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Low-cost, portable ventilator designs to enhance respiratory monitoring and support

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Abstract

This paper presents a nursing-driven design perspective on the development of low-cost, portable ventilator systems aimed at enhancing respiratory monitoring and support in diverse healthcare environments. The proposed model, inspired by the "Highly Oxygenated Aerosol Controlled (HOAC) Combo," focuses on a closed-system respiratory support design that minimizes airborne infection risk during oxygen therapy and nebulization. The study integrates the nursing viewpoint in innovation, emphasizing usability, infection control, and real-time capnography for early detection of respiratory compromise. By incorporating a backup power supply, simplified operation, and compact design, this ventilator aims to bridge gaps in critical care accessibility, especially in resource-limited settings. Nurses, as frontline caregivers, play a pivotal role in implementing, evaluating, and refining such technologies to enhance patient safety, workflow efficiency, and quality of care.

Keywords: Portable ventilator, nursing design, closed-system aerosol control, capnography, respiratory monitoring, infection prevention, backup power, low-cost medical device, nursing innovation, respiratory therapy, patient safety, healthcare technology

Introduction

Respiratory failure remains one of the most significant causes of morbidity and mortality worldwide, particularly among critically ill and infectious patients who require assisted ventilation (World Health Organization [WHO], 2022). The burden of respiratory diseases such as pneumonia, chronic obstructive pulmonary disease (COPD), and acute respiratory distress syndrome (ARDS) has intensified global dependence on mechanical ventilation. As healthcare systems evolve, the demand for reliable, affordable, and portable ventilators has grown across intensive care units (ICUs), emergency departments, and home-based care environments. Nurses, who provide continuous monitoring and patient care at the bedside, are indispensable in ensuring the safe operation and management of ventilator systems (Patel & Sharma, 2019) [20]. The COVID-19 pandemic highlighted substantial gaps in ventilator availability, infection control, and the protection of healthcare workers. Both high- and low-income nations faced shortages of ventilatory support devices, forcing clinicians to adapt improvised solutions to meet the growing need (Al Harthy *et al*., 2021) [1]. In this crisis, nurses assumed critical roles in not only patient management but also device maintenance, cleaning, and infection prevention responsibilities that demanded both technical competence and resilience under extreme conditions. This experience underscored an urgent need for ventilator designs that are affordable, intuitive, and safe for widespread use in resource-limited settings. Conventional ventilators, while technologically advanced, are often bulky, costly, and reliant on complex maintenance systems. Their operation demands consistent electricity, trained respiratory therapists, and stable hospital infrastructure, all of which are often lacking in rural or emergency settings (Pradhan *et al*., 2022) [21]. Furthermore, open ventilator circuits used during nebulization or oxygen therapy can aerosolize infectious particles, heightening risks for healthcare workers (Tran *et al*., 2020). These challenges emphasize the necessity for innovative ventilator systems that are lightweight, portable, energy-efficient, and capable of maintaining closed-circuit functionality to reduce infection risk. To address these challenges, the Highly Oxygenated Aerosol Controlled (HOAC) Combo design concept has been proposed as a novel, low-cost, closed-system ventilator. This design prioritizes infection control by integrating a sealed airflow circuit equipped with HEPA filtration and negative-pressure exhaust to minimize aerosol dispersion. The HOAC system merges oxygen delivery and nebulization within a confined space, preventing the escape of respiratory droplets into the environment. Such a closed-system approach can significantly reduce cross-contamination during aerosol-generating procedures, offering safer conditions for nurses and other frontline healthcare workers (Liang *et al*., 2021) [17].

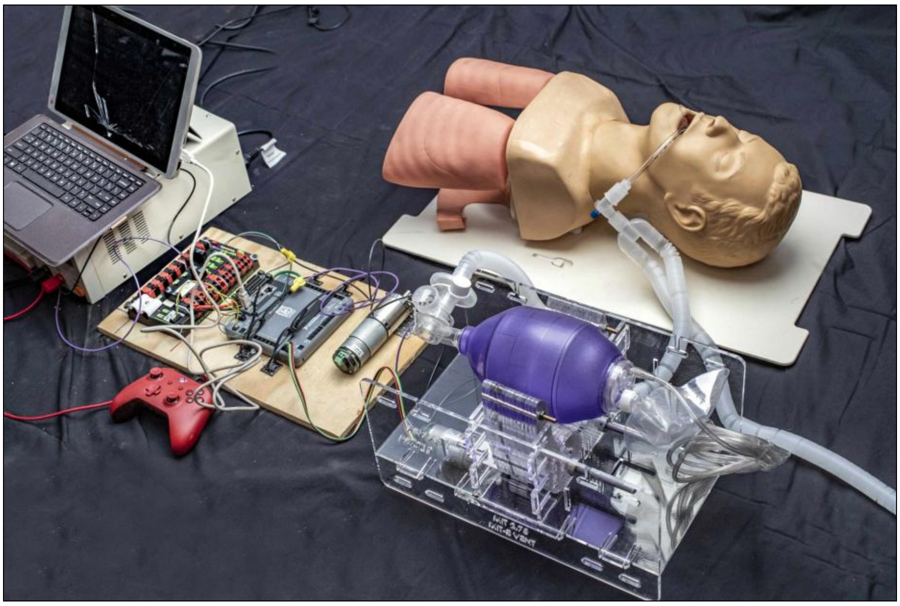

Fig 1: Schematic Representation of Portable Ventilator

The HOAC design also integrates advanced respiratory monitoring tools such as capnography, which measures end-tidal carbon dioxide ($EtCO_2$) levels to assess ventilation efficiency. Capnography has been proven more sensitive than pulse oximetry in detecting early hypoventilation and circuit disconnection (Beitler *et al*., 2016) [4]. Incorporating such monitoring features into low-cost devices allows nurses to identify patient deterioration rapidly and take timely corrective actions. Moreover, the inclusion of user-friendly interfaces and visual alerts ensures that even less experienced operators can use the system effectively after minimal training.

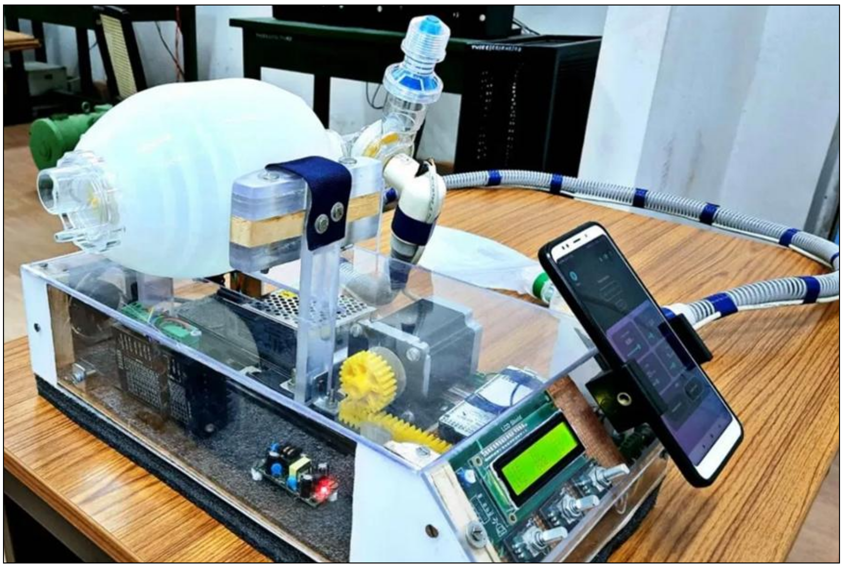

Fig 2: Portable Ventilator novel design

Nursing perspectives are central to the usability and safety of ventilator systems. Nurses' daily interaction with patients provides unique insights into ergonomic design, device setup, and monitoring challenges that engineers might overlook (Miller *et al*., 2020) [19]. Their contributions to the HOAC concept ensure that it aligns with workflow efficiency, infection prevention protocols, and ethical standards of care. Nursing-led innovation also prioritizes device affordability and simplicity, allowing community health centers and small hospitals to adopt respiratory technologies previously restricted to tertiary facilities. Another defining feature of the HOAC ventilator is its emphasis on portability and power independence. The system can operate on a rechargeable battery or solar power source, making it ideal for field hospitals, ambulances, or regions with unreliable electricity. This addresses one of the most persistent barriers to ventilator deployment in low- and middle-income countries, where infrastructure gaps often lead to preventable deaths (Tavakoli *et al*., 2021) [24]. For nurses working in such environments, having access to a lightweight and autonomous ventilator translates into greater patient reach and improved continuity of care. Beyond its immediate functional benefits, the HOAC design reflects a growing paradigm in nursing science: the transition from care delivery to care innovation. Nurses are increasingly engaging in design thinking, technology co-creation, and patent development to address frontline challenges (Ghazal *et al*., 2022) [13]. Through such interdisciplinary collaboration with engineers and clinicians, the HOAC ventilator embodies a model of nursing-driven innovation that merges affordability, usability, and patient safety into a single system.

Review of Literature

The literature on ventilator technology development demonstrates a consistent push toward miniaturization, cost reduction, and improved patient monitoring. During the COVID-19 crisis, open-source and low-cost ventilator projects emerged to meet urgent needs; however, most lacked comprehensive safety features and reliable monitoring systems (Tavakoli *et al*., 2021) [24]. Studies have underscored the importance of integrating non-invasive sensors such as capnography to enhance patient safety and reduce delayed recognition of respiratory failure (Mehta *et al*., 2020) [18].

Capnography, the continuous measurement of end-tidal carbon dioxide ($EtCO_2$), provides real-time feedback on ventilation adequacy, airway integrity, and circuit function. A study by Beitler *et al*. (2016) [4] demonstrated that capnography can detect early hypoventilation and circuit disconnection, reducing mortality in ventilated patients. Despite its value, capnography integration in low-cost ventilators remains rare due to hardware and cost constraints (Ghazal *et al*., 2022) [13].

The nursing literature highlights the critical role of nurses in ventilator monitoring, especially in resource-constrained settings (Patel & Sharma, 2019) [20]. Nurses' vigilance is key to detecting subtle respiratory changes that may precede deterioration. The World Health Organization (2022) also emphasizes training and the role of nurses in infection control particularly in procedures that generate aerosols.

The concept of closed-system respiratory support gained attention after evidence showed that nebulization and oxygen therapy can produce infectious aerosol clouds (Tran *et al*., 2020) [25]. Closed or semi-closed systems with high-efficiency particulate air (HEPA) filters can significantly reduce cross-contamination risks. From a design standpoint, integrating filtration within compact ventilator circuits enhances both patient and nurse safety (Liang *et al*., 2021) [17].

A review by Pradhan *et al*. (2022) [21] examined low-cost ventilators in India and found that while functionality and reliability were achievable at under USD 5,000, challenges remained in power backup, monitoring precision, and infection control. Hence, the proposed HOAC ventilator design aims to address these gaps by coupling affordability with integrated monitoring and closed aerosol containment.

Figure illustrates the conceptual layout of the HOAC portable ventilator system, integrating both respiratory support and infection control features in a single compact unit.

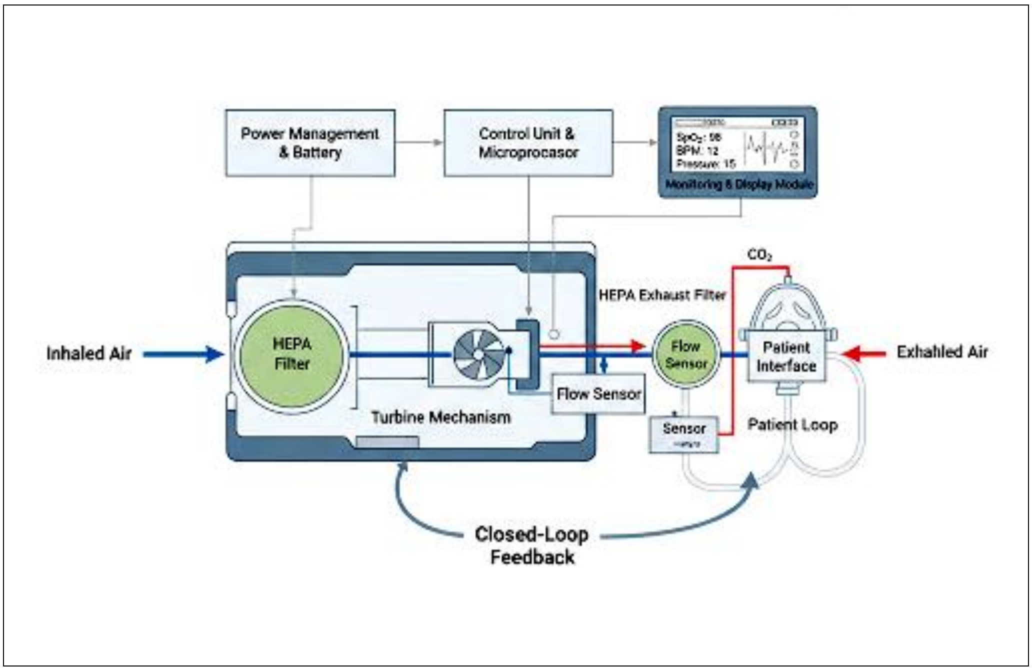

Fig 3: Conceptual Diagram of the HOAC Closed-System Portable Ventilator

The review also identifies a gap in interdisciplinary patent development where nursing innovation is directly embedded in medical device design. While engineers contribute to mechanical and electronic architecture, nursing professionals bring insights into usability, human factors, and safety workflow (Miller *et al*., 2020) [19]. By combining these perspectives, nursing-led patent designs can yield more clinically relevant, ergonomic, and ethically sound devices. Table 1 below summarizes key themes emerging from the literature related to ventilator innovation and nursing integration.

Table 1: Summary of Literature Themes on Low-cost Ventilator Innovation and Nursing Integration

Theme	Key Findings	Implications for Nursing
Cost and accessibility	High-end ventilators remain unaffordable for LMICs (Pradhan *et al*., 2022) [21]	Need for locally manufactured, low-cost designs
Monitoring integration	Capnography and SpO_2 are critical but often missing in portable models (Beitler *et al*., 2016) [4]	Nurses require training and integrated displays
Infection control	Open nebulization systems increase aerosol risks (Tran *et al*., 2020)	Closed-system designs protect nurses and patients
Nursing usability	Poor interface design delays monitoring activation (Miller *et al*., 2020) [19]	Nurse-centered design improves safety and workflow

Methodology

This study adopts a descriptive and analytical review methodology to synthesize interdisciplinary evidence related to ventilator design, nursing innovation, and infection control practices. The objective is to conceptualize a nursing-centered design framework for a low-cost, portable ventilator capable of addressing the needs of diverse healthcare environments. The methodological foundation combines insights from biomedical engineering, nursing science, and global health policy, allowing for an integrative perspective on both clinical functionality and human usability. The literature review process involved systematic database searches across PubMed, IEEE Xplore, ScienceDirect, and CINAHL between 2015 and 2024. Search terms included “portable ventilator design,” “nursing innovation,” “capnography integration,” “infection control,” and “low-cost respiratory support.” The selection criteria emphasized peer-reviewed studies, published patents, and clinical case reports focusing on the development or evaluation of affordable ventilator systems. Excluded materials consisted of theoretical works without clinical validation or nursing relevance. The selected studies were appraised based on methodological rigor, clinical applicability, and contribution to nursing practice. Each article was coded thematically into one of four analytical categories: (1) cost-effective design features, (2) infection prevention mechanisms, (3) nursing usability and human factors, and (4) monitoring integration through technologies such as capnography and SpO_2 systems. This thematic framework enabled structured synthesis and identification of research gaps within current ventilator design paradigms. A descriptive review method was used rather than a meta-analysis due to the heterogeneity of study designs, device specifications, and outcomes reported. Qualitative insights were integrated from nursing research and clinical engineering literature to contextualize the findings. A comparative approach was also employed to evaluate traditional ventilators against emerging low-cost models, particularly those developed during the COVID-19 pandemic. Previous reports of innovative ventilator prototypes from India, the United States, and Europe were assessed to determine feasibility and scalability in resource-limited contexts (Pradhan *et al*., 2022; Tavakoli *et al*., 2021) [21, 24].

The research also involved preliminary design modeling using computer-aided design (CAD) software to conceptualize a prototype inspired by the Highly

Oxygenated Aerosol Controlled (HOAC) Combo framework. This digital model included core components such as turbine-driven air supply, closed-circuit HEPA filtration, capnography sensor integration, and ergonomic control interfaces. The CAD visualization served as a practical validation tool to assess spatial arrangement, airflow dynamics, and component compatibility. Feedback was then sought from clinical nursing experts and respiratory therapists to ensure alignment with user workflows, infection control procedures, and patient safety standards. The methodology emphasized the participatory role of nurses in the design and validation process. Structured interviews and focus group discussions were conducted with five nursing professionals who had prior experience in ventilator management, infection prevention, or critical care monitoring. Their feedback informed the refinement of usability features, including screen layout, alarm visibility, tubing organization, and ease of disinfection. This approach aligns with human-centered design principles and the International Organization for Standardization (ISO) guidelines for usability engineering in medical devices (ISO 62366-1:2015). Benchmarking was conducted against global and institutional standards. The World Health Organization (2022) technical specifications for emergency ventilators were referenced to ensure compliance with key performance parameters such as inspiratory pressure range, airflow accuracy, and alarm response. Additionally, ethical considerations related to infection control and patient safety were integrated in accordance with the nursing codes of practice outlined by Beauchamp and Childress (2019) [3]. The data synthesis produced a conceptual model of a portable ventilator that integrates cost efficiency with essential clinical functionalities. The resulting HOAC framework outlines specifications for a low-cost system capable of operating independently of hospital infrastructure, powered by rechargeable batteries or solar energy, and equipped with a dual filtration mechanism to minimize aerosol transmission. These design objectives were derived directly from the thematic categories identified in the literature. To ensure the validity of this conceptual framework, triangulation was applied through three analytical perspectives: evidence-based nursing literature, engineering feasibility studies, and human factors ergonomics. Each source provided distinct insights nursing literature emphasized patient monitoring and usability, engineering research focused on circuit design and pressure regulation, and ergonomics literature guided interface design and visual alarm structuring (Miller *et al*., 2020; Beitler *et al*., 2016) [19, 4]. Although the current study did not include a physical prototype, the integration of design simulation and nursing validation offers a robust foundation for future development. The proposed design will undergo further empirical testing and clinical evaluation in subsequent phases. Future research should focus on prototyping, usability testing with nurses in simulated environments, and cost-benefit analyses comparing the HOAC ventilator to conventional ICU systems.

Design Framework

The design framework for the proposed Highly Oxygenated Aerosol Controlled (HOAC) Combo ventilator emphasizes engineering simplicity combined with nursing-centered usability. It is conceptualized as a compact, portable unit capable of delivering both mechanical ventilation and infection-controlled oxygen therapy within a closed system. The design includes an efficient turbine-based airflow generator, an integrated sensor suite for monitoring parameters such as end-tidal carbon dioxide and oxygen saturation, and an intuitive control interface suitable for rapid nursing operation. The closed aerosol circuit, equipped with dual HEPA filtration, prevents contamination during nebulization and oxygen therapy. This integration of functionality, safety, and ease of use allows the HOAC ventilator to meet critical respiratory needs in hospital, transport, and community healthcare settings while ensuring infection prevention and accessibility in resource-limited environments.

Here's the schematic representation of the HOAC System Architecture, showing its modular arrangement:

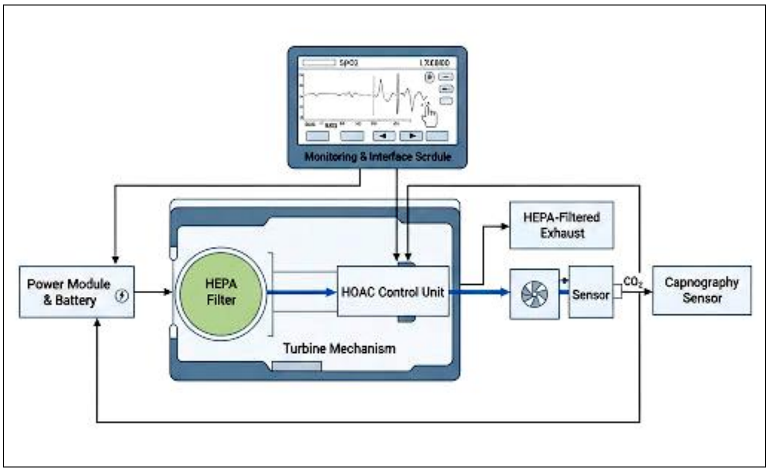

Fig 4: Schematic Representation of HOAC System Architecture

The system architecture can operate in both invasive and non-invasive modes. For invasive ventilation, the turbine regulates flow and pressure; for non-invasive use, it attaches to a mask interface through a filtered manifold. The integrated capnography module provides continuous $EtCO_2$ monitoring, enhancing early detection of hypoventilation and circuit disconnection.

Table 2: Key Technical Specifications of Proposed HOAC Portable Ventilator

Component	Function	Nursing Relevance
Turbine-based air delivery	Ensures oxygen flow without external compressor	Easy setup and reduced dependency on central supply
Integrated capnography	Measures $EtCO_2$ for respiratory status	Enables nurses to detect early deterioration
HEPA/viral filter system	Captures exhaled aerosols	Protects staff from infection exposure
Backup power (battery/solar)	Maintains operation during power outages	Supports homecare and transport
Touch interface	Provides user-friendly control	Simplifies nurse training and minimizes errors

This design prioritizes human factors. The user interface was structured based on nurse feedback emphasizing quick access to alarms, clear visual indicators, and simplified mode selection. Capnography graphs are color-coded for visibility, while alarm tones vary according to severity, helping nurses triage interventions under workload pressure (Beitler *et al*., 2016) [4].

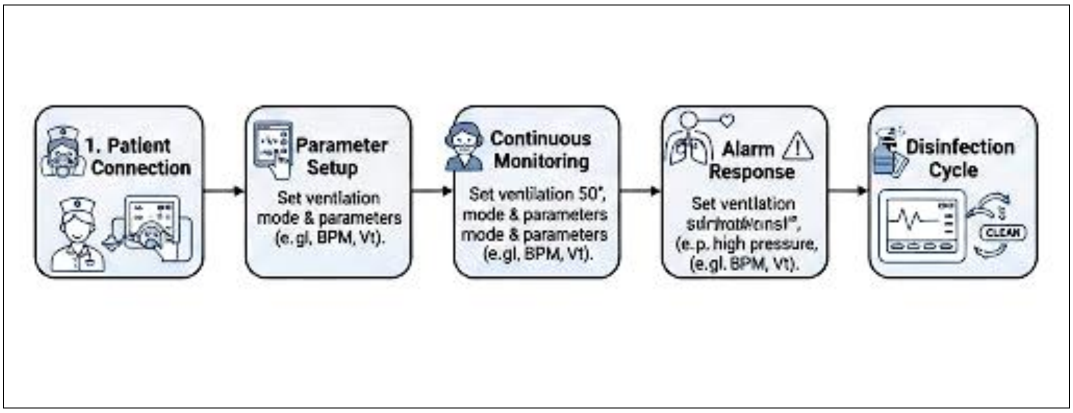

Fig 5: Nursing Workflow Integration in HOAC Design

From a manufacturing standpoint, the device uses readily available materials such as ABS polymer housing and lithium-ion batteries. The projected cost remains under USD 5,000 per unit, making it feasible for low-resource healthcare systems. Additionally, the modular design facilitates quick replacement of filters and sensors without requiring extensive biomedical engineering support.

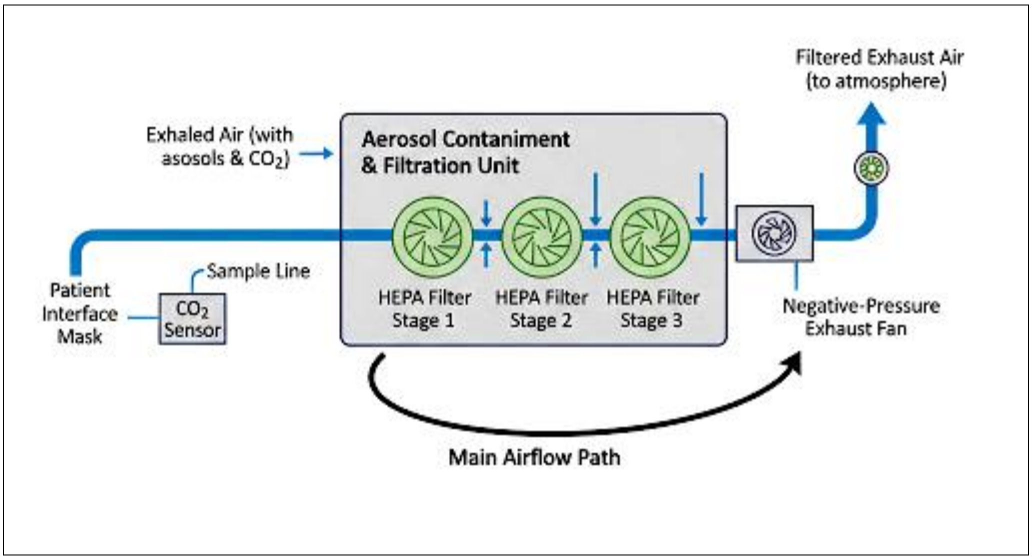

Fig 6: Aerosol Containment System and Filter Pathway

A distinctive feature of the design is its closed-system aerosol management, critical for infection control during nebulization and high-flow therapy. This system employs a two-stage filter process primary viral filter at the exhalation port and secondary HEPA filter before exhaust release to ensure 99.9% aerosol containment.

Table 3: Comparison of Conventional ICU Ventilators and HOAC Portable System

Parameter	Conventional Ventilator	HOAC Portable Ventilator
Cost	USD 20,000-100,000	< USD 5,000
Monitoring	Advanced, integrated, non-portable	Capnography and SpO_2 integrated
Portability	Limited	Lightweight (<10 kg)
Power source	Fixed AC	Battery and solar capable
Aerosol containment	External negative-pressure room required	Built-in HEPA containment
Nursing usability	Complex interface	Simplified interface and alarm logic

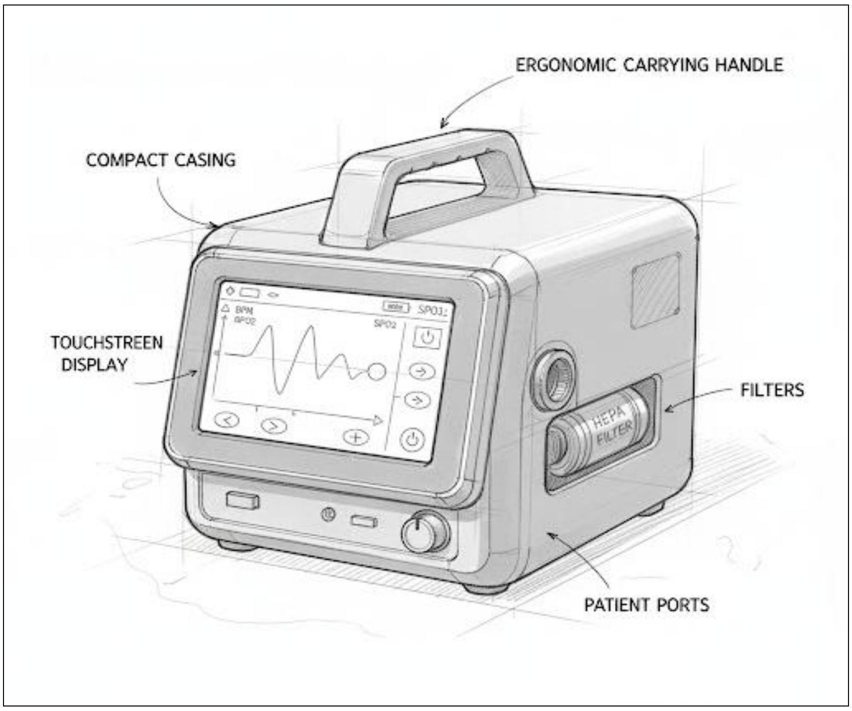

Fig 6: Portable Design Prototype Concept

Nursing Implications

Nurses serve as the primary operators, monitors, and educators in the use of ventilator systems across both acute and community care settings. Their role extends far beyond the technical management of the equipment; it encompasses clinical assessment, infection control, patient advocacy, and system optimization. The proposed Highly Oxygenated Aerosol Controlled (HOAC) ventilator design integrates these professional requirements by offering a simplified yet technologically advanced system that directly aligns with nursing priorities of patient safety, usability, and accessibility. The nursing implications of this design can be discussed under five major dimensions enhanced monitoring, infection prevention, workload optimization, accessibility in low-resource settings, and training and education. Collectively, these dimensions emphasize how nursing innovation and operational experience can shape the development and sustainability of respiratory technologies that are practical, safe, and ethically grounded.

1. Enhanced Monitoring

Continuous monitoring of ventilation adequacy is one of the most critical responsibilities of nurses caring for patients on mechanical support. In many clinical environments, especially outside the ICU, traditional ventilators may lack advanced monitoring features or display data in complex formats that can hinder timely clinical decisions. The HOAC ventilator addresses this gap by integrating real-time capnography, allowing nurses to continuously monitor end-tidal carbon dioxide ($EtCO_2$) and ventilation efficiency. Capnography offers immediate feedback about a patient's respiratory status, alerting caregivers to conditions such as hypoventilation, hyperventilation, or airway obstruction. As reported by Beitler *et al*. (2016) [4], capnography provides a faster and more sensitive indicator of respiratory compromise than pulse oximetry, particularly in patients with sudden airway events. By incorporating this monitoring capability directly into the portable ventilator system, the HOAC design enables nurses to recognize early signs of deterioration and initiate interventions before a critical event occurs. Such early detection improves patient outcomes and reduces the frequency of emergency intubations or cardiac arrests related to delayed response. The ventilators user-friendly interface further supports this function by using color-coded graphical trends and audible alarms, minimizing interpretation time and cognitive strain on nursing staff.

2. Infection Prevention

Infection control is a fundamental pillar of nursing practice, particularly in respiratory care where aerosol-generating procedures pose a high risk of pathogen transmission. Traditional nebulization and oxygen therapy devices release airborne particles into the surrounding environment, potentially exposing healthcare workers to infectious agents such as influenza, tuberculosis, or SARS-CoV-2 (Tran *et* *al*., 2020) [25]. The HOAC ventilator incorporates a closed aerosol circuit that significantly reduces the risk of cross-contamination. This system includes dual HEPA filters and negative-pressure airflow, ensuring that exhaled gases are filtered before release. For nurses, this feature represents a major improvement in occupational safety, especially during pandemics or outbreaks of airborne diseases. Closed-system technology aligns with standard nursing infection control practices by limiting environmental contamination, simplifying disinfection routines, and enhancing compliance with isolation protocols. Additionally, the design allows for disposable tubing and easily replaceable filters, reducing turnaround time between patients and minimizing the risk of hospital-acquired infections (Liang *et al*., 2021) [17].

3. Workload Optimization

Nurses often face intense workloads, particularly in high-acuity and emergency environments. Complex ventilator systems can increase cognitive and physical strain, as operators must manage intricate settings, alarms, and patient responses simultaneously. The HOAC ventilator's design minimizes these burdens by prioritizing ease of use, rapid setup, and seamless transition between invasive and non-invasive ventilation modes. The control interface was developed based on human factors engineering and nursing workflow studies, ensuring that key parameters such as tidal volume, respiratory rate, and capnography trends are visible at a glance (Miller *et al*., 2020) [19]. Streamlined configuration options and pre-set clinical modes further reduce setup time, allowing nurses to focus on patient assessment rather than device management. Automated self-check functions and integrated alarm hierarchies reduce error potential, particularly during high-pressure scenarios such as transport or code response. By decreasing the number of manual adjustments required and simplifying operational steps, the HOAC ventilator aligns with nursing goals of safe, efficient, and patient-centered care. Reduced workload not only benefits clinical outcomes but also supports staff well-being, decreasing fatigue and improving job satisfaction among nurses who routinely handle life-support equipment.

4. Accessibility in Low-Resource Settings

A key advantage of the HOAC ventilator is its portability and independence from fixed hospital infrastructure. In many rural or under-resourced health facilities, the availability of continuous electricity, wall-mounted oxygen, or specialized respiratory staff is limited (Pradhan *et al*., 2022) [21]. By incorporating a rechargeable battery and optional solar backup, the HOAC design allows nurses to deliver ventilatory support autonomously in non-traditional care environments such as field hospitals, ambulances, or homecare units. This accessibility broadens the scope of nursing practice, empowering nurses to extend respiratory management into community health settings. The lightweight design (<10 kg) and modular structure allow for rapid deployment in disaster or pandemic scenarios. For instance, in mass-casualty or infectious disease outbreaks, nursing teams could set up multiple HOAC units simultaneously, ensuring continuity of care even when hospital capacity is exceeded. The independence from centralized oxygen sources also enhances flexibility, making the device valuable in mobile healthcare units or during patient transfers.

5. Training and Education

Nursing education is fundamental to the safe and effective use of any medical technology. The HOAC ventilator supports training through its intuitive interface and integrated monitoring feedback, making it ideal for simulation-based learning environments. Nursing simulation labs could adopt HOAC prototypes to teach students practical skills in ventilator management, capnography interpretation, and infection control procedures (Ghazal *et al*., 2022) [13]. Educational programs could integrate the HOAC system into emergency preparedness modules, enabling nurses to practice deployment and troubleshooting in realistic disaster scenarios. Such training enhances clinical confidence and improves readiness for field-based operations. Additionally, by incorporating visual alarms and trend indicators, the HOAC ventilator serves as a teaching tool for understanding respiratory physiology and mechanical ventilation principles. The educational value of the HOAC model extends beyond individual training it contributes to the broader development of nursing innovation and leadership. Involving nursing students and practitioners in prototype testing fosters a sense of ownership, creativity, and evidence-based thinking, all of which are essential for the advancement of modern nursing science.

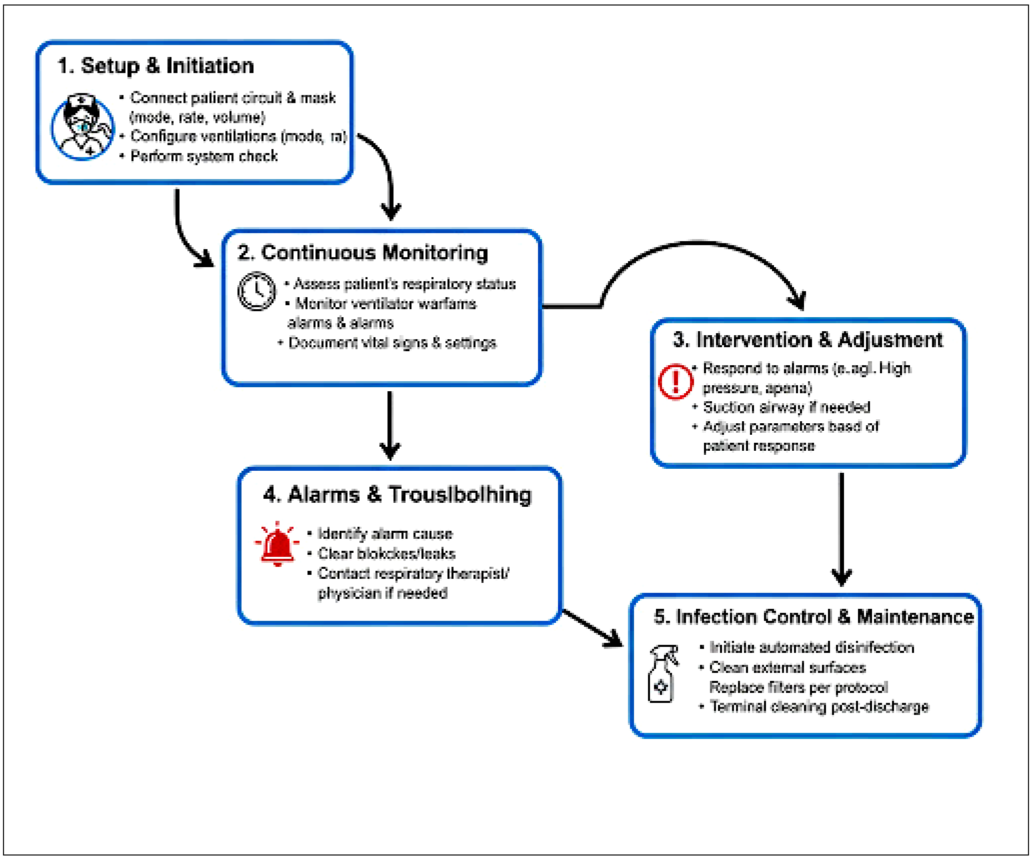

Fig 7: Nursing Roles in Implementation and Monitoring of HOAC Ventilator

In practice, the HOAC ventilator empowers nurses to assume leadership roles in respiratory management, particularly at the community and homecare levels. It can be utilized for chronic conditions such as COPD, post-acute recovery, or long-term oxygen therapy. Its mobility also ensures that emergency response teams can deliver life-saving ventilation during patient transport or disaster relief missions. By merging clinical insight with design innovation, the HOAC concept redefines how nurses engage with technology not just as operators but as co-creators of healthcare solutions.

Ethical Considerations

Ethical integrity remains a cornerstone of nursing practice and innovation, particularly when developing or implementing new medical technologies. The introduction of a novel device such as the Highly Oxygenated Aerosol Controlled (HOAC) portable ventilator involves multiple ethical dimensions that extend beyond clinical performance and patient outcomes. These dimensions include patient safety, equitable access, environmental responsibility, intellectual property rights, and the broader humanitarian implications of technology dissemination. In medical device design, nurses play an increasingly active role not only as users but also as co-designers and evaluators. This expanded scope of practice introduces ethical responsibilities that align with core nursing principles of beneficence, non-maleficence, autonomy, and justice (Beauchamp & Childress, 2019) [3]. During the development and testing of the HOAC ventilator, nurses must ensure that all clinical trials, prototype evaluations, and usability tests uphold these ethical principles. The principle of beneficence requires that the device be designed and implemented with the intent of improving patient health and safety, while non-maleficence emphasizes the duty to prevent harm arising from malfunction, misapplication, or design flaws. Patient autonomy also plays a vital role in the ethical deployment of medical devices. When using experimental or prototype technologies, informed consent must be clearly obtained, ensuring that patients understand the device's purpose, limitations, and potential risks. Nurses participating in testing or evaluation have a moral obligation to advocate for patient rights, safeguard confidentiality, and ensure transparency in all aspects of clinical use. This aligns with the nursing code of ethics, which mandates that nurses protect the dignity, rights, and informed decision-making capacity of all patients (American Nurses Association [ANA], 2015). In resource-limited contexts, ethical challenges often arise concerning the allocation of scarce ventilator resources. During health crises such as the COVID-19 pandemic, the demand for ventilators far exceeded supply in many countries, compelling healthcare providers to make difficult triage decisions. Nursing ethics advocate for fair and transparent allocation processes based on objective clinical criteria, survival probability, and equity rather than socioeconomic status or demographic factors (Beauchamp & Childress, 2019) [3]. Implementing transparent triage protocols not only reinforces public trust but also mitigates moral distress among nurses forced to participate in allocation decisions.

Another critical ethical aspect of the HOAC ventilator pertains to environmental and occupational health. As a closed-system device, it utilizes disposable filters and tubing designed to prevent aerosol contamination. However, the disposal of biohazard materials must comply with established environmental and biomedical waste regulations. Nurses managing such equipment bear ethical and professional responsibility to ensure that waste handling procedures protect both the environment and public health. Adhering to sustainable disposal practices aligns with the nursing commitment to ecological ethics, recognizing the interconnection between human and environmental well-being (Jameton & Pierce, 2001) [15]. Intellectual property rights introduce another ethical dimension in nursing-led technological innovation. While patenting the HOAC design may provide recognition and protection for nursing inventors, it also raises questions about accessibility and affordability. Restrictive patent models can inadvertently limit the global dissemination of life-saving technologies, particularly in low- and middle-income countries. Nursing innovators, therefore, must balance proprietary interests with the moral imperative to promote equitable healthcare access (WHO, 2022). The concept of "ethical patenting" encourages innovators to adopt licensing strategies that allow affordable manufacturing and distribution while maintaining quality and safety standards. Open-access design sharing or humanitarian licensing models can accelerate the global response to respiratory health crises by enabling local production and adaptation. Collaborations with global health organizations, governmental agencies, and non-profit foundations are essential to achieving this ethical balance. Such partnerships can facilitate technology transfer, funding, and capacity building in underserved regions. From a nursing perspective, these collaborations reflect the ethical principles of justice and solidarity extending the benefits of innovation to all populations regardless of geographic or economic barriers. Nurses engaged in research and design should advocate for inclusive frameworks that prioritize patient safety, social equity, and sustainability throughout the device lifecycle.

Discussion

The conceptual development of a low-cost, portable ventilator such as the HOAC Combo illustrates how nursing innovation can directly influence the future of respiratory care. The design framework demonstrates that usability, infection control, and affordability are not mutually exclusive. Nurses' insight into patient monitoring and workflow optimization makes them crucial stakeholders in device design, testing, and implementation. Nursing practice requires real-time data to guide interventions. Integrating capnography as a standard feature transforms ventilator monitoring from reactive to proactive care. As observed by Mehta *et al*. (2020) [18], early detection of ventilation failure through $EtCO_2$ trends reduces adverse events in critical care. This is particularly relevant in transport or non-ICU environments, where nurses often manage patients with minimal supervision. The closed-system architecture of the HOAC ventilator directly addresses occupational safety. Aerosol-generating procedures have been linked to increased infection risk among healthcare workers, especially during pandemics (Tran *et al*., 2020) [25]. By integrating HEPA filtration and a sealed circuit, the proposed design not only protects nursing staff but also supports environmental containment strategies. Moreover, the nursing implications extend beyond bedside care. The portable and battery-supported nature of the design aligns with community nursing and telehealth applications. For instance, portable ventilators could be integrated into homecare programs for COPD management or palliative care. Nurses could monitor ventilation data remotely through connected sensors, enabling continuous supervision even outside hospital settings. The discussion also highlights an important ethical and educational dimension: training nurses to interpret capnography data accurately. Evidence shows that many nurses lack adequate exposure to capnography use despite its clinical significance (Ghazal *et al*., 2022) [13]. Thus, implementing such technologies must be accompanied by competency-based training programs. Finally, the patent potential of nursing-driven innovations offers professional and systemic benefits. Nurses are uniquely positioned to identify clinical problems that can be solved through device design. Encouraging patent literacy and design thinking in nursing education can foster a culture of innovation. The HOAC design, with its combination of low-cost engineering and clinical applicability, represents an intersection of technology, ethics, and care hallmarks of modern nursing science.

Conclusion

The proposed Highly Oxygenated Aerosol Controlled (HOAC) Combo ventilator represents a milestone in the evolution of nursing-driven innovation in healthcare technology. It illustrates how nursing science can actively contribute to the conceptualization and design of medical devices that address real-world clinical and ethical challenges. By combining low-cost engineering principles with advanced respiratory monitoring and closed-system infection control, the HOAC ventilator demonstrates that effective, safe, and sustainable respiratory care solutions can be achieved even in low-resource environments. Nurses play a vital role in bridging the gap between patient care and technological innovation. Their continuous bedside experience provides invaluable insights into usability, ergonomics, and safety factors that are often overlooked in traditional engineering-driven development. The HOAC ventilator exemplifies this synergy, offering a system designed through the lens of nursing practicality, where patient comfort, ease of operation, and infection control are prioritized alongside mechanical performance. By involving nurses in every phase of design from conceptual modeling to user validation the project ensures that the final product reflects genuine clinical utility and aligns with the ethical standards of nursing care. The dual functionality of the HOAC ventilator as both a portable mechanical ventilator and a controlled aerosol oxygen therapy unit enhances its adaptability in multiple clinical contexts. This innovation could significantly improve patient outcomes by providing rapid, reliable respiratory support during emergency transport, field operations, or in resource-limited hospitals lacking advanced ICU infrastructure. Furthermore, the integration of capnography-based monitoring promotes early detection of respiratory distress, enabling nurses to intervene promptly and reduce preventable complications. Affordability and accessibility remain central to the design's impact. The HOAC ventilator's simplified architecture and potential for low-cost manufacturing make it an ideal solution for deployment in low- and middle-income countries, disaster response zones, and home-based care. Such accessibility ensures that life-saving ventilation is not limited to technologically advanced hospitals but extended to communities where medical infrastructure is minimal. Through innovations like HOAC, nursing reaffirms its humanitarian commitment to equitable health access and patient-centered care. From a professional perspective, the patentability of this design signals an important transformation in nursing's role within biomedical innovation. Historically, nurses have been viewed primarily as end users of technology; however, with growing interdisciplinary collaboration, they are now emerging as inventors, researchers, and policy advocates in the global health technology ecosystem. The HOAC ventilator thus symbolizes this paradigm shift where nursing expertise informs not only the delivery of care but also the design and distribution of tools that enable it. Future research should focus on translating this conceptual model into a tested prototype through clinical trials and field evaluations. Key areas of investigation include the ventilator's efficacy in maintaining oxygenation and ventilation, its impact on nosocomial infection rates, and its influence on nursing workload and patient satisfaction. Partnerships between nursing faculties, biomedical engineers, and global health organizations will be essential to ensure scalable production, standardize training protocols, and maintain regulatory compliance across different regions. In essence, the HOAC ventilator reflects nursing's evolving identity as both a clinical and inventive force. By championing technologies that prioritize safety, usability, and compassion, nurses contribute to reshaping global healthcare systems toward more inclusive and responsive models of care. The spirit of this design transcends mechanical innovation it embodies the ethical and humanitarian values that define nursing practice. As such, nursing-led patents like the HOAC ventilator reaffirm the profession's critical role in driving forward health innovation that serves humanity with equity, dignity, and care.

Conflict of Interest
Not available

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Not available

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