and observational studies. Many reports evaluate only one HFE element and include mixed healthcare populations rather than nurses alone.

This review therefore aimed to synthesize primary studies published in 2020–2025 that evaluated HFE-informed CPR training or performance strategies and reported rescuer fatigue, CPR quality, or resuscitation-team performance. The review question was: among nurses, nursing students, or other healthcare providers performing CPR, how do HFE-informed educational or performance strategies, compared with conventional training or alternative conditions, affect fatigue and CPR quality?

RESEARCH METHOD

Design and reporting

A systematic literature review with narrative synthesis was undertaken and reported in accordance with PRISMA 2020. No meta-analysis was planned because the interventions, participants, simulation durations, measurement devices, and outcome definitions were heterogeneous. A prospective protocol registration was not available; this is acknowledged as a limitation.

Eligibility criteria

Eligibility criteria were established using the Population, Intervention, Comparator, Outcomes, and Study Design (PICOS) framework. Studies were eligible for inclusion if they involved nurses, nursing students, or other healthcare providers performing cardiopulmonary resuscitation (CPR) in training, simulation, or clinical settings. Eligible studies investigated at least one Human Factors Engineering (HFE) component, including physical ergonomics, posture, anthropometry, workload or fatigue management, feedback technology, team simulation, leadership, communication, role allocation, or environmental adaptation. Comparators, where applicable, included conventional training, absence of feedback, alternative postures or equipment, pre-intervention performance, or other HFE conditions. Studies were required to report at least one relevant outcome, including objective or subjective fatigue measures, chest-compression quality, chest-compression fraction, technical performance, or validated teamwork or leadership outcomes. Eligible study designs comprised peer-reviewed primary quantitative, mixed-methods, simulation-based, interventional, observational, and quality-improvement studies published in English or Indonesian between January 2020 and December 2025. Studies were excluded if they were reviews, meta-analyses, editorials, study protocols, conference abstracts, theses, non-peer-reviewed reports, studies focusing exclusively on mechanical chest-compression devices, studies that did not

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assess human-performance outcomes, or publications outside the specified period. Systematic reviews were used solely to identify potentially relevant primary studies and were excluded from the final synthesis.

Information sources and search strategy

The source manuscript contained auditable numerical records for PubMed/MEDLINE, ScienceDirect, SpringerLink, and Google Scholar; therefore, only these four sources are reported in the PRISMA counts. Earlier references to Scopus and CINAHL were removed because source-specific counts and export files were unavailable. The searches were last run on 13 July 2026 and were restricted to studies published from 1 January 2020 through 31 December 2025. The core Boolean structure was: (cardiopulmonary resuscitation OR CPR OR chest compression) AND (human factors OR ergonomics OR biomechanics OR posture OR body position OR teamwork OR leadership OR feedback device) AND (training OR education OR simulation OR intervention) AND (fatigue OR rescuer fatigue OR workload OR CPR quality OR compression depth OR compression rate). Terms were adapted to the syntax of each source. Reference lists and forward citations of eligible articles were checked.

Study selection, data extraction, and appraisal

Ni Wayan Sukerti conducted title/abstract screening, full-text assessment, and data extraction. Ni Luh Putu Inca Buntari Agustini and Ni Luh Dwi Indrayani checked methodological decisions and eligibility judgments; disagreements were resolved through discussion with I Wayan Edi Sanjana. The review retained exactly 20 identifiable primary studies. Extracted fields were author/year, population and setting,

Design-appropriate Joanna Briggs Institute (JBI) checklists were applied: the randomized controlled trial, quasi-experimental, analytical cross-sectional, cohort, or case-series tools, as applicable. Ni Wayan Sukerti completed the initial appraisal; Ni Luh Dwi Indrayani verified the methodological judgments, with consensus discussion involving Ni Luh Putu Inca Buntari Agustini when required. Appraisal informed interpretation rather than exclusion by an arbitrary numerical cut-off. Domain-level concerns are therefore reported instead of unsupported percentage scores.

PRISMA flow

The documented search yielded 1,200 records: PubMed (n=215), ScienceDirect (n=368), SpringerLink (n=187), and Google Scholar (n=430). After removal of 285 duplicates, 915 records were screened and 765 were excluded. Full texts of 150 reports were assessed; 130 were excluded for wrong intervention/exposure (n=44), wrong outcome (n=31), wrong population/setting (n=18), ineligible publication type (n=17), or insufficient reporting/duplicate cohort (n=20). Twenty primary studies were included.

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RESEARCH RESULTS

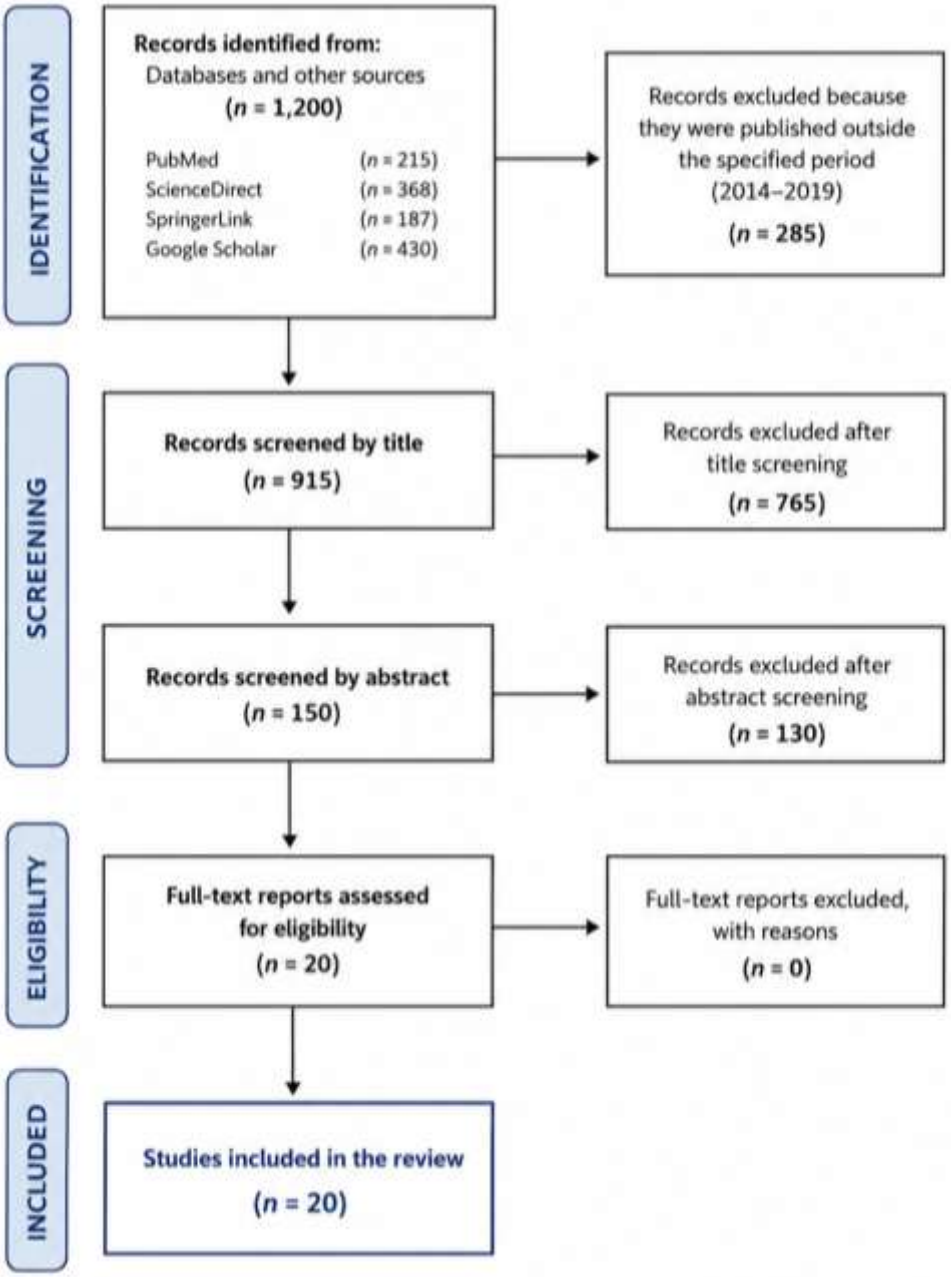


Figure 1. PRISMA Flow Diagram of the Study Selection Process

Study characteristics and thematic synthesis

The 20 studies comprised randomized and crossover simulations, prospective interventions, observational analyses, quality-improvement work, and mixed-method or in-situ simulation evaluations. Participants included nurses, healthcare professionals, medical students, lifeguards, and multidisciplinary resuscitation teams. Most studies were simulation based. Four connected themes emerged: physical ergonomics and fatigue; feedback technology; teamwork and cognitive workload; and translation into clinical systems.

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Table 1. Characteristics of the Included Studies

Author (Year), Country	Purpose	Population/ Design	HFE Components	Outcomes	Main finding	Key limitation
Tian et al. (2021), China	To investigate whether the use of N95 mask affects rescuer's fatigue and chest compression quality during cardiopulmonary resuscitation (CPR).	Simulated CPR; rescuers	N95 mask vs no mask	Fatigue; depth/rate	N95 increased fatigue and impaired several compression-quality measures.	Simulation; narrow exposure.
Bae et al. (2021), South Korea	To determine whether real-time heart rate is a measure of fatigue in compression providers.	Prospective simulation	Heart rate monitoring during compressions	Heart rate; perceived fatigue	Heart rate correlated with subjective fatigue and may inform switching.	No patient outcomes.
Nabecker et al. (2022), Switzerland	To investigate instructors' and course participants' perceptions of human factors assessment after two different summative assessments.	ALS-course teams; randomized cohort	Human-factor assessment in simulated vs real teams	Team assessment	Assessment context influenced ratings; technical and non-technical skills should be integrated.	Course-based setting.
Augusto et al. (2020), Portugal	To evaluate the impact of a real-time visual feedback device on Chest comparison (CCs) rate and depth delivered by healthcare professionals	Manikin study	Real-time visual feedback	Depth/rate accuracy	Visual feedback improved chest-compression quality.	Short-term simulation.
Suet et al. (2020), France	To compare the effects on immediate and 3-month retention of ECM technical skills when using feedback devices compared with training without feedback as part of a half-day training session in medical students.	Medical students; randomized	Two feedback methods vs standard training	Compression quality	Feedback-supported training improved selected performance measures.	Students, not nurses.

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Author (Year), Country	Purpose	Population/ Design	HFE Components	Outcomes	Main finding	Key limitation
Lee et al. (2023a), South Korea	To investigate the effect of real-time audiovisual feedback on various measures of CPR quality, including compression depth, compression rate, and release velocity.	CPR recertification; prospective randomized	Device-based visual feedback	CPR skill quality	Feedback improved recertification performance.	Retention/clinical transfer uncertain.
Palmisano et al. (2024), Italy	To analyze the effects of a blended team-based CPR and AED simulation training (riAniMO program) on HCPs performance, satisfaction and perception on transferability, and costs.	Healthcare professionals; mixed methods	Team-based blended simulation	CPR/AED performance; perceptions	Training improved performance and perceived preparedness.	No direct fatigue measure.
Li et al. (2025), China	To assess the effects of compression angle (90° vs. 100°) and audiovisual feedback on compression quality and rescuer fatigue.	29 participants; randomized crossover	Forward leaning/arm angle with audiovisual feedback	Quality; heart rate; Borg RPE	Some forward-leaning conditions improved depth but increased physiological and perceived exertion.	Manikin setting.
Sa-Couto et al. (2025), Portugal, Germany, and Finland	To objectively assess muscle fatigue during CPR by analyzing triceps brachii sEMG activation during continuous chest compressions (CCs) across different rescuer positions and arm angles.	72 healthcare providers; multicenter crossover	Position, arm angle, anthropometry	sEMG fatigue; performance	Arm angle and anthropometry influenced muscle fatigue and endurance.	Simulation only.
Liu et al. (2024), China	To compare the quality of compressions in supine cardiopulmonary resuscitation (CPR) and prone CPR by performing chest compressions on a manikin.	Comparative prone-CPR simulation	Hand and body position	Compression quality; fatigue	Position affected both CPR quality and rescuer fatigue.	Prone CPR limits generalizability.

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Author (Year), Country	Purpose	Population/ Design	HFE Components	Outcomes	Main finding	Key limitation
Li et al. (2024), China	To compare participant's fatigue with the quality of manual chest compressions performed in the head-up CPR (HUP-CPR) and supine CPR (SUP-CPR) positions for two minutes on a manikin.	Comparative positional simulation	Supine vs head-up position	Quality; rescuer fatigue	Head-up CPR produced poorer quality and greater fatigue than supine CPR.	Small simulation study.
Preuss et al. (2025), Germany	To investigate the differences between chest compressions at night and during the day, with and without the use of a feedback device.	158 participants; randomized simulation	Audiovisual feedback, day vs night	Compression performance	Feedback improved performance across day and night conditions.	Night work was simulated.
Ruibal-Lista et al. (2025), Spain	To examine how 100-meter and 200-meter rescues on a natural beach impact the quality of CPR performed by lifeguards.	Lifeguards; repeated measures	CPR after 100/200-m rescue	Borg RPE; heart rate; CPR quality	Rescue distance increased fatigue; quality did not always decline in parallel.	Non-nurse population.
Picard et al. (2022), Canada	To determine whether handheld visual feedback and backboard use improved chest compression quality, whether resuscitation team size affected resuscitation indicators, and whether feedback sources are comparable.	50 clinical resuscitations; QI	Handheld feedback/backboard	Target rate/depth; team indicators	Feedback increased compressions at target rate; backboards increased target-depth compressions.	Single-center QI; nonrandomized.
Hirsch et al. (2025), Germany	To examine the effect of task-switching requirement on chest-compression quality to gain insights into the cognitive mechanisms underlying performance in standard CPR.	Randomized simulation	Cognitive-motor multitasking	Compression quality	Concurrent cognitive-motor demand altered compression performance.	Simulation; fatigue not primary.

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Author (Year), Country	Purpose	Population/ Design	HFE Components	Outcomes	Main finding	Key limitation
Leo et al. (2023), Singapore	To investigate the compression quality and patient outcomes in IHCA with the use of a feedback device via a retrospective study of inpatient code blue activations in a Singapore hospital over one year.	Clinical retrospective study	CPR feedback device	CPR quality; patient outcomes	Device-recorded quality metrics were associated with selected outcomes.	Confounding; retrospective.
Won et al. (2024), South Korea	To conduct simulations of adult cardiac arrest and to evaluate whether the device improved the CPR indicators.	Experienced providers; simulation	Real-time compression feedback	Correct depth/rate	Feedback increased the likelihood of correct compression depth.	Short-term performance.
Lee et al. (2023b), South Korea	To compare the effects of real-time device-based visual feedback and conventional instructor-based feedback on the chest compression skills and self-efficacy of nurses receiving a CPR recertification program.	Prospective before-after IHCA study	Monitor/defibrillator audiovisual feedback	Appropriate depth and rate	Real-time feedback improved the proportion of compressions meeting targets.	Before-after design.
Lin et al. (2023), Canada	To describe the leadership performance of team leaders and CPR Coaches, and to determine if there is a correlation between leadership scores and CPR performance during management of simulated pediatric cardiac arrest events.	20 pediatric resuscitation teams	CPR coach and team leadership	Leadership; excellent CPR; CCF	Leadership scores correlated with excellent CPR and chest-compression fraction.	Secondary analysis; pediatric simulation.
Schwartze et al. (2024), The United Kingdom	To determine ISS impact on teamwork, technical skill performance, healthcare staff perception and latent error identification during simulated medical emergencies.	Ward healthcare staff; in-situ simulation	Interprofessional ward simulation	Teamwork; technical performance; latent errors	In-situ simulation supported teamwork learning and identified system hazards.	Single hospital; broad outcomes.

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Methodological quality

Most randomized and crossover simulations clearly described conditions and objective manikin outcomes, but participant blinding was generally impossible and allocation concealment was often unclear. Quasi-experimental and before-after studies were vulnerable to temporal effects and co-interventions. Observational and quality-improvement studies contributed clinical relevance but had greater confounding risk. The evidence was therefore judged most credible for immediate technical performance and less certain for long-term skill retention, fatigue reduction, and patient outcomes. No study was excluded solely because of an arbitrary percentage score.

Study group	Applicable JBI tool	Overall concern	Main appraisal issue
Randomized/crossover simulations: Tian; Suet; Lee 2023a; Li 2025; Preuss; Hirsch	JBI RCT checklist	Some concerns	Blinding infeasible; concealment and carry-over control variably reported.
Quasi-experimental simulations/interventions: Bae; Augusto; Palmisano; Sa-Couto; Liu; Li 2024; Ruibal-Lista; Won; Lee 2023b; Schwartze	JBI quasi-experimental checklist	Moderate concerns	Baseline equivalence, repeated-measure effects, follow-up, and concurrent changes varied.
Team/secondary analyses: Nabecker; Lin	JBI analytical cross-sectional/cohort tool	Moderate concerns	Selection and residual confounding; team-level clustering.
Clinical observational/QI: Picard; Leo	JBI cohort/case-series tool	Moderate-to-high concerns	Nonrandom exposure, incomplete control of arrest and system confounders.

DISCUSSION

This review indicates that HFE-informed CPR strategies can improve immediate CPR quality, but the evidence does not support a single universal training package. Feedback devices consistently helped participants recognize and correct depth or rate errors (Augusto et al., 2020; H. Lee et al., 2023a; Preuss et al., 2025; Won et al., 2024). Clinical studies also suggest that device use and backboards can improve selected compression metrics (P.-H. Lee et al., 2023b; Picard et al., 2022). Technology should nevertheless be treated as one component of a work system. Feedback may sustain technical accuracy while physiological demand continues to rise; it cannot replace rotation, posture optimization, workload management, or effective team coordination.

Physical ergonomics influenced both performance and fatigue. Position, arm angle, forward leaning, anthropometry, and patient orientation changed muscular load and compression characteristics (Li et al., 2025; Liu et al., 2024; Sa-Couto et al., 2025). Importantly, a condition that increases compression depth may simultaneously increase exertion. Training should therefore teach a neutral and stable posture, shoulders aligned above the sternum, appropriate bed or step height, use of body mass rather than isolated arm force, early recognition of fatigue, and a rapid, low-interruption compressor switch. Rotation should be guided by both recommended intervals and observed deterioration or excessive exertion.

The organizational and cognitive dimensions of HFE were also important. Leadership, a dedicated CPR coach, clear role assignment, and team-based or in-situ simulation were associated with better coordination or CPR metrics and helped identify latent system hazards (Lin et al., 2023; Nabecker et al., 2022; Palmisano et al., 2024; Schwartze et al., 2024). Cognitive-motor multitasking can compete with

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compression performance (Hirsch et al., 2025). Supporting the separation of compressor, leader, monitor/defibrillator, airway, medication, and documentation roles. Closed-loop communication and anticipatory switching should be practised under realistic constraints, including PPE and restricted workspace.

For nursing practice, a defensible HFE-informed curriculum should combine four domains: (1) guideline-concordant technical CPR with objective feedback; (2) physical ergonomics and fatigue monitoring, including Borg RPE or physiological indicators; (3) non-technical skills such as leadership, closed-loop communication, situational awareness, and role clarity; and (4) system adaptation through in-situ simulation, equipment placement, bed-height adjustment, backboards, and structured debriefing. Outcomes should include compression depth, rate, recoil, chest-compression fraction, interruption duration, perceived exertion, heart rate, musculoskeletal discomfort, teamwork, retention, and where feasible clinical outcomes.

Strengths and limitations

This revision removed a systematic review and three unverifiable placeholders from the primary evidence table, reconciled PRISMA arithmetic, separated source-specific counts, and replaced unsupported numerical JBI scores with design-domain judgments. Nevertheless, important limitations remain. The review was not prospectively registered; only four sources had auditable counts; Google Scholar has limited reproducibility; screening was led by one reviewer with senior verification rather than fully independent duplicate screening; and considerable clinical and methodological heterogeneity precluded meta-analysis. Most evidence arose from manikin simulation and mixed healthcare populations, so direct inference to nurses during actual adult in-hospital cardiac arrest should be cautious. These limitations reduce certainty but do not negate the consistent directional evidence for feedback, ergonomic adaptation, workload management, and team training.

CONCLUSIONS AND RECOMMENDATIONS

HFE-informed CPR education and performance strategies are associated with better immediate chest-compression quality and more effective team coordination, while fatigue is amplified by prolonged compressions, PPE, unfavorable posture, and demanding patient positions. The strongest practical message is not that one device or posture solves CPR-quality deterioration, but that technical skill, physical ergonomics, workload, technology, teamwork, and environment must be trained as an integrated system. Hospitals should incorporate objective feedback, ergonomically appropriate positioning, fatigue recognition, planned compressor switching, role clarity, closed-loop communication, CPR coaching, in-situ simulation, and structured debriefing into recurring nurse CPR education. Future multicenter randomized studies should test a standardized nurse-focused HFE training package and report fatigue, CPR quality, skill retention, musculoskeletal effects, implementation fidelity, and patient-centered outcomes.

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AUTHOR CONTRIBUTIONS

Conceptualization: Ni Wayan Sukerti and Ni Luh Putu Inca Buntari Agustini. Methodology: Ni Luh Putu Inca Buntari Agustini and Ni Luh Dwi Indrayani. Formal analysis: Ni Luh Dwi Indrayani. Investigation and data curation: Ni Wayan Sukerti. Writing—original draft: Ni Wayan Sukerti. Writing—review and editing: Ni Luh Putu Inca Buntari Agustini, Ni Luh Dwi Indrayani, and I Wayan Edi Sanjana. Supervision: Ni Luh Putu Inca Buntari Agustini. All authors reviewed and approved the final manuscript.

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